Genotype Alteration: The Basis for Agricultural Transformation in Tropical Drylands

Volume 1: Selected Research Publications of Dr N.G.P. Rao:

Sorghum Breeding and Genetics

NGPRF

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Preface

The three decades of 1960s, 1970s, and 1980s represent a crucial phase in India's history of agricultural transformation, from a position of food shortages and imports to one of food self sufficiency, food security, and food exports. The 1960s was the decade of initiation of the science led green revolution in India, the 1970s of its consolidation, and the 1980s of its spread (more crops and regions) and sustainability. While the new varieties of wheat and rice were the focus of the green revolution in irrigated areas, hybrid sorghum (jowar) was the focus for the green revolution in the rainfed drylands that occupy more than half of the cultivated area in India. During 1970s and 80s, average yields of the rainfed hybrid sorghum could be stabilized at about 2000-2500 kg/ha against the national average of only 400-500 kg for the local varieties. Maximum yields of up to 7000kg/ha could be realized under optimal conditions. With spread of new hybrids and varieties, national average rainfed kharif sorghum yields doubled to over 1000 kg/ha, and its compounded annual growth rate exceeded that of irrigated wheat and rice during 1970s and 80s.

Dr NGP Rao led the visionary and transformative research on sorghum as the National Coordinator of the All India Coordinated Sorghum Improvement Project, from its inception in 1961 to 1978. The first commercial sorghum hybrid (CSH-1) was released in 1964, perhaps the shortest period ever for commercial hybrids in plant breeding history. Between 1965 and 1978, nine commercial sorghum hybrids (CSH 1 to CSH 9) and eight high yielding varieties (CSV 1 to CSV 8R) were released with profound impacts in the dryland areas of the States of Maharashtra, Karnataka, Telangana, Tamil Nadu, Rajasthan, Madhya Pradesh, and Uttar Pradesh, covering an area of over 8-10 mha. The new hybrids and varieties raised dryland farmer incomes substantially. They also led to the development of a flourishing seed industry in India, first in the public sector and later in the private sector.

The Trustees of the NGP Rao Foundation considered it appropriate to capture in this consolidated Volume, the series of research papers that bring out the scientific basis of the sorghum green revolution in India, and Dr NGP Rao's unique philosophy and approach to the theory and practice of plant breeding in rainfed drylands. Such a comprehensive and consistent record of long term systematic research in plant breeding, and its communication periodically in a popular style to farmers and extension agencies through designated magazines, is perhaps not available over an extended period for any crop other than sorghum in India or elsewhere.

The uniqueness of Dr NGP Rao's research philosophy and approach was with regard to three aspects. First, till 1960's, crop improvement research in India on sorghum relied on crosses between only local tropical cultivars, which contributed to only marginal yield increases, and 'did little to cross the environmental barrier or the yield barrier'. He introduced the idea that only quantum jumps in yield 'cutting across environmental barriers have the potential to bring about the much needed transformation in dry land productivity', and that this was feasible only through temperate (exotic) x tropical crosses. Second, was the development of a systematic breeding methodology to understand the genetics of temperate x tropical crosses of sorghum to establish the basis of genotype alteration for cultivar changes to achieve the objectives of high productivity and stability. As a result, sorghum yield improvement in both tropical and temperate regions of the world has since involved temperate x tropical crosses. Equally significant is the meticulous documentation of the systematic research in a long series of papers published in the Indian Journal of Genetics and Plant Breeding during 1960-1986. Third, was the emphasis on simultaneously developing varieties that equalled hybrids in performance, which enabled easy access to the new improved cultivars for small and marginal farmers. This unique approach helped to lay the foundation of a long term programme for sorghum improvement in India which ensured that significant and stable increases in the crop's productivity are sustained across different regions over several decades. It also enabled simultaneous incorporation of valuable traits of grain quality, nutritional upgradation, multiple disease and insect resistance, and higher drought resistance and water use efficiency, in the new cultivars to stabilize productivities at higher levels, and enhance grain quality.

In addition to research on plant breeding of tropical sorghums, Dr NGP Rao contributed significantly to several aspects of basic research in sorghum genetics with potential implications for future plant breeding. These include discovery of several diverse cytoplasmic sources of male sterility in sorghum and their genetic, physiological, biochemical and electron microscopy characterizations. He discovered the phenomenon of apomixis (asexual seed formation) in grain sorghums in 1968, in which plants can form seeds without fertilization. Apomictic technology is considered revolutionary for agriculture as it reduces breeding times and avoids many complications of sexual reproduction (e.g. incompatibility barriers), and is one of the areas of focus of crop improvement research in present times.

The contents of this Volume comprise selected published research papers on sorghum breeding, basic genetics aspects related to it, and on apomixis in grain sorghums. Papers 1 to 102 address sorghum breeding and related aspects. Papers 103 to 114 are on apomixis in sorghum and its potential implications fort plant breeding. These are presented in a separate section. Paper 1, the Presidential address to the Indian Society of Genetics and Plant Breeding in 1981, sets the stage by presenting the broad philosophy and approaches adopted by Dr NGP Rao and his colleagues for breeding superior hybrids and varieties of tropical sorghums. All other papers in this section are in their chronological order of publication. Papers 2 to 17 document the research in initial phases, leading towards the release of the first two high yielding commercial hybrids CSH-1 and CSH-2 and the variety Swarna, studies on their performance and stability, and the national recognitions that followed their release.

The 18th paper is the first in the systematic series of 39 papers, titled '*Genetic analysis of some exotic x Indian crosses in sorghum' - I to XXXIX*, that document the systematic methodology of cultivar alteration for yield and other useful traits. The series that began in 1970, and continued to 1986, describes the genetics of temperate x tropical crosses in sorghum involved in the nature of gene action in yield heterosis, gene x environment interactions, disease and insect resistance, nutritional quality, character associations, selection criteria and methods, crop ideotypes, testing procedures, adaptability analyses, etc. The 39 papers of the series appear in clusters of 2 to 5 papers in different years. The clusters are interspersed by other papers that describe related basic scientific information generated for input to subsequent papers of the series, periodic conference papers that summarize the scientific research up to that time and point the way forward, and papers that present the scientific information up to that time in popular form to progressive farmers and extension agencies through ICAR’s in-house magazine (Indian Farming). The last 4 papers in this section (100-103) essentially present future perspectives in the context of India’s agriculture challenges: paper No. 100 is a chapter in ICAR’s Publication: “An Era of Self-Sufficiency in Food production – A Tribute to Indira Gandhi” (a commemorative volume published in 1987); paper 101 (1989) addresses future perspectives of how plant manipulations via breeding can address food security and production risk concerns in the context of climate change; Paper 102 (1991- Second BP Pal Memorial Lecture at Indian Society of Genetics and Plant Breeding) points to how plant manipulations through breeding can be synergistically combined with environmental modifications (that is with land, soil and water technologies) for greater productivity and stability of dryland agriculture systems; and paper 103 (2004) presents a perspective on Plant Breeding in Twenty First Century. Papers 104 to 115 are concerned with apomixis in grain sorghum and its potential implications for sorghum breeding.

The Trustees expect that this selection of DR NGP Rao’s research papers that document his transformative research on sorghum breeding and genetics over a continuum of three decades will not only be valuable resource material for young students, teachers and scientists of the science of plant breeding across the world, but that it will also motivate them to work towards agricultural transformation in risk prone drylands.

Selected publications on Dr NGP Rao’s research on other dryland crops - pigeon pea, groundnut, cotton, and castor - will be presented separately in Volume 2.

Trustees

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GENOTYPE ALTERATION : THE BASIS FOR AGRICULTURAL TRANSFORMATION IN TROPICAL DRYLANDS

N. G. P. RAO

"FARMING and particularly rainfed annual cropping is par excellence an activity which brings rewards to the more enterprising, the more intelligent, the more industrious, the man who gets up early in the morning, the better organiser and the businessman" (Forde). Yet, it continues to be largely traditional; a way of life, a compromise between hope and despair and a difference between famine and feast. It does draw political sympathy and charity but attracts little investment since risks involved are greater than returns anticipated. Apart from production risks, there are reward risks and the more intelligent tend to shy away in pursuit of greener areas. Food aid, a short term solution, might do more harm in the long range.

The first responsibility of agriculture to development is towards feeding the family and the nation. The green revolution itself favoured irrigated areas while the need for it is greater for people living in tropical rainfed regions, which constitute a much larger chunk. Both at home and abroad, they are the most vulnerable areas. The need for agricultural transformation here is urgent and well beyond economics and politics, for, it influences the every day life of millions of people and their daily bread.

Obstacles exist only to be overcome. My long association with sorghum research and development; the opportunities I had to manipulate sorghum, pulses and oilseeds as components of dryland cropping systems; the association with a large number of agencies, colleagues and students in this pursuit; the progress of sorghum production in some of the states of India and its potential to others; the conviction that geneticists and breeders have a beneficial role to play—these inspired me in the choice of the subject.

Genotype alteration as the very basis for green revolution in rainfed lands is, therefore, the theme of my address.

DRYLAND AGRICULTURAL SYSTEMS

Rainfed agriculture in tropics is climate dependent. Compared to the temperate regions, it is the tropics and semi-tropics which are poor or very poor. This correlation with climate should certainly be spurious—yet, it is a fact of life. Climate, therfore, has been an important parameter in the evolution of tra-

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ditional subsistence agricultural systems and will continue to be significant in the development of alternate strategies leading towards stable and productive agriculture.

Traditional tropical cultivars across continents are generally characterized by tallness, lateness, photosensitivity, localized adaptation, low harvest indices, individual superiority at times but poor community performance, lower rates of fertility response and greater vulnerability for climate changes, particularly, rainfall. Production risks rather than price risks continue to be the cause of under investment. Crop diversification, through practices of mixed or inter-cropping, over centuries has been beneficial, but did not change the productivity status.

Till the 1960's, research and development efforts in drylands were oriented towards improving yields of local or local improved cultivars through resource management. They involved crossing of related varieties to develop improved cultivars similar to locals in plant architecture and duration with some added attributes which generally reflected marginal superiority in yields; use of organic manures; lower population densities with low levels of fertilizer use; soil and water conservation measures such as mulching, contour bunding etc.; advocacy of rotations and other cultural practices. These measures contributed to some yield advances, but did little to cross the environmental barrier or the yield barrier.

It is only after radical genotypic changes in dryland crops like sorghum and pearl millet, that perceptible yield advances have been recorded. Drawing primarily on my experience with sorghum, the predominant food crop of the semi-arid tropics, I propose to analyse the basis and role of genotype transformation in the development of stable and productive dry land agricural production systems. Throughout, it has been my feelling, that not small gains, but only quantum jumps cutting across environmental barriers have the potential to bring about the much needed transformation in dry land productivity.

The Basis of Genotype Alteration

Sorghum originated in the tropical north east Africa and moved to other parts of Africa, Asia and the western hemisphere. Domestication in the various agroclimatic regions led to diversification. The mutant forms selected and improved under the long day conditions of the USA, are referred to as temperate sorghums. While tropical yields stagnated at lower levels, the temperate regions saw rapid advances in sorghum productivity over a relatively short period but later tended to stagnate at higher levels. Yield advancement in both tropical and temperate regions now involves handling temperate—tropical crosses, which furnish the means towards radical genotype changes (Rao and Rana, 1978).

Besides the development and release of superior cultivars, we attempted to develop a genetic basis and greater understanding leading towards cultivar changes. A series of papers on genetic analysis of exotic × Indian (temperate ×

tropical) crosses in sorghum, besides others, have now been published in our journal.

The duration of the normal rainy season in most parts of India influenced by south west monsoon is from the beginning of July to the middle or end of September, a period of 80–90 days. August normally represents the peak rainfall month and October rains are uncertain. While this is so, most *kharif* sorghums of Deccan and Malwa plateaus flower towards the second week of October. They have only about 30% of the total dry matter accumulated in the ear. They are characterized by a single peak for the rates of growth coinciding with flowering. If rains are low or cease prematurely, they fail to reach maturity. Several of the temperate sorghums, on the other hand, are characterized by less of total dry matter, two peaks for rates of growth and a 50 : 50 distribution of dry matter (Rao and Venkateswarlu, 1971; Anantharaman *et al.* 1978). Superior hybrids and varieties now developed have reduced duration to match the rainy season and less dry matter but with a 50 : 50 distribution. The critical stages of seedling growth, flower initiation and grain filling coincide with assured periods of profile moisture; they yield well during normal and subnormal years of rainfall exhibiting less vulnerability to rainfall fluctuations (Rao *et al.* 1975; Rao *et al.* 1979).

Our studies on optimum genotype indicate that an 'intermediate optimum' for height and maturity with linear pattern of internode elongation would yield well and meet the needs of most Indian and other tropical conditions (Rao *et al.* 1973; Balarami Reddy *et al.* 1981). A similar change with regard to growth rhythms and duration enabled perceptible yield improvement in castor (Ankineedu *et al.* 1975).

Once the basis of genotypic alteration is established, alternate methods could be explored to achieve the objectives of stability and productivity.

Exploitation of Heterosis

The use of commercial sorghum hybrids based on cytoplasmic-genetic male sterility in the USA, prompted the initiation of the accelerated hybrid sorghum project in India during 1961. Although I was earlier instrumental in identifying an improved sorghum variety D. 340 at Dharesugur in the erstwhile Hyderabad state (Rao *et al.* 1959), my close and continued association with sorghum began towards the end of 1961 at the Indian Agricultural Research Institute as sorghum botanist and associate co-ordinator. At that time, since Combine Kafir 60 was chosen as the female parent for hybrids, we based our programme on an understanding of the limitations in the choice of male parents, the use of off-season nurseries for crossing and initiation of multilocation testing all over India. The first sorghum hybrids were released in the country by 1965. This was essentially a common sense based programme which, perhaps in any plant breeding history, yielded results in the shortest possible period and stood the test of time (Rao and House, 1965; Swaminathan *et al.*, 1970; Rao, 1972a).

Subsequent efforts in the all India co-ordinated sorghum improvement project led to the release of nine commercial sorghum hybrids. This involved development of new male steriles, greater use of tropical germplasm, more particularly the alteration of African *zerazeras* and improved Indian cultivars like *Aispuri*, B.P. 53 etc., for the development of new male and female parents that went into hybrid combination (Rao *et al.* 1977; Rao *et al.* 1981). The development and release of commercial sorghum hybrids gave birth to an organised hybrid sorghum seed industry in public and private sectors.

Considerable amount of basic research has been carried out on heterosis and combining ability and their interaction with seasons, years and locations (Rao, 1968; Rao, 1970 b; Singhania and Rao, 1976 a); phenotypic, genotypic and physiological criteria for the choice of parents (Ramachandram and Rao, 1973; Sinha *et al.* 1972; Rana *et al.* 1974; Singhania and Rao 1975; Damodar *et al.* 1978 a, b,; Jayamohan Rao *et al.* 1981; Mishra *et al.* 1981); the value of early testing procedures in selecting for heterosis and capitalization of non-additive gene action (Mishra and Rao, 1980 a, b); these should be of considerable value for future improvement of hybrids.

Alternate sources of cytoplasmic-genetic male sterility have been discovered (Rao, 1962) and characterized genetically, biochemically and through electron microscope studies (Tripathi, 1979; Tripathi *et al.* 1980; Tripathi *et al.* 1981 a, b, c, d, e). These studies have furnished a new dimension to our understanding of the basis and genetics and cytoplasmic-genetic male sterility and fertility restoration and should be of value in future.

Varietal Improvement

The development of high yielding varieties in sorghum began with the release of *Swarna* (Rao *et al.* 1968; Rao, 1969), which is still cultivated in some areas of Andhra Pradesh. Besides continuing efforts on varietal improvement, our subsequent studies were directed towards the development of a genetic basis and breeding methodology for varietal improvement primarily through the use of temperate-tropical crosses. These included studies on nature of gene action for yield and yield components (Rao, 1970 c); character associations and their role in selection (Harinarayana *et al.* 1971; Rao *et al.* 1973); phenotypic and physiological criteria for selection (Subba Reddy and Rao, 1971; Ramachandram and Rao, 1973; Rajagopal *et al.* 1976; Damodar *et al.* 1978 a; Mishra *et al.* 1981 a, b); selection effects on yield and yield components (Tripathi *et al.* 1976); the growing conditions under which selection should be practiced (Vidyasagar Rao *et al.* 1980) and selection gains under various mating systems (Seshagiri Rao, 1979). The studies on mating systems did not favour the breaking up of adaptive gene complexes indiscriminately and indicated that the gene frequencies could be shifted in the desired direction under controlled and specific cross combinations, a point which came out as early as 1972 (Rao, 1972 b).

Plant modifications for efficient water use received our priority attention and formed the very basis of genotype alteration (Rao *et al.* 1979). The contribution of the new hybrids and varieties to production advances during some of the most dry years encountered stand testimony to the value of the rationale behind their development.

Since the exotic (temperate) germplasm used in the breeding programmes exhibited greater susceptibility to shoot fly and stem borer attack, considerable emphasis was laid on understanding the genetic basis of insect resistance in sorghum leading to incorporation of greater levels of resistance. Non-preference was observed to be the primary mechanism of resistance to most sorghum pests. Consequently, the genetic basis of non-perference, particularly of shoot fly, was established and breeding methodology for its utilisation has been developed (Rao *et al.* 1974; Balakotiah *et al.* 1975; Rana *et al.* 1975; Sharma *et al.* 1972; Singh *et al.* 1978). Stem borer and midge, particularly the management aspect of midge (Rao and Jotwani, 1974), received considerable attention. A comprehensive account of host plant resistance to sorghum insect pests has been presented by us (Rao *et al.* 1977).

Compared to insect resistance, incorporation of resistance to major sorghum diseases resulted in greater success (Rao *et al.* 1978). Most released hybrids and varieties are resistant to downy mildew, several leaf spots, grain moulds and grain deterioration. The nature of inheritance of rust (Rana *et al.* 1976), downy mildew (Rana *et al.* 1981) and grain deterioration (Rana *et al.* 1976 and 1978) has been critically analysed. Charcoal rot and striga resistance are now receiving greater attention.

Our concentration, presently, is on incorporation of multiple insect and disease resistance in improved cultivars and to develop a genetic basis towards this end.

Our work on mutational approach to varietal improvement has been limited. Based on induced mutation studies, we felt that the genetics of height and maturity in tropical sorghums and their allelism to temperate sorghums might need a second look (Rao *et al.* 1970). In fact it is the height-maturity-yield relationships which considerably limit progress from selection in temperate-tropical crosses. We analysed the efficiency of different mutagens and their role in sorghum improvement (Reddy and Rao, 1981). We observed that the total solar eclipse caused stimulation of seedling growth and chromosome aberrations in sorghum (Reddy *et al.* 1981).

To date, eight high yielding varieties have been released and some more are under pre-release multiplication (Rao, *et al.* 1972; Rao *et al.* 1981). For historical reasons, the hybrid programme in India preceded varietal improvement. The hybrids being comparatively superior, varietal spread continues to be limited. There is definitely a case for varieties of approximately similar duration as hybrids. This is because the hybrids may not be expected to cover the entire area and the remaining late locals will be prone to drought and midge. To stabilise sorghum yields all over the country, it is necessary that we reestablish the maturity equilbrium and towards this end varietal supplementation is essential. Seed programmes of varieties should receive same attention of certification etc., as hybrids so as to ensure quality standards

Continued varietal improvement will contribute to parental improvement of future hybrids and is, therefore, the basis of all improvement in sorghum.

That steps in varietal improvement similar to sorghum if initiated could lead to considerable yield advances in pigeonpea has been shown by us (Pankaja Reddy and Rao, 1980). The potentialities of somatic variation in the improvement of grain legumes were also brought out (Pankaja Reddy and Rao, 1975; Rao *et al.* 1977).

Adaptability and Stability

One of the major consequences of genotype alteration is changed adaptation.

Traditional cultivars are known to be highy local in their adaptation and consequently, breeding objectives have been oriented to the needs of several small areas limited by eco-geographical and agro-climatological considerations. The development of relatively photosensitive high yielding hybrids and varieties resulted in their adaptability to almost the entire *kharif* sorghum belt of the country (Rao, 1970a). The genotype × year interaction was also low. This has given a new dimension to the breeding approaches. With the multi-location testing mechanism spread all over the country, the superiority of a genotype could now be established even during a single year's testing. Hybrids like CSH 1, CSH 5, CSH 6 and CSH 9 and high yielding varieties like CSV 1, CSV 3, SPV 221 and SPV 245 are all high yielding and adapted all over the *kharif* areas of the country. All India releases of sorghum or pearl millet, which could not even be conceived of some time back, are to day *fait accompli.*

At the genotypic level, our studies so far indicate the homeostatic superiority of hybrids over varieties although under more favourable conditions some superior varieties tended to yield as much or even exceed hybrid yields (Rao and Hainarayana, 1968). Some male parents developed from exotic × Indian crosses also exhibited similar behaviour (Singhania and Rao, 1976b). The interaction of the additive component with the environments was generally greater than that of the dominance component (Singhania and Rao, 1976a).

Recent studies based on the performance of hybrids and varieties at a number of locations over a three year period also confirmed hybrid superiority (Rao *et al.* 1981). Technically, it appears that atleast immediately, hybrids have advantages in terms of yield, adaptability and superior buffering ability under environmental stress.

Our present studies (Balarami Reddy and Rao, 1981) indicate that it may not be impossible to bridge the gap between hybrids and varieties both for yield and stability. At comparable heights and maturities, an increase in biomass without detriment to harvest index brought about favourable changes. One thing appears certain that unique performance and wide adaptability are not uncorrelated; in fact, they are more closely correlated. This is also evident from our study that high yielding parents selected at one location yielded hybrids of wide adaptability (Mishra and Rao, 1980b). Further, utilization of apomixis might eventually provide the means to combine the antagonistic demands of uniformity for immediate fitness and diversity for adaptability (Rao, 1972b).

In cooperation with economists, the concept and use of risk aversion in plant breeding has been developed and applied to sorghum (Barah *et al.* 1981). Adaptability and stability were highly correlated. Measures of farmers' risk aversion were used to rank genotypes according to preferences taking into account both yield and stability. Preference based rankings did not differ markedly from yield based rankings, further confirming the validity of our breeding approaches.

Genotypic Basis For Production Technology

Plant breeding in the past has frequently been oriented towards changing agronomy. In recent years, it is the genotype that influenced production technology involving input use and management practices.

Genotypic differences for tissue concentration of nitrogen and phosphorus have been demonstrated (Rao and Venkateswarly, 1971). High yielding hybrids and varieties of sorghum have returned 20–25 kg of grain per kg. of nitrogen at the 0–50 kg N/hect. as against 7–8 kg of grain for locals. There has not been any indication of the crossover of nitrogen response curves to justify locals for low fertilizer levels and hybrids for higher levels only (Rao, 1977, 1979). Our studies on response to high and low management levels only further confirmed this (Vidyasagar Rao *et al.* 1980).

The superiority of new hybrids under increased population levels has amply been demonstrated. Practices like early planting with the onset of monsoon during *kharif* enabled to avoid shoot fly and enbloc coverages of hybrids reduced midge incidence on locals (Rao, 1979).

The genotype-input-management interactions have been spectacular with the *rabi* hybrids. Advanced plantings, fertilizer use and increased populations, as against the practice of late planting, no fertilizer and low populations resulted in substantial yield increases. However, this yield advantage was lost when plantings went into late October, when the local M-35-1 was superior to the hybrids. This has been attributed to the temperature sensitivity of present hybrids largely based on *kharif* germplasm. To get over this difficulty, we have initiated efforts to breed temperature insensitive parents for *rabi* hybrids.

Dryland agriculture being climate dependent, the new genotypes should resist climatic fluctuations. Our analysis of sorghum yields during 1972, one the worst drought hit years encountered (Rao *et al.* 1975) and subsequent abnormal years (Rao *et al.* 1979) and their performance on farmers' fields on large scale during normal and subnormal years justify their lower vulnerability.

throughout, our efforts have been directed towards realization of assured single crop yields during all years and optimal yields during years of better rainfall. This led us to the design and development of transgressive and productive cropping systems in place of the subsistence ones.

Based on our studies of inter and intra-species competition, genotype × density interactions and alternate planting patterns (Tarhalkar and Rao 1974; Tarhalkar *et al.* 1975; Rao *ét al.* 1979), we attempted to develop productive, stable and profitable cropping systems. Based on all India trials, we (Rao and Rana, 1980) analysed the impact of such sorghum=based cropping systems and felt that the present sorghum acreage in India could meet the shortages of pulses and edible oilseeds. I do hope that the sole cropping of hybrids largely practiced today will yield place to the practice of new intercropping systems in low rainfall areas and multiple cropping in high rainfall areas.

Ratooning hybrid sorghum has become a common practice in large areas of Jalgaon district in Maharashtra, some tank fed areas of Andhra Pradesh and under supplemental irrigation at several places.

Economic analyses justified that the technology developed is compatible with the needs and capabilities of the small farmer, in fact more suited to him; that it is economically sound and viable and that there is no need or justification for the development of separate technologies for small and large farms (Binswanger *et al.* 1979; Ryan *et al.*1 979).

Nutritional quality

Even though some economists argue on the priorities of nutritional improvement of cereals, the fact that attributes like high lysine exist in sorghum (Singh and Axtell, 1973) and that its transference to a desirable grain type presents difficulties, is enough challenge to combine high lysine with acceptable yield levels and grain type. A recent FAO estimate (1980) on protein consumption in grams per person per day places industrial countries at 98·5 g, developing countries at 57·8 g, Africa at 54·9 g and Far East at 49·6 g.

Our work on nutritional quality of sorghum began with the analysis of β-carotene, protein, protein fractions and all the amino acids including lysine and leucine, the nature of their inheritance, their interrelationships and with yield (Singhania *et al.* 1970; Austin *et al.* 1972; Nanda and Rao, 1974, 1975 a, b).

In cooperation with the National Institute of Nutrition, considerable amount of work was done on varietal screening for lysine, leucine and isoleucine and their role in aminoacid antagonism (Deosthale *et al.* 1970). Tannins do not pose digestibility porblems in Indian sorghums. A more balanced aminoacid pattern is needed to render sorghums nutritionally superior.

Recently, we attempted the transfer of the high lysine trait from the Ethiopean and P. 721 sources to agronomically desirable grain type and yield levels through the Ph.D. work of Jayamohan Rao (1980). We isolated high protein and high lysine plants in crosses which did not exhibit the known negative relationship between protein and lysine. It now appears that this negative relationship between protein and lysine could be broken. Specific crosses, which did not exhibit such a relationship, are being pursued. A breeding methodology towards the incorporation of high lysine trait in plump, transluscent seeds is now emerging. I do hope and wish that we will be able to take this work to its logical conclusion.

The Breeding System

Sorghum furnishes a fascinating breeding system; it may be totally self pollinated, cleistogamy having been recorded; various levels of outcrossing are frequent; the occurrence of genetic and cytoplasmic-genetic male sterility promotes complete out-crossing.

Our contribution to sorghum on this aspect has been the discovery of self-incompatibility (Rao *et al.* 1971), apomixis (Rao and Narayana 1968; Rao and Murty, 1972; Rao *et al.* 1978), and cross sterility (Murty and Rao, 1980). The discovery of apomixis attracted considrable attention although progress on its exploitation is understandably slow. Present studies have certainly enhanced our understanding of the phenomenon. Progeny tests with crosses involving apomicts (Murty and Rao, 1979) and the isolation of dihaploids (Murty *et al.* 1981) do provide leads towards fixation of heterozygosity. Studies in this direction are now in progress and we do look forward towards commercial fixation of heterozygosity.

There is now a feeling, and rightly so, that future crop improvement will depend on findings from basic researches. The role of recombinant DNA in plant modification, the various asexual approaches including somatic cell hybridization, the genetics of metabolic efficiency and nitrogen fixation, the areas of environmental stresses and crop growth modelling are only a few to mention and there are several emerging areas with which many plant breeders, including myself, are less familiar. For quite some years to come, genotype alteration will continue to be the focus. I, therefore, feel that an interaction between applied and basic researches is essential and the Society should focus on potential areas that could influence future plant modifications. We attempted to organise a symposium towards this end. I fondly hope that this will materialise in the near future.

The past two decades, the sixties and seventies, are a land mark in our agricultural history. It is the genotype alteration that provided the basis for the happy situation on our food front; I consider it fortunate to have been involved in one aspect of this most important and significant event of our history. Agriculture is not merely business; it has been a way of life and it should certainly be a profitable way of life. It is *Yagna*; to add at least one *Samidha* to keep the eternal fire burning is our sacred duty.

I have oriented this address towards rainfed agriculture; to us it has been an integrated exercise in plant breeding; to me it has been a learning process and I hope it will be meaningful to the students of genetics and plant breeding.

I am beholden to the Society for the honour; the past two decades have been the most rewarding and most satisfying part of my life and I thank Him for His kindness. I salute all colleagues, fellow geneticists and plant breeders, extension workers, farmers and every one to whom the cause of agriculture is near and dear.

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A NOTE ON D. 340, A POPULAR *JOWAR* STRAIN OF TUNGABHADRA PROJECT

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Research Notes

A NOTE ON D. 340, A POPULAR *JOWAR* STRAIN OF TUNGABHADRA PROJECT

Under the Tungabhadra project an area of about 6.63 lakh acres, nearly 80% of the command area, has facilities for light irrigation. In this vast area, termed 'irrigated dry', *jowar (Sorghum vulgare)* would be the important food and fodder crop. Anticipating this, work was initiated in 1944 - 45 at Tungabhadra Agricultural Research Station, Dhadesugur (In the erstwhile Hyderabad state), to evolve a *kharif jowar* variety suited to light irrigated conditions of the Tungabhadra ayacut.

While this was in progress, an improved variety, Co. 9 was recommended for the project area, as a result of the researches conducted at the Agricultural Research Station, Sirguppa. The performance of Co. 9 was consistant but it possesses pithy stalks and as such its fodder value is less; its grain has a reddish base, which imparts a colour to the bread; its duration being short, it is caught in rains; due to compact nature of its head, water does not drain well and causes the grain to become mouldy and germinate on the head. While this variety, Co. 9 was recommended as the immediate improved variety available, attempts were in progress to evolve a superior variety through hybridisation, the object being to isolate a dual purpose variety with a semi compact head and a fortnight later in duration than Co. 9.

At Tungabhadra Agricultural Research Station, Dhadesugur, an improved variety D. 340 was evolved as a result of selection from local '*Palmadi*' *(Sorghum subglabarascens* var. *compactum* Snowden). It has all the advantages over Co. 9 with juicy stalks, semi compact earheads and bold white grain. It matures in 100 to 105 days, which is later by a fortnight than Co. 9. The performance of D. 340 during the period of its trial is given below; the local was a white seeded one till 1953—54 and as its yields were consistantly poor, a yellow local was taken as control from 1954 - 55 onwards.

GRAIN YIELDS IN POUNDS PER ACRE

Year	Local	D. 340	Remarks
1951—52	164	321	Under rainfed conditions
1952—53	219	322	,, ,, ,,
1953—54	196	698	Under light irrigation
1954—55	1,574	1,774	,, ,, ,,
1955—56	1,130	1,447	,, ,, ,,

The irrigation facilities during the years 1953—54 to 1955—56 were not adequate However, the variety fared consistantly better than the local during all the years of its trial and responded well to irrigation. Since it possesses all the desirable characters, it is spreading fast under the Tungabhadra ayacut.

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N. GANGAPRASADA RAO
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OCCURRENCE OF CYTOPLASMIC-GENETIC MALE STERILITY IN SOME INDIAN SORGHUMS*

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THE development of cytoplasmic-genic male steriles has made hybrid *Sorghum* a commercial proposition. Stephens and Holland (1954) found that Milo cytoplasm interacted with Kafir nuclear factors resulting in male sterility; by substituting the entire Milo genome with that of Kafir by repeated backcrosses, a hundred per cent. male sterile line was developed. Subsequently, a number of male steriles have also been built up by introducing genomes of appropriate *Sorghum* varieties into Milo cytoplasm.

In India, out of the several male sterile stocks obtained from the U.S.A., male sterile Kafir 60 has been accepted as most suitable and is being tested in crosses with indigenous and exotic types from the point of view of immediate utility. It has, however, been a general observation that these hybrids do not generally compare in quality with most of the Indian *Sorghums*. Hence, attempts are also under way to substitute the genomes of appropriate quality *jowars* of India in the ' sterile ' cytoplasm and develop male steriles of Indian origin by the backcross method.

It is in the above context that a number of male sterile plants spotted in different types in the maintenance plot of *jowar* at Mohol during 1959-60 *rabi* are of interest. It was observed that in such plants, the primary heads which had been selfed did not set seed while the secondary heads arising from the axils set seed on open pollination. The open pollinated seed, as well as the very few seeds, if any, on selfed heads, on the same plant, were collected separately; their progenies were raised under optimum conditions of irrigation and manuring in the 1960-1961 *rabi* season and they were tested for seed setting on selfing. The results of the study are presented in Table 1. Fig. 1 shows male sterile and fertile earheads in the progeny of Red *Jonna*, which has actually pearly white seeds.

It would be observed that in a majority of the cases, the progeny was almost wholly sterile. If the sterility were to be due to genetic factors only, fertile plants would be expected to be more frequent in the progenies. It would, therefore, appear that the sterility recorded is not under gene control only. Besides, segregation for morphological characters such as glume colour, grain colour and panicle shape were noticed in the progenies, a majority of the plants resembling *rabi jowar* types. These observations suggest that the origin of male sterility in these varieties could be traced to natural cross pollination and may be due to the interaction of cytoplasm of the variety in question and nuclear factors from unknown sources. In the case of C. 10-2, the population raised being small, the nature of sterility could be understood only after further study. The occurrence of a few fertile individuals in two progenies resulting from selfing also needs further study.

All the varieties under study, with the exception of Norghum and Burma black, are of Indian origin and it is thus seen that the cytoplasm of some of the Indian *Sorghums* also reacts with certain nuclear factors resulting in cytoplasmic-genetic male sterility, as was noted between Milo cytoplasm and Kafir nuclear factors.

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*Based on a paper presented at the Second Conference of Millet Research workers held at Kanpur (1961).

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TABLE 1

Behaviour of selfed and open pollinated progeny of male sterile individual plants detected in some varieties of Sorghum

Sl. No.	Variety in which steriles were spotted and Plant No.	Source of Seed*	Behaviour of Progeny		
			No. of plants tested by selfing	No. Sterile	No. Fertile
1.	W.E. 1	Selfed head	5	5	..
		OP head	30	30	..
2.	Bilichigan ..	Selfed head	1	1	..
		OP head	53	43	10
3.	Red Jonna-1 ..	Selfed head	33	31	2
		OP head	68	65	3
	Red Jonna-2 ..	Selfed head	3	3	..
		OP head	37	36	1
4.	Indore local-1 ..	Selfed head	8	8	..
		OP head	37	35	2
	Indore local-2 ..	Selfed head	4	3	1
		OP head	53	53	..
5.	G.J. 103	Selfed head	2	2	..
		OP head	8	7	1
6.	B.D. 8	OP head	3	3	..
7.	Burma black-1 ..	Selfed head	3	3	..
		OP head	35	35	..
	Burma black-3 ..	OP head	63	63	..
8.	Norghum-1 ..	OP head	39	39	..
	Norghum-2 ..	OP head	28	20	8
9.	C. 10-2	OP head	7	2	5

*The selfed and open pollinated (OP) heads were collected from the same plant.

The *rabi jowars* grown in the Deccan, being pearly and white seeded, are the best available for any quality standards and sterile forms developed out of them would be valuable in the exploitation of heterosis. The seed collected on open pollination in most of the male sterile progenies is of as good a quality as the *rabi jowars* indicating that the natural crossing which took place was of a complex nature; the local *rabi jowars* appear to have been involved in the natural crossing, as most of the segregants tend to revert to the local *rabi jowar* forms. Even in case of Norghum and Burma black, the seed obtained on open pollination was mostly pearly white. The varieties referred to represent sources of 'sterile' cytoplasm and the appropriate genomes that could react with them need further study to facilitate their utilisation in the development of hybrid *Sorghums*.

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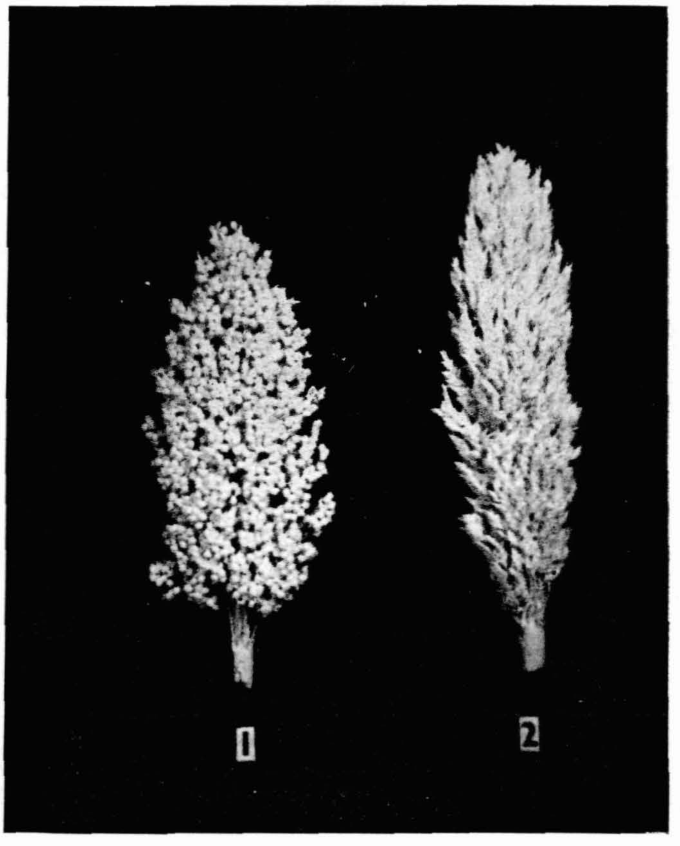

FIG. 1. Red *Jonna* fertile; 2. Red *Jonna* sterile

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CO-ORDINATED SORGHUM HYBRID NO. I

(N. Gangaprasada Rao and Leland R. House)

(Sorghum Hybrid No. 1 (CSH 1) is a welcome addition to the family of hybrids. CSH I is the first of the sorghum hybrids recently released under the Accelerated Hybrid Sorghum Project. In this article the authors give an important account of the evalution of this hybrid and its appreciable impact on increasing yields of sorghum in India. (Editor.)

Utilisation of hybrid vigour through development of commercial hybrids has often been cited as one of the major plant breeding achievements. The release of co-ordinated sorghum hybrid for general cultivation is a major step in the realisation of the objectives of the accelerated hybrid *jowar* project initiated by I.C.A.R. in the year 1960. This also marks the arrival of hybrid sorghum in Indian agriculture.

Based on the results of extensive testing of twelve promising hybrids all over the country, this hybrid has been found to be suitable for early and medium duration *kharif* areas and for the irrigated summer season. This high yielding hybrid is the product of hybridisation between male sterile *Combine Kafir* 60 and a yellow endosperm *Feterita* known for its high carotene content.

On an average, the hybrid has recorded an increase of 60-80% in grain yields over the local improved varieties while there has been a 20-30% reduction in fodder yields. It has creamy white pearly grains which are generally preferred. Of the total area of 43 million acres, about 14 million is estimated to be suitable for the cultivation of this hybrid. The early and medium duration *kharif* tracts in the states of Madras, Andhra Pradesh, Mysore, Rajasthan, Gujarat, Madhya Pradesh and Uttar Pradesh, the irrigated *kharif* areas under the Tungabhadra Project and the irrigated summer tracts in the states of Madras and Andhra Pradesh are most suitable. Besides the hybrid has done well in Delhi and Orissa where presently only fodder *jowars* are raised. In the black cotton soils of Maharashtra, Mysore, Gujarat, Rajasthan and Madhya Pradesh, where presently very late *kharif jowars* are grown, the hybrid could be cultivated as an early *kharif* crop to be followed by a *rabi* crop even under rainfed conditions.

For a successful cultivation of this hybrid it is advisable to sow it before 15th of July in *kharif* season and in the first week of March for the summer season. Under a spacing of 18″ between rows and 6″ between plants, which is the normal practice, an application of 60 lbs. nitrogen per acre under rainfed conditions and 90 lbs. nitrogen per acre under irrigation is recommended. Phosphatic fertilisers could be applied according to the local practice. Average yields of over 2,000 lbs. per acre under normal rainfall conditions and over 4,000 lbs. per acre under irrigation have been realised with this hybrid and with in tensive cultivation it is possible to further maximise the yields.

The produce from a commercial crop should not be used as the source of seed to plant another crop. Fresh certified hybrid seed has to be obtained from authorised sources every year. The Natoinal Seeds Corporation supplies certified stocks of foundation seeds to authorised seed producers. Hybrid seed produced by such producers is properly certified for its purity and germination. It is marketed in standard sized sealed bags carrying a blue certification tag of the National Seeds Corporation. Purchase of such seed stocks by the farmers from certified seed producers will not only ensure purity of seed but also help in securing maximum returns to the grower.

A lush crop of CSH-1. Left : Female parent ms CK 60 Right : Male parent IS 84

"Reprinted from May 196
issue of 'Indian Farming'"

CSH-

CSH-1 (centre) and its parents

THE recent release of the Co-ordinated Sorghum Hybrid 1 (CSH-1) by the Central Variety Release Committee for general cultivation in the short and medium duration *kharif* areas and the irrigated summer tracts of the country marks the advent of hybrid *jowar* to Indian agriculture.

With an annual area of about 43 million acres, sorghum is truly the great millet of India. The annual production of nine million tons of grain is, however, not commensurate with this vast area. The cultivation of *jowar* is spread over *kharif*, *rabi* and summer seasons. A major portion is grown in the *kharif* season; the period of maturity during the season ranges from 130-170 days in respect of late varieties, 120-130 days for medium and 90-100 days with early varieties. The *rabi jowars* are usually late maturing while the summer crop is early and matures in about 100 days. The flowering period and the maturity of any local variety are the result of selection over a long period and are adjustments with the rainfall pattern and the availability of soil moisture.

AND NOW HYBRID JOWAR

MAKES ITS APPEARANCE

N. GANGA PRASADA RAO and LELAND R. HOUSE
Indian Agricultural Research Institute, New Delhi

From the quality point of view, the yellow seeded types predominate in the States of Madras and Andhra Pradesh; chalky whites in Madras, Madhya Pradesh and Rajasthan and pearly whites in Maharashtra, Mysore and Gujarat. A few red seeded types are also grown but the general preference from the point of view of quality is for white pearly grain. If a hybrid conforms to the flowering and maturity of a given tract and satisfies the quality requirements, it will be favoured by the farmer.

Development of the Hybrid

One of the steps towards increasing the yields per acre of *jowar* is through the exploitation of hybrid vigour. In accordance with the recommendation of an *ad hoc* committee constituted by the Indian Council of Agricultural Research, male sterile combine kafir 60 was accepted as the common female parent for the first hybrids. Acceptance of this exotic male sterile as the constant female towards breeding single cross hybrids combining yield, quality and adaptability over widely varying eco-geographic regions and seasons presented certain limitations as well as potentialities. Since the female parent was considered to be of inferior quality with chalky white seeds, particular attention was paid to combine high yields with acceptable quality in the hybrid.

Small-scale regional trials conducted all over the country during 1962 enabled the identification of 12 promising hybrids for large-scale testing. Extensive testing of these 12 hybrids commenced from the 1963 summer season and was carried through the *kharif* all over the country. Based on the results of these trials, the present hybrid has been chosen for general cultivation. A prief description of the parents of this hybrid is given below.

The seed or female parent. Male sterile combine kafir 60 (CK60A) is the female parent. It is non-photosensitive and adaptable over the entire country. It grows about 150 cms. tall with about 10 leaves and has juicy stalks; flowers in about 60 days; grains of chalky white colour.

Pollinator or male parent. IS84 is the pollinator parent and is a selection from an yellow endosperm called a *feterita*. It generally grows to a height of 140-180 cms. with about 10 leaves and has juicy stalks. Flowers come in about 60-65 days with oblong panicle and light yellow endosperm grains. It is known to be associated with a high carotene content.

Performance of the Hybrid

The relative grain and fodder yields of the hybrid and the local improved variety in the early, medium, and late duration areas where only forage varieties are presently cultivated, and irrigated summer season are presented in the following table. The hybrid had returned an average of 60-80 per cent increase in yield over the local improved variety of the tract while there is 20-30 per cent decrease in fodder yields.

MEAN PERFORMANCE OF THE CO-ORDINATED SORGHUM HYBRID–1
(1963-64)

Mean grain yield (kgs./hect.) Hybrid	Local Imp. Strain	% of Local	*Mean fodder yield (kgs./Hect.)* Hybrid	Local Imp. Strain	% of Local
Region 1. Early tract—(flowering in 60 days)					
1296	713	182%	4305	5581	77%
Region 2. Medium duration—flowering in 70 days					
2578	1519	170%	4964	6493	77%
Region 3. Late duration.—(flowering over 80 days)					
2249	1269	170%	5623	8623	65%
Region 4. Areas where grain sorghums are not grown but forage varieties are cultivated					
2486	1269	196%	8849	10643	83%
Region 5. Irrigated summer season—(flowering in 60 days)					
4885	3032	161%	10191	12343	83%

Areas of Adaptation

The general area of adaptation for this hybrid is estimated at 14 million acres. The data from regional trials indicate that the early and medium duration *kharif* and the irrigated summer tracts are the general areas where the hybrid could be most profitably cultivated. The districts of Guntur, Kurnool, Hyderabad, Mahboobnagar, Medak, Nalgonda, Warangal, and Karimnagar in Andhra Pradesh; Raichur, Bellary, Bijapur, Bidar, and Gulbarga in Mysore; Ahmedabad, Banaskanta, Mehsana in Gujarat and Pali; Nagaur, Jodhpur, Jaipur, and Ajmer in Rajasthan; the irrigated *kharif* areas under the Tungabhadra Project and the irrigated summer tracts of the States of Madras and Andhra Pradesh may be considered most suitable for this hybrid. It has potentialities as a short duration crop also in the late duration areas to be followed by a second crop and in the non-grain sorghum regions (where only forage sorghums are presently grown) as a dual purpose crop.

Agronomic Characters

The comparative data on some agronomic characters of importance are listed in the table below.

COMPARISON OF CSH-1 AND LOCAL

Character	*CSH-1*	*Local improved strain*
Days to 50% bloom	58-60	60-70 (over 80 days in some late tracts)
Plant height (cms.)	140-160	200-300
Lodging percentage	0-1	0-40
Grain colour	cream, pearly	yellow, white-chalky, red, white pearly.
Fodder quality	juicy, high proportion of leaf to stem	juicy to pithy
Threshability	good	good
Taste	satisfactory	satisfactory
Reaction to shootfly	susceptible	susceptible

Details of Cultivation

Data from the co-ordinated agronomic trials revealed that the hybrids are more responsive to nitrogenous fertilization than the improved variety checks. The response at 60-90 kg.N per hectare at 18′ spacing between rows and 6′ between plants was satisfactory and the response continued at higher levels. As such, an application of 60 N. under rainfed conditions and 90 N per hectare under irrigation is a satisfactory recommendation at the normal spacing of 18″ between rows and 6″ between plants till more precise data are obtained. The phosphate fertilizer may be applied according to the locally available advice.

This high yielding hybrid is no more tolerant to stemborer *Atherigona indica* and *Chilo zonellus* insect pests than the local *kharif* varieties being grown in the tracts for which it is recommended. Therefore, insect control measures will normally be required to ensure maximum yields. Limited information available indicates that shootfly incidence and losses will usually be least when the crop is sown well within the normal sowing period for each tract.

For successful cultivation of this hybrid it is advisable to sow it before the 15th of July in *kharif* season and in the first week of March for the summer season. Under a spacing of 18″ between rows and 6″ between plants, which is the normal practice, an application of 60 lb. nitrogen per acre under rainfed conditions and 90 lb. nitrogen per acre under irrigation is recommended. Phosphatic fertilizers could be applied according to the local practice. Average yields of over 2,000 lb. per acre under normal rainfall conditions and over 4,000. lb. per acre under irrigation have been realised with this hybrid and with intensive cultivation it is possible to step up the yields.

It should be noted that the produce from a commercial crop of hybrid *jowar* should never be used as the source of seed for another crop. If this is done, the crop raised from such seed, being in the second generation, will be most non-uniform and the yields will not be comparable to a first generation crop. It is therefore essential that the hybrid seed be purchased every year from authorized sources. The National Seeds Corporation supplies certified stocks of foundation seeds to authorized seed producers.

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COORDINATED SORGHUM HYBRID NO. 2

(N. Gangaprasada Rao and Leland R. House)

(The release of CSH 2 is another significant achievement in the direction of exploiting hybrid vigour for getting higher agricultural yields. The release of CSH 1 (see NSC Bulletin, Volume 1 No. 2 and 3. January and March 65) was announced a few months back and production of certified seed of this hybrid has already been taken up on all India basis. CSH 2 has extended the scope of hybrid sorghum cultivation in areas where mid late kharif crop can be grown.

The authors of this article are, in fact, the brains behind the evolution of the sorghum hybrids, CSH 1 and 2. In this article they have given different characteristics of CSH 2 with regard to its performance, adaptability etc— Editor).

The earlier release of CSH 1, suitable for the early and medium duration *kharif* areas and the irrigated summer tracts, marked the advent of Hybrid Sorghum to Indian Agriculture. The recent release of Coordinated Sorghum Hybrid No 2 (CSH 2) by the Central Varietal Release Committee fills the needs of the vast mid late *kharif* tracts all over the country.

CSH 2 has been developed by crossing male sterile combine kafir 60 with a yellow endosperm *Hegari* as the pollinator parent. This hybrid has been extensively tested all over the country during the years 1963 and 1964. It has a 77 per cent superiority with respect to grain yields while the fodder yields are almost equal to the locals. The comparative performance of this hybrid in the mid late *kharif* tracts, where it was found to be superior to both CSH 1 and local improved strains is summarized below :

	Grain Yield as % of Local			Fodder Yield as % of Local		
Year	CSH 2	CSH 1	Local	CSH 2	CSH I	Local
1963	192	151	100	135	92	100
1964	177	145	100	98	68	100

Unlike CSH 1, this hybrid is medium tall, about 6 feet, but not as tall as locals. It does not lodge ; the stem is leafy and remains green almost till harvest. It is later in maturity than CSH 1, flowering in 70-75 days and matures in 110-120 days. The grains are white pearly, the protein content and cooking tests are comparable to locals.

Regarding the area of adaptability, particular mention may be made of the Dharwar-Belgaum-South Satara region of the Mysore and Maharashtra States and eastern districts of Madhya Pradesh, Gwalior, Bhind, Morina, Shivpuri, Guna, Sehore, Bhopal and the adjoining Bundelkhand region of Uttar Pradesh. In addition, the following *kharif* tracts should be considered as the general area of adaptation. The monsoon sorghum tract of Madras States ; Visakhapatnam, Srikakulam and parts of Adilabad in Andhra Pradesh, the mid late areas of the Vidarbha region in Maharashtra, the forage sorghum areas in Orissa, Bihar and Uttar Pradesh, including the hilly areas.

Under reasonably good rainfall conditions average yields of 3000 kgs. of grains per hectare have been realised while under higher fertility conditions over 6000 kgs/Ha have been recorded. The hybrid responded upto 150 kgs of N per hectare. For a successful cultivation, sowing around the middle of July with normal spacing of 18" between rows and 6" between plants is recommended. Fertilization upto 80-100 N/acre could be done as a normal practice while higher doses could further maximise the yields. Phosphates and potash could be applied according to local recommendations. Appropriate plant protection measures, particularly against the fly and shoot borers are highly desirable.

As is the case with all hybrids, the produce of a commercial crop should not be used as seed. The National Seeds Corporation will be taking up the multiplication of this hybrid, and certified seeds in sealed bags will be available to the farmer in due course.

It has to be emphasized that the areas for CSH 1 and CSH 2 overlap in some cases. The two hybrids are not mutually exclusive in their areas of adaptation. As far as the *kharif* season is concerned, the guiding principle in choosing the hybrid has to be the maturity. If an early hybrid is needed. CSH 1 should be grown and if a slightly later one is the need, CSH 2 could be recommended.

HYBRID JOWAR CSH. I.
MARKS A NEW ERA IN INDIAN AGRICULTURE

Shri C. SUBRAMANIAM AWARDS
To the Scientists and Institutions
Responsible for the Development of
Hybrid Sorghum

Presented on
17-12-1966

By

COIMBATORE SEEDS CORPORATION
COIMBATORE - 10.

CSH-1.
MARKS ADVENT OF HYBRID SORGHUM TO INDIAN AGRICULTURE

Sorghum is the world's third most important food crop and in respect of acreage it is India's second cereal. The trends in sorghum production during the past twenty years do not reveal any marked increase, the average yields remaining around 200 Kgs of grain per hectare. Since the development of commercial hybrids provided the most important genetic tool in improving yields of crop plants substantially, such an effort was initiated in the year 1961 under the Accelerated Hybrid Sorghum Project. The first hybrid, Coordinated Sorghum Hybrid-1 (CSH-1) was released in 1964 by the Central Variety Release Committee of the ICAR for general cultivation in the early and medium duration **kharif** areas and irrigated summer tracts all over the country. This event marked the advent of **Hybrid Jowar** to Indian Agriculture and a break-through in the yield levels of this major cereal.

This high yielding hybrid is the product of hybridisation between male sterile combine kafir 60 and a selected yellow endosperm **feterita** (IS-84). It is early maturing in 100 days and gives on an average about 60-80% increased yield over the presently available improved varieties. Under optimum fertilisation and plant protection, yields of over 6000 Kgs/Ha have been realised. Against the limited adaptation of the available improved varieties which necessitates the development and cultivation of numerous varieties, CSH-1 is widely adaptable, being suitable for cultivation over one third of the present acreage in the country.

In some of the rice deltas after the harvest of the paddy crop, facilities exist for limited supply of water and crops like cotton and groundnut are grown. A crop of CSH-1 planted in January-February in such fallows returned 5000 Kg of grain per hectare without interfering with the normal rice. Paddy followed by **Hybrid Jowar** in the off-season, a crop of CSH-1 preceding wheat, barley, gram or other crops in the **rabi**, CSH-1 in summer followed by a ratoon and then a cotton crop, are becoming established practices. CSH-1, therefore, offers great potentialities for its being cultivated as an additional off-season crop.

Consequent on the development of the hybrid, a Hybrid Seed Industry is beginning to develop. This industry is growing with vigour and confidence in the different States and is well on its way to fulfil the seed requirements for the realisation of the Fourth Plan Targets.

CSH-1 together with CSH-2 provide the mainstay for the High Yielding Varieties Programme of the Fourth Plan with regard to **jowar** improvement. It is gratifying to note that necessary seeds of CSH-1 for 1967 has been already produced and is on hand. While the role of CSH-1 in improving the yield levels of traditional **jowar** areas is well-known, the central conference on intensive agricultural programmes recognised the impact of CSH-1 as an additional off-season crop in rice fallows and adopted that a substantial area of rice fallows be put to CSH-1 immediately. It is, therefore, appropriate that these awards are being made during the celebrations of the International Rice Year. While rice is the major cereal of the country, rice fallows could feed a good proportion of the Jowar consumer.

The Coimbatore Seeds Corporation is a pioneer in hybrid seed production, having started the production of CSH-1 seeds in November, 1964, immediately after the release of the hybrid by the Central Variety Release Committee.

In Madras State this Hybrid has made a great impact on increasing **jowar** grain production during the last two years. The hybrid had covered nearly 25,000 acres during 1966 with an estimated additional production of 25,000 tonnes of **jowar**. The Department of Agriculture, Madras, has programmed to grow 75,000 acres during the 1967 summer season with CSH-1. The Coimbatore Seeds Corporation has agreed to deliver 100 tonnes of CSH-1 seeds to the Dept. Of Agriculture for covering 30,000 acres in 1967 summer season.

The Coimbatore Seeds Corporation has at present a total seed production area of 500 acres and proposes to expand the hybrid seed production programme over an area of 2,000 acres in the near future with modern seed processing and air conditioned seed storage facilities.

The Coimbatore Seeds Corporation is proud to associate itself with the recognition accorded to Agricultural Scientists and Institutions which have made a significant contribution to the development and release of Hybrid Sorghum in India and thus usher a new era of Agricultural Prosperity in the Country,

AWARDS PRESENTED TO :

1. The Director-General of the Indian Council of Agricultural Research.
2. The Director and staff of the Rockefeller Foundation.
3. The Director and staff of the Indian Agricultural Research Institute.
4. The Dean and staff of the Millet Section of the Agricultural College and Research Institute, Coimbatore.
5. The Head and staff of the IARI Regional Research Centre, Coimbatore.
6. Shri N. Ganga Prasad Rao, Sorghum Breeder and Associate Project Co-ordinator, Indian Agricultural Research Institute.

As a Small Token of the deep Indebtedness of Sorghum Farmers and Seed Producers.

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PRODUCTION BREEDING AND HETEROSIS IN SORGHUM.

N. GANGA PRASADA RAO AND LELAND R. HOUSE

PRODUCTION BREEDING AND HETEROSIS IN SORGHUM

N. GANGA PRASADA RAO AND LELAND R. HOUSE

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With an annual area of over 17 million hectares, sorghum is truly the great millet of India. The yearly production of about 9 million metric tons of grain is, however, not commensurate with this vast acreage. Natural selection and domestication over many thousands of years has resulted in the development of numerous varieties, highly local in their adaptation. Cultured under different soil and climatic conditions, these varieties exhibit a wide range of variability with respect to duration and grain quality. The present-day improved strains have been evolved mostly by pure line selection from the principal local varieties. Limited inter-varietal hybridization followed by selection, till now, has primarily contributed towards combining grain yields with desirable fodder quality.

The discovery and development of cytoplasmic-genetic male steriles has made hybrid sorghum commercially possible (Quinby and Martin, 1954). The introduction of hybrid sorghum in 1956-57 into U.S. agriculture had the same impact on the sorghum industry as the development of hybrid maize. Sorghum improvement work at this Institute is of recent origin. The initiation of the Accelerated Hybrid Sorghum Project by the Indian Council of Agricultural Research in collaboration with the Rockefeller Foundation, in the year 1960, may be considered the beginning of a coordinated effort towards the improvement of this widely grown millet on a country-wide basis. The attempts towards exploitation of heterosis in production breeding are presented in this paper.

BREEDING HYBRID SORGHUMS

An *ad hoc* committee constituted by the Indian Council of Agricultural Research recommended that as an immediate measure, male sterile Combine Kafir 60 (Fig. 1) be used as the common female parent and the wide range of sorghum germ plasm available used as male parents so as to find out the best hybrids. Acceptance of the exotic male sterile as the common female parent presented certain potentialities as well as limitations.

The choice of the parents : In the utilisation of heterosis, selection is for combining ability of two parents. The acceptance of a single male sterile as the female parent limited the choice to the pollinator parent. Ms.CK60 grows well under varying conditions in India and is stable with respect to male sterility. It is non-photo-sensitive and flowers in about 60 days. Crosses with yellow, brown and even white seeded varieties with a brownish sub-coat result in brown seeded hybrids, which are not acceptable to the Indian farmer.

The sorghum germ plasm available consists of about 7000 stocks, half of which represent indigenous collections and improved strains evolved in India while the rest are exotic strains. Amongst the indigenous types, only the improved strains and the collections coming mainly from the States of Maharashtra, Mysore and Gujarat have white pearly grains ; collections from the other parts of the country have coloured or chalky white seed. Amongst the exotics, which are mostly from the United States of America and Africa, only the yellow endosperm types and their selections and the *zerazeras* yield white, pearly seeded hybrids of acceptable quality. Thus, the choice of pollinator parents is limited to the selected yellow endosperm materials, the *zerazeras* and the white pearly types; these, numbering about eighty have provided the parental material for the promising hybrids.

The testing of hybrids : It was decided in 1962-63 to test these eighty hybrids in small scale trials over a wide range of environment, in preference to a few large scale trials. The tests were located in all sorghum growing States representing late, medium and early tracts and *kharif*, *rabi* and summer seasons. The results were particularly encouraging where the flowering period of the hybrids coincided, at least approximately, with that of the local improved strains. In contrast to the highly localised behaviour of the improved strains, the hybrids with msCK60 performed well under diverse environmental and seasonal conditions indicating their greater adaptability.

The promising hybrids : Based on the performance in these regional trials, twelve promising hybrids were selected for further large scale testing in 1963-64. These hybrids represent a range in plant height varying from dwarf combine types to tall hybrids similar to Indian strains. A brief description of these hybrids is as follows :

1. *ms CK 60×IS 84* : Hybrid early, flowering in about 60 days ; medium dwarf (140-160 cm.) ; grain creamy white and pearly and bold ; stalks juicy.

2. *ms CK 60×IS 532* : Early, flowering in 58-60 days; dwarf (125-140 cm.); grain creamy white and pearly ; stalks juicy.

3. *ms CK 60×IS 2930* : Early, flowering in 58-60 days : medium dwarf (140-150 cm.) ; grain creamy white and pearly ; stalks juicy.

4. *ms CK 60×IS 2945* : Similar to the above hybrids in all respects—early, medium dwarf and juicy stalks.

5. *ms CK 60×IS 3691* : Medium tall (175 cm.) ; good compact heads ; flowers in 65-70 days ; white pearly grain.

6. *ms CK 60×IS 2931* : Medium tall (200 cm.) ; flowers in about 75 days in *kharif* and 60 days in summer ; grains white pearly.

7. *ms CK 60×IS 2932* : Medium tall (200 cm.) ; flowers in 60-65 days in *kharif* and 55 days in summer ; white pearly grains.

8. *ms CK60×IS 3687* : Tall (300 cm.) in *kharif* and medium tall (200 cm.) in summer ; flowers in about 65-70 days in *kharif* and 55 days in summer ; long, big heads ; grains white pearly.

9. *ms CK 60×IS 3555* : Tall (260 cm.) ; flowers in 50-60 days.

10. *ms CK 60*× Nandyal : Hybrid tall (about 280 cm.) but not taller than the male parent ; flowers in 75-78 days ; stands well ; grains white tending towards pearliness ; stalks juicy. Hybrids with *Karad Local* and *Shenoli* 4-5 are similar to ms CK 60×*Nandyal* in most respects.

11. *ms CK 60*× Aispuri : About 280 cm. tall ; stalks juicy ; flowers in about 70 days ; grains white tending towards pearliness.

12. *ms CK 60×M. 35-1* : Hybrid non-photosensitive unlike the male parent which is cultivated only in the *rabi* season ; tall (about 260 cm.) and juicy ; flowers in 65 days ; grain white pearly.

In addition to increased yields the maturation period and grain quality are important in determining the acceptability of a hybrid. The flowering period and consequently the maturity of any local variety are the result of selection over a long period and are adjustments with the rainfall pattern and the availability of soil moisture. From a quality viewpoint, the yellow seeded types predominate in the States of Madras and Andhra Pradesh; chalky whites in Madras, Madhya Pradesh and Rajasthan and pearly whites in Maharashtra, Mysore and Gujarat. A few red seeded types are also grown, but the general preference from the point of view of quality is for pearly white grain. Since sorghum grain provides the staple food for a large section of the population and the stalks furnish the principal fodder for cattle, the sorghum improvement programmes aim at combining high yield and good quality of grain without sacrificing fodder yields. If a hybrid conforms to the flowering and maturity of a given tract and satisfies the quality requirements it will find favour with the farmer.

Released hybrids and their performance : On further regional testing of these twelve hybrids, two hybrids ms CK60 × IS 84 and ms CK60 × IS 3691 were released for general cultivation during 1964 and 1965 as CSH-1 and CSH-2 respectively (Rao and House, 1965a, 1965b). CSH-1 (Fig. 2) is an early hybrid maturing

TABLE I

Summary of the performance of released sorghum hybrids (1963-64)

Hybrid	Yield as per cent of Local improved strain		No. of locations tested	Region
	Grain	Fodder		
(a) *Early Khariff Tract—Flowering 60 days*				
CSH-1	182	77	4	Very early tracts of Andhra Pradesh, Rajasthan and Gujarat.
(b) *Medium Duratian Kharif Tract—Flowering 70 days*				
CSH-1	170	77	8	The medium duration light soil tracts of Andhra Pradesh, Mysore, Maharashtra, Gujarat and the irrigated Tungabhadra project area.
CSH-2	154	164		
(c) *Late Kharif Tract—Flowering over 80 days*				
CSH-1	170	65	11	The light soil areas of Madras, Madhya Pradesh, Uttar Pradesh and the black soil areas of parts of Andhra Pradesh, Maharashtra and Mysore (Area of adaptation for CSH-2).
CSH-2	180	91		
(d) *Very late Kharif Tract—Flowering over 90 days*				
CSH-1	68	41	11	Madhya Pradesh and Rajasthan (None of the Hybrids are promising.)
CSH-2	77	69		
(e) *Kharif—Regions where only forage sorghums are grown*				
CSH-1	196	83	5	Delhi, Bihar and Orissa.
CSH-2	267	157		
(f) *Irrigated Summer Tract—Flowering 60 days*				
CSH-1	189	75	3	The Co. 18 tract of Madras State, parts of Andhra Pradesh and Mysore.
CSH-2	153	124		

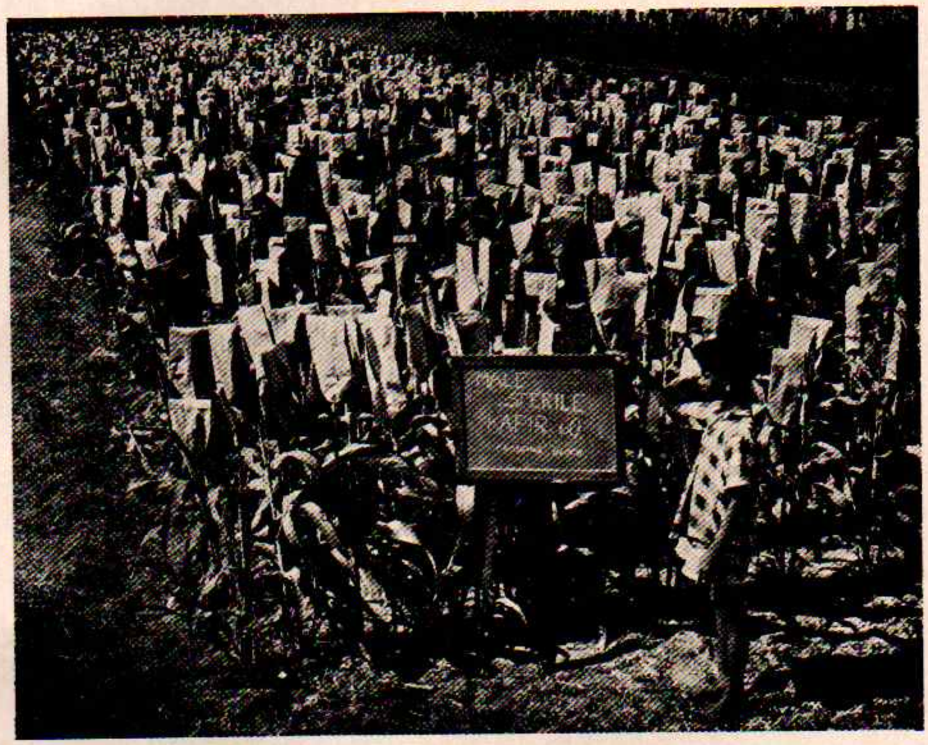

Fig. 1. A crossing block of ms CK 60 bagged for making experimental hybrids

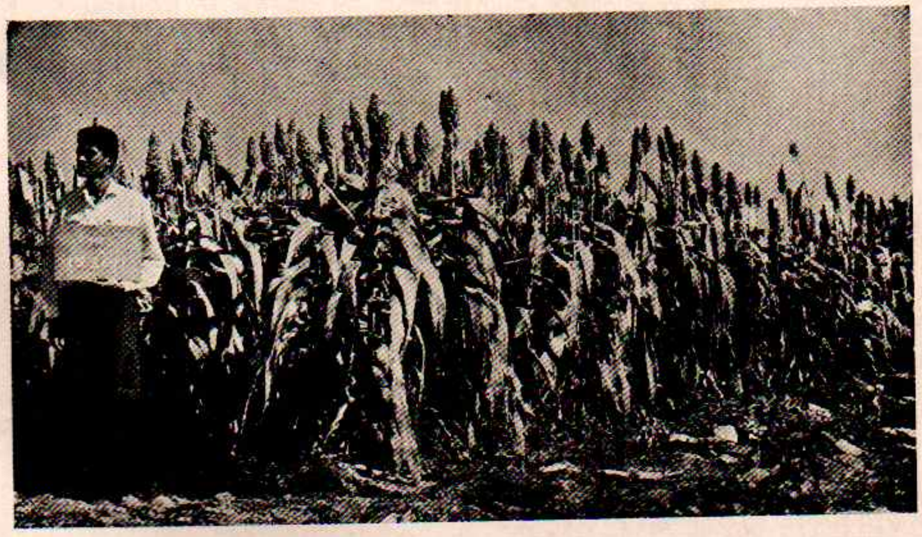

Fig. 3. A commercial crop of CSH-2

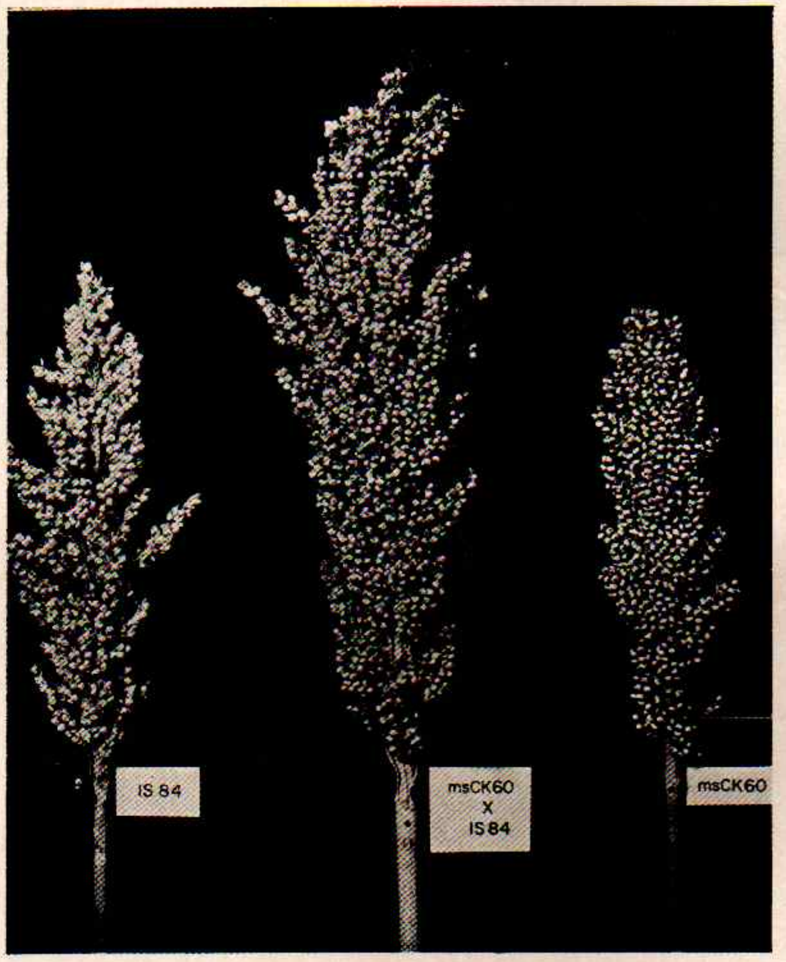

Fig. 2. CSH-1, the first sorghum hybrid released, and its parents

in 90-100 days and gives on an average 60-80 per cent increase in grain yields over the locals; the fodder yields are about 60-80 per cent of the local checks. CSH-2 (Fig. 3) has a 70-90 per cent superiority with respect to grain yields while the fodder yields are almost equal to the locals. The performance of the promising hybrids in different seasons and areas during 1963-64 is summarized in Table I. The season-wise behaviour and potentialities are discussed below :

(1) Kharif *season* : A major portion of the sorghums, about 11 million hectares, are grown in the *Kharif* or monsoon season (July-December). The period of maturity ranges from 130-170 days in respect of late varieties, 100-130 days with medium and 90-100 days with early varieties.

The early, medium and parts of late tracts are potential areas for hybrid sorghums. The hybrid CSH-1 is promising in the early and medium duration areas all over the country. CSH-2 is highly promising in respect of both grain and fodder yields in the medium as well as a portion of the late tract.

(2) Rabi *season* : The winter sorghums are grown during October-February in an area of about 6 million hectares and are highly reputed for their quality. The incidence of *Atherigona indica* is acute in this season and the hybrids are more susceptible than the local varieties. Besides, the yield increases are also moderate and the quality of the grain, except in comparison with the *rabi* yellows of Andhra, is not comparable to the white pearly types. Studies are, therefore, in progress to develop hybrids that have comparable quality and insect tolerance as the local varieties.

(3) *Summer season* : In Madras and in parts of Andhra Pradesh and Mysore, short duration (90-100 days) sorghums are grown in the summer season (March-May) under irrigation. The estimated area during this season is about 2 lakh hectares. The hybrid CSH-1, selected on the basis of its performance in the *Kharif* season and tested directly in the regional trials commencing from 1963, has been found to be most promising in the States of Madras and Andhra Pradesh.

Maximisation of Grain Yields

No sooner the promise of CSH-1 and CSH-2 was established, a few maximum potential trials were conducted providing 100-120 kg. N/ha. and adequate plant protection. The yield levels reached in 1964 are presented in Table II.

TABLE II

Maximum potential trials (Kharif, *1964*)

Location	State	Grain yield (Kg./Hect.)	
		CSH-1	CSH-2
Dharwar (Red soil)	Mysore	5582	7212
Dharwar (Black soil)	"	6704	6368
Yemmiganur	A. P.	5101	...
Indian Agricultural Research Institute	Delhi	6139	...

The hybrids were also tried in National Demonstrations with a plot size of one hectare each during *Kharif*, 1965. In spite of an unprecedented drought the yield levels attained could be considered satisfactory. A summary of these demonstrations is presented in Table III.

TABLE III

National Demonstrations (Kharif, *1965*)

State	No. of Demons-trations	Total area covered by Demonstrations (Hectares)	Grain yield in Quintals per hectare		
			Maximum recorded	Minimum	Average
1. A. P.	6	6	65.61	16.60	35.46
2. Mysore	9	8	38.87	10.52	25.79
3. Rajasthan	5	4	51.68	22.12	29.65
4. Gujarat	7	7	36.71	9.00	22.90
5. Uttar Pradesh	2	2	49.06	45.38	47.22
6. M. P.	4	4	24.00	13.00	20.13
7. Maharashtra	11	10	41.57	7.51	24.31
8. Bihar	1	1	48.30	...	48.30
9. Punjab	1	...	32.35	...	32.35

HYBRID-BASED NEW PRACTICES

The hybrids as well as the parents stand ratooning and being early it has been possible to take a main and ratoon crop both in commercial fields as well as in seed production plots where normally a single crop is taken. This, in effect, is two crops where only one is normally taken.

A major part of the sorghum area particularly in Maharashtra, Mysore, Madhya Pradesh and parts of Andhra Pradesh is grown under late varieties which mature in 5-6 months and yield about 600—900 kg. of grain per hectare. The soils here are of the black cotton type and the rainfall is so distributed that even under rainfed conditions double cropping may be a possibility. Under irrigated conditions CSH-1 followed by barley or wheat, or paddy followed by CSH-1 in the off-season have returned remunerative yields (Table IV). CSH-1 has, therefore, excellent opportunities to be grown as an off season crop or as an additional crop without disturbing the normal cropping patterns.

TABLE IV

New cropping patterns

Location	Grain yield (Kg./Hectare)			
	I Crop		II Crop	
Delhi-1964	CSH-1 (Rainfed)	6139	Barley (Irrigated)	2420
Dharwar-1964	CSH-1 (Rainfed)	6704	Gram Wheat Safflower (Rainfed)	440 355 227
Hyderabad—1964	Rice (irrigated)	Normal yields	CSH-1	5000

Hybrid sorghum seed production : Once the hybrids are released by the Central Variety Release Commtitee, the responsibility for multiplication of the parental lines (foundation stocks) and production of hybrid seeds rests with the National Seeds Corporation. The Corporation produces the foundation stocks on its own farms and the hybrid seed on the fields of certified seed producers.

GENETIC DIVERSITY AND HETEROSIS

In inter-varietal crosses, a positive relationship between genetic diversity of parents and expression of heterosis is generally observed. Using geographic origin as a criterion of genetic diversity, Moll, Salhuana and Robinson (1962) reported that greater genetic diversity was associated with greater heterosis in variety crosses of maize. In sorghum, King *et al.* (1961), observed that since most A lines are essentially *kafirs* or *kafir-milo* derivatives there was less genetic diversity for combining ability among A lines than among R lines. Maximum hybrid vigour was obtained in crosses between different groups such as *kafir* and *milo* or *kafir* and *feterita* than in within group crosses. Quinby (1963) reported that the maximum heterotic response was for the number of stalks per plant and the number of seeds per panicle.

On account of the adaptability to certain zones and greater genetic diversity provided by the Indian sorghums, it was expected that the exotic × Indian crosses would be high yielding and will be of immediate value. Since grain sorghums do not tiller under Indian conditions and the major contribution to yield is provided by the primary panicle the extent of heterosis in respect of yield and yield components was studied (Rao, unpublished) in three exotic × exotic and three exotic × Indian crosses. The crosses studied, though limited in number, were representative of some of the promising hybrids with both exotic and local strains. Contrary to expectations, the extent of heterosis exhibited by exotic × Indian crosses was found to be lower than in exotic × exotic hybrids. An examination of the heterotic response of the yield components indicated that the direction of evolution of these yield components may have a bearing on the combining ability. It is observed that for ear length, as the parental range increased heterotic response also increased. On the other hand, the tertiary branches bearing grain decreased as the parents became increasingly diverse. Since the number of tertiary branches are more on the compact varieties where the panicle axis is reduced in length there may be lack of co-adaptation between genes or gene complexes for length of primary axis and genes for long secondaries with more number of tertiaries. Heterotic response appears to be maximum in respect of characters evolved in the same direction. In general, as the yield level of the pollinator parents increased, heterosis decreased (Rao, unpublished).

Heterosis and Combining Ability

The nature of gene action in yield heterosis has a bearing on the development of efficient breeding procedures. General combining ability is attributed to additive genetic effects and additive × additive epistasis and is, theoretically, fixable. Specific combining ability attributable to non-additive gene action may be due to overdominance or epistasis or both. The presence of non-additive genetic variance is the primary justification for initiating a hybrid programme (Cockerham, 1961).

Evidence on the nature of combining ability is sorghum is limited. Studies of Reddy (1963) and Kambal and Webster (1966) revealed that the variance for general combining ability was much greater than for specific combining ability. The general and specific combining ability variances obtained from crosses between a set of exotic male steriles used as females and a set of improved Indian strains used as pollinator parents are presented in Table V (Reddy, 1963).

In crosses between open pollinated maize varieties, a genetic situation of partial to complete dominance of genes with high but differing gene frequencies in the two varieties was suggested (Robinson, Khalil, Comstock and Cockerham, 1958). Smith (1952), recognizing that the heterosis in self-pollinated crops is not a genetic

TABLE V

Estimates of general and specific combining ability variances obtained by mating a series of exotic male steriles to a series of improved Indian strains as pollinator parents (Reddy, 1963)

Character	Variance*			
	gca	sca	w	e
Weight of panicle (Gm.)	41271.1	1221.2	278.4	617.2
Grain weight (Gm. per panicle)	8968.6	350.1	209.4	279.3
Panicle length (Cm.)	693.5	11.5	3.1	6.7

*gca=general combining ability ; sca=specific combining ability : w=sampling error ; e=experimental error.

accident, attributes it to a combination of divergent alleles acting in a complementary manner to produce a more efficient physiological condition. Subsequent selection and inbreeding would permit accumulation of more favourable alleles or gene complexes in a homozygous condition as achieved by him in fixing transgressive vigour in *Nicotiana rustica*. As pointed out by Lonnquist (1963) the increase in the knowledge of gene action for yield in corn has provided a basis for re-evaluating breeding methods and aided development of new breeding schemes. Studies in this direction have been initiated and are expected to provide a rationale for the development of efficient breeding methods for sorghum improvement.

STUDIES ON MALE STERILITY

Various aspects relating to seed set on ms CK 60 were studied during 1961-62 (Hussaini, 1962). Stigma receptivity was satisfactory for a period of five days after its emergence. A period not exceeding 45 minutes from the time of collection of pollen and pollination resulted in good seed set under field conditions. Maximum seed set was obtained when pollinations were made between 6.30 to 7.30 A.M., but could be continued till 11:30 A.M. without excessive decrease in seed set. Foliar feeding of pollinator parents with boron appeared to have a favourable effect on pollen germination and consequently better seed set.

The need to develop new male steriles of diverse origin is recognized as this will allow of a choice of the female parent so as to develop hybrids for the late *kharif* and the *rabi* tracts for which ms CK 60 was not found suitable. A number of non-fertility restoring lines, both indigenous and exotic, have been identified and are being used in a back crossing programme to develop new male steriles. Rao

(1962) reported the occurrence of cytoplasmic-genetic male sterility in some quality winter sorghums of India and attempts are in progress to develop their fertile counterparts. The new steriles, when available are not only expected to provide a choice of the female parent, but also alleviate some of the drawbacks of ms CK 60 with respect to quality and susceptibility to insect pests.

ACKNOWLEDGEMENTS

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FURTHER STUDIES IN BREEDING HYBRID SORGHUMS*

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Development of commercial hybrids has provided the most important tool in improving yields of crop plants substantially. Utilizing the source of cytoplasmic-genetic male sterility from Combine Kafir 60 (msCK 60), it has been possible to develop and release the first sorghum hybrid for general cultivation in the early and some of the medium duration *kharif* tracts and the irrigated summer areas of India (Rao and House, 1966); further studies in this direction are presented in this paper.

Material and Methods

Fifteen selected hybrids with msCK60 as the common female parent were further tested in a regional trial conducted at 37 locations during the 1965 *kharif* season and at two centres during the summer season. The experiment was laid out as randomized blocks replicated five times. The gross plot size was 375 sq. ft. and the net plot 300 sq. ft. Three of the five replications were protected from pests and diseases through appropriate pest control measures while the remaining two did not receive any such treatment. The hectare yields were, however, computed from all the replications.

Results

(1) Hybrids vs. local improved strains

Out of about twenty hybrids tested extensively all over the country during 1963 and 1964, two hybrids, CSH-1 and msCK60 $\times$ IS 3691, were generally superior combining high grain yields, grain quality, plant type and adaptability. They have been most promising in early, medium and mid-late *kharif* tracts and the summer season, but their performance in some of the late *kharif* tracts and during *rabi* season was not markedly superior to local varieties. The comparative performance of these two hybrids over 39 locations during 1964 is presented in Table 1.

It is seen that the hybrids have a 40 per cent. superiority over the local improved strains with respect to grain yields. Even though the hybrids were comparatively low yielding than the locals at 4 out of the 39 locations, the general

*Based on a paper presented at the All India Sorghum Workers' Conference, Hyderabad, 1965.

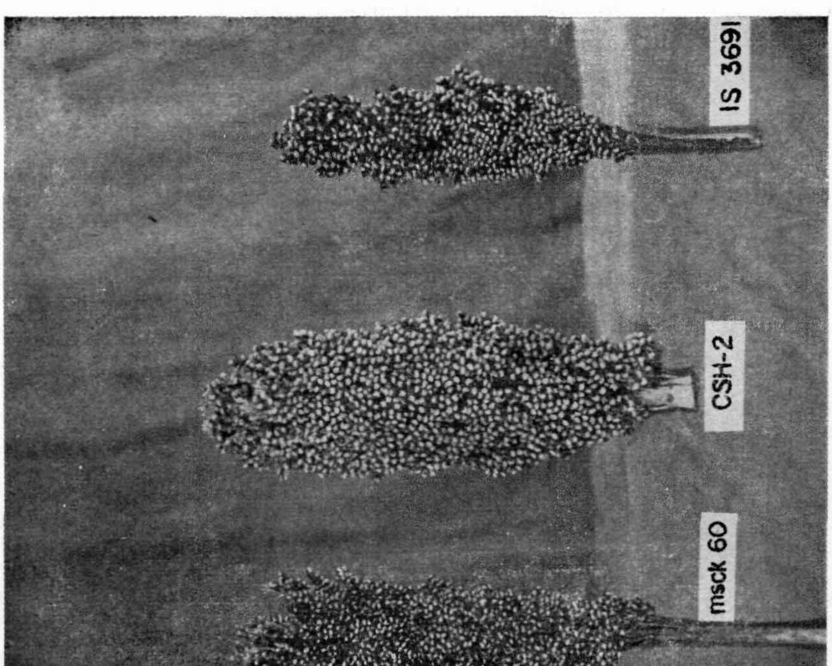

FIG. 1. The experimental hybrid ms CK 60 × IS 3691 has since been released as CSH-2.

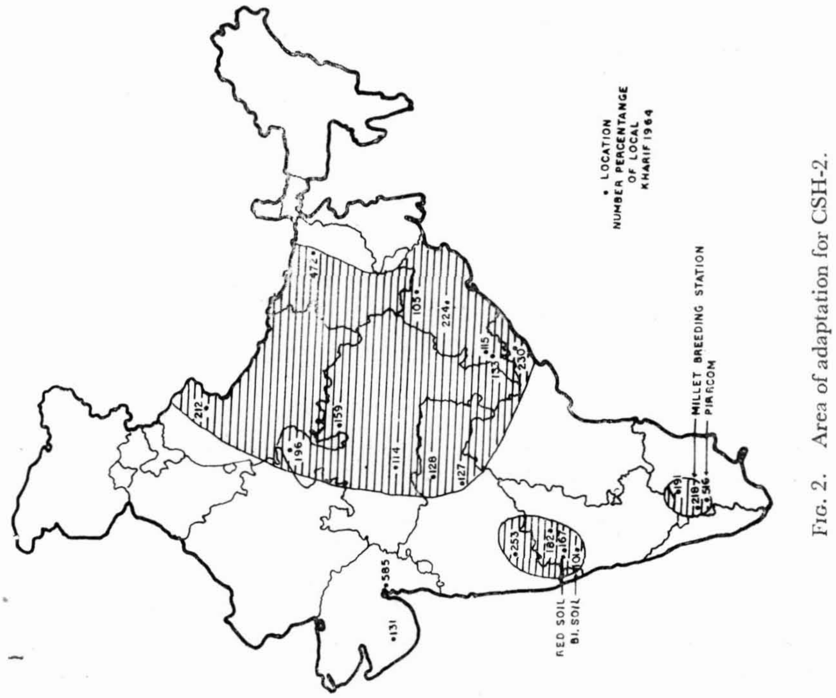

FIG. 2. Area of adaptation for CSH-2.

superiority of the hybrids in increasing the genetic potential of yields in sorghum is brought out by these extensive studies.

TABLE 1

Average performance of hybrids vs. locals in 39 locations

Hybrid/Variety	Grain yields		Fodder yields	
	Kg/ha.	Per cent of Local	Kg/ha.	Per cent of Local
CSH-1	2617	135	6025	61
msCK 60 × IS 3691*	2756	142	9439	95
Local improved strains	1942	100	9914	100

*Since released as CSH-2

(2) PERFORMANCE OF CO-ORDINATED SORGHUM HYBRID-1

The grain and fodder yields of CSH-1 in areas where this hybrid is superior to both the local and msCK60 × IS 3691 are presented in Table 2. These results further confirm the earlier findings (House and Rao, 1965) that CSH-1 is best suited to the early and medium duration *kharif* tracts and the summer season. In most of these areas either the rainfall is low or the soils are lighter or a second crop is taken and consequently earliness is an advantage. Further, the yields of this hybrid are also very encouraging in some late tracts like Parbhani in Maharashtra and Adilabad in Andhra Pradesh. The mean increase in grain yield is 64 per cent. over the local improved strains.

(3) POTENTIALITIES OF HYBRID msCK60 × IS 3691

A comparison of CSH-1 ,msCK60 × IS 3691 and the local checks revealed that this hybrid is generally superior in the mid-late and some late tracts of Andhra Pradesh, Mysore, Maharashtra, Madhya Pradesh, Gujarat, Uttar Pradesh, Orissa and Bihar. The yield data are presented in Table 3 and the locations indicate the areas of adaptation.

It is observed that msCK60 × IS 3691 has given a 67 per cent. increase in grain yields over the local while the fodder yields are approximately equal. In the States of Orissa and Bihar which grow essentially forage sorghum, the hybrid offers possibilities of increasing grain yields as well.

(4) AGRONOMIC ATTRIBUTES OF HYBRIDS AND LOCALS

Some of the agronomic attributes of the two hybrids in comparison with local are presented in Table 4.

It is to be noted that the areas of CSH-1 and msCK60 × IS 3691 are not mutually exclusive. In the *kharif* season, CSH-1 is particularly suitable wherever earliness is an advantage and msCK60 × IS 3691 for later areas.

TABLE 2

Comparative performance of CSH-1 in areas where it is superior in grain yields to both msCK 60×IS 3691 the local improved strain (Kharif, *1964*)

Location	State	Grain yields (kg./ha.)				Fodder yields (kg./ha.)			
		CSH-1	msCK-60 × IS 3691	Local improved strain	C.D. 5 per-cent.	CSH-1	msCK-60 × IS 3691	Local improved strain	C.D. 5 per-cent.
Mudhol	A.P.	1,323	1,146	1,206	412	3,301	4,234	6,458	1,392
Yemmiganur	,,	4,522	3,270	2,777	400	5,943	12,819	7,374	2,039
Siruguppa	Mysore	4,461	3,302	2,646	416	5,339	13,319	6,437	1,525
Raichur	,,	2,831	1,952	1,543	958	4,754	15,787	12,199	4,833
Bagalkot	,,	2,908	2,850	1,938	812	6,583	10,822	12,480	3,510
Annigeri	,,	2,515	1,987	647	189	4,007	6,624	4,648	1,035
Dhulia	Maharashtra	2,146	868	1,618	919	4,521	3,911	3,193	2,641
Parbhani	,,	4,864	3,584	2,833	1,088	7,059	16,146	21,138	2,632
Khargone	M.P.	1,564	1,528	1,145	588	2,834	4,951	6,638	2,045
Viramgam	Gujarat	861	578	771	545	4,485	7,284	5,274	1,692
Deesa	,,	1,302	1,091	1,112	Not Sig.	3,229	5,454	7,284	1,687
Bassi	Rajasthan	616	776	463	225	5,131	9,795	7,284	
Delhi	Delhi	3,387	2,870	1,665	1,033	—	—	—	—
Mean		2,562	1,985	1,567		4,766	9,262	8,367	
% over local		164	127	100		57	111	100	

TABLE 3

Comparative performance of msCK 60×IS 3691 in some mid-late areas where it is superior in grain yields to both CSH-1 and local improved strains (Kharif *1964*)

Location	State	Grain yields (kg./ha.)				Fodder yields (kg./ha.)			
		msCK-60 × IS 3691	CSH-1	Local improved strain	C.D. 5 per-cent	msCK-60 × IS 3691	CSH-1	Local improved strain	C.D. 5 per-cent
Coimbatore (MBS)*	Madras	1,916	1,780	893	608	4,937	3,520	4,729	1,001
Coimbatore (PIRRCOM)	,,	3,695	2,405	670	665	5,740	5,025	5,290	780
Bhavanisagar	,,	2,956	3,064	1,550	879	5,597	4,506	5,281	944
Vizianagaram	A.P.	3,131	2,771	1,359	416	7,133	4,097	8,209	969
Dharwar (Red soil)	Mysore	4,542	4,270	2,727	563	12,558	8,468	16,361	1,654
Dharwar (Black soil)	,,	5,375	4,901	5,332	545	17,150	14,424	26,479	1,033
Bailhongal	,,	4,248	3,204	2,339	800	10,190	4,880	17,976	2,727
Digraj	Maharashtra	1,927	2,009	761	865	2,063	1,704	3,050	Not Sig.
Akola	,,	2,077	1,686	1,625	419	7,032	4,413	6,745	1,683
Gwalior	M.P.	2,727	2,332	1,392	685	19,375	11,912	13,993	1,848
Nowgong	,,	1,162	309	732	249	4,090	3,193	4,664	1,428
Betul	,,	2,325	1,521	2,038	897	3,875	2,870	4,987	1,435
Tanchha	Gujarat	1,881	1,938	322	610	10,271	6,970	10,063	2,318
Junagadh	,,	757	574	578	260	4,079	2,958	3,541	1,165
Almora	U.P.	3,090	2,053	1,455	738	22,923	10,963	9,727	4,465
Jeypore	Orissa	2,691	2,299	2,018	1,045	3,532	3,924	3,252	1,641
Phulbani	,,	4,375	3,192	1,957	881	4,375	3,192	6,151	1,631
Keonjhar	,,	2,690	2,279	2,560	861	8,370	8,703	7,087	2,047
Rayagada	,,	2,888	1,363	2,512	—	16,505	12,020	14,172	—
Sabour	Bihar	5,588	5,355	1,184	933	25,026	17,581	26,999	3,749
Mean		3,002	2,465	1,700		9,741	6,766	9,938	
% over local		177	145	100		98	68	100	

*MBS—Millet Breeding Station

TABLE 4

A comparison of some agronomic attributes of hybrids vs *locals*

Character	CSH-1	msCK60 × IS 3691 (CSH-2)	Local improved strains
Days to 50% Bloom	58–60	70–75	60–95
Plant Height (Cm.)	140–160	150–200	200–300
Lodging percentage	0–1	0–10	0–90
Grain Colour	Cream, pearly	Cream, pearly	Yellow, white-chalky, red, white pearly
Fodder Quality	Juicy, high proportion of leaf to stem	Juicy, high proportion of leaf to stem	Juicy to pithy
Threshability	Good	Good	Good
Taste	Satisfactory	Satisfactory	Good
Reaction to shootfly	Susceptible	Susceptible	Susceptible

DISCUSSION

An account of the attempts towards exploitation of heterosis in increasing the yield levels of the sorghum crop in India were presented by Rao and House (1965). The results leading towards the release of CSH-1 and the implications of some of the findings on the adaptability of hybrids and local improved strains were reported subsequently (House and Rao, 1965).

Results of hybrid testing during 1964 further confirmed the suitability of CSH-1 to early and medium duration tracts. The acre yields of this early hybrid were encouraging in the late sorghum tracts as well and opened up the possibilities of double cropping even under rainfed conditions in otherwise single cropped lands. Some of the deep black soil areas in the States of Andhra Pradesh, Mysore, Maharashtra, Gujarat, Madhya Pradesh and Rajasthan represent such areas where double cropping potentialities could be explored. In the rice deltas after the harvest of paddy crop, facilities exist for limited supply of water and attempts are in progress to grow crops like cotton, groundnut *etc.*, as an off-season crop without interfering with the normal rice cultivation. Indications are available that this hybrid did well as an off-season crop in such paddy fallows in Andhra Pradesh and Orissa (unpublished data). It, therefore, seems feasible that even a portion of the rice fallows could produce a substantial requirement of the sorghum crop releasing the traditionally long duration single cropped sorghum areas for cultivation of more profitable crops. Millet crops, could, perhaps, in future be grown essentially as additional off-season crops or as short duration crops facilitating double cropping. Further studies in this direction are, therefore, needed to evolve suitable cropping patterns and cultivation practices.

The promise of experimental hybrid msCK60 × IS 3691 for some of the midlate *kharif* tracts is well brought out by these studies. The male parent of this hybrid is a selection from yellow endosperm *hegari*. It has a 77 per cent. superiority with respect to grain yields while the straw yields are almost on par with locals. In States like Orissa and Bihar which grow forage sorghums, this hybird could contribute to substantial grain yields which could be used as a better cattle feed in addition to realizing comparable straw yields. Comparative yield data of CSH-1 and msCK60 × IS 3691 has enabled a broad demarcation of the area of adaptability for this hybrid.

The changing of the plant type has played a significant role in increasing sorghum yields in U.S.A. Development of shorter plants has changed the yield status of wheat and rice. Sorghum stalks in our country are more valued for fodder than wheat or rice. While certain amount of dwarfing of the present day tall Indian varieties is essential, it may still be possible to combine high yields with non-lodging hybrids of an intermediate height. The experimental hybrid msCK60 × IS 3691 is one such in that the height is less than the locals and what is lost in fodder by way of plant height is made good by increasing the number of plants per unit area. It is expected that this hybrid will be released for general cultivation in the mid-late *kharif* sorghum tracts.

Summary

The results achieved in the development of hybrid sorghums subsequent to the release of CSH-1 have been presented. The performance of this hybrid is in conformity with the earlier findings and confirmed its suitability to the early and medium duration *kharif* areas and the summer season. The potentialities of this early hybrid in converting traditionally single cropped sorghum tracts into double cropped areas and the feasibility of growing it as an additional off season crop were discussed.

The performance of experimental hybrid msCK60 × IS 3691 (CSH-2) is critically reviewed and an attempt is made to demarcate the area of adaptation for this hybrid. With a 70 per cent. increase in grain yields and comparable fodder yields with local improved strains, it is expected that this hybrid will be released for general cultivation.

The general superiority of hybrids over local varieties in stepping up the genetic potential of yields was brought out.

Acknowledgement

Grateful thanks are due to the various co-operators at the State and PIRRCOM experiment stations where the regional trial was conducted. The yield data reported is from the 1964 regional trial.

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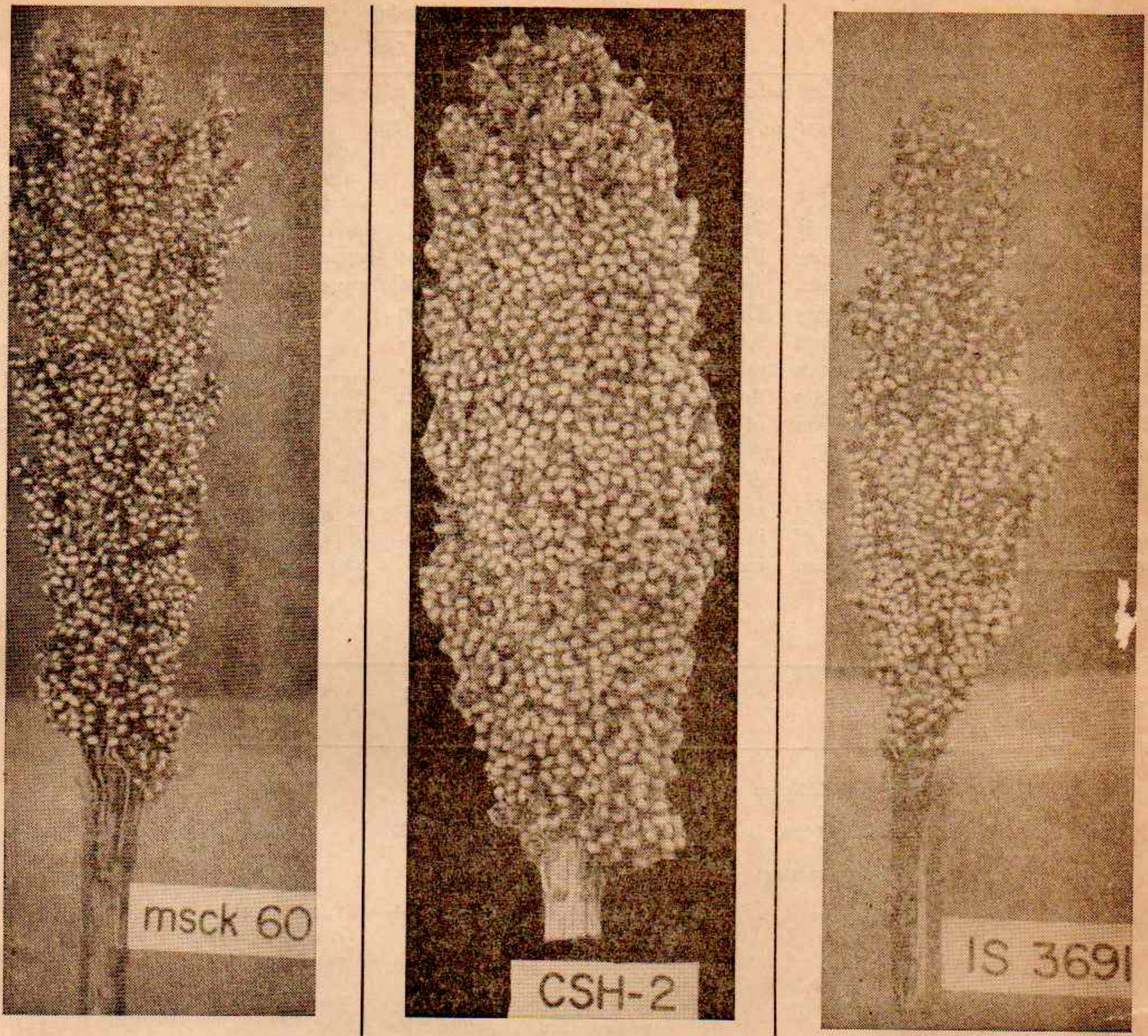

CSH-2 and its parents

csh-2-the second jowar hybrid

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COMING IN THE wake of the well-received CSH-1, Coordinated Sorghum Hybrid 2 (CSH-2) released by the Central Variety Release Committee in August 1965, caters to the needs of the vast mid-late *kharif* tracts all over the country. CSH-2 has been developed by crossing male-sterile combine kafir 60 with a selected yellow endosperm *hegari* (IS 3691) as the male parent. This hybrid was cultivated by the farmers of Maharashtra on a limited scale during 1966 *kharif* season and is expected to become widely available from the 1967 *kharif* season.

Comparative Performance

It has a 70-90 per cent superiority with respect to grain yields, while the fodder yields are almost equal to the locals. The comparative performance of this hybrid in the mid-late *kharif* tracts, where it was found to be superior to both CSH-1 and local improved strains is summarised on page 5.

Unlike CSH-1, this hybrid is medium-tall, about 6 feet, but not as tall as locals. It does not lodge: the stem is leafy and remains green almost till harvest. It is later in maturity than CSH-1, flowering in

SUMMARY OF THE PERFORMANCE OF CSH-2

Region	Av. Grain yield (kg-ha)			% of local	
	CSH-2	CSH-1	Local	CSH-2	CSH-1
Mid-late kharif, 1963 (av. of 15 trials)	2948	2324	1535	192	151
Mid-late kharif, 1964 (av. of 20 trials)	3002	2465	1700	177	145

80-85 days and matures in 115-125 days. The grain are white, pearly and the protein content and cooking tests are comparable to locals. Under optimum moisture, fertility and plant protection, maximum yields up to 7000 kg/ha have been realised. The agronomic attributes of the two hybrids in comparison with the locals are presented below.

Area of Adaptability

Regarding the area of adaptability particular mention may be made of the Dharwar-Belgaum-Satara region of the Mysore and Maharashtra Station, Shivpuri Guna, Sehore, Bhopal of Madhya Pradesh and the adjoining Bundelkhaand region of Uttar Pradesh. In addition, the following kharif tracts should be considered as the general area of adaptation: the monsoon sorghum tract of Madras State; parts of Adilabad in Andhra Pradesh, the mid-late areas of the Vidarbha region in Maharashtra and forage sorghum areas in Orissa, Bihar and Uttar Pradesh, including the hilly areas. In general, the hybrid may be grown in all the kharif areas where presently local varieties maturing in 120-140 days are cultivated.

Package of Practices

Seed. Obtain certified seeds of CSH-2 hybrid from certified seed producers, National Seeds Corporation, or the State Department of Agriculture.

Preparatory tillage. Obtain good tilth by ploughing and two or three harrowings.

AGRONOMIC ATTRIBUTES

Character	CSH-1	CSH-2	Local improved strains
1. Days to 50% Bloom	58-60	75-80	70-95
2. Plant height (cm.)	140-160	150-200	200-300
3. Lodging percentage	0-1	0-10	0-90
4. Grain colour	Cream pearly	Cream pearly	Yellow, white-chalky, red, white pearly
5. Fodder quality	Juicy, high portion of leaf to stem	Juicy, high portion of leaf to stem	Juicy to pithy
6. Threshability	Good	Good	Good
7. Taste	Satisfactory	Satisfactory	Good
8. Reaction to shootfly	Susceptible	Susceptible	Susceptible
*9. Nutritional quality:			
Moisture (%)	10.9	10.8	9.9
Protein (%)	9.7	11.1	8.9
Fat (%)	2.8	2.2	2.5
Minerals (%)	1.7	1.5	1.8
Carbohydrate (%)	74.9	74.4	76.9
Calories/100 g	364	362	366
Calcium mg/100 g	34.3	23.3	32.0
Phosphorus mg/100 g	327.3	314.2	311.4
Iron mg/100 g	6.3	5.7	8.7

*Analysis from the Nutrition Research Laboratory, Hyderabad. Hybrids were grown at Delhi and the local compared was from Hyderabad, grown in laterite soils.

Fertilization. In addition to any organic manures applied, the following levels of fertilization are recommended.

Nitrogen	—	80-100 kg/hect
P_2O_5	—	60-80 kg/hect
K_2O	—	According to local recommendation

All the phosphatic fertilizer and potash and half the dose of nitrogen should be given as a basal dressing. If a fertilizer-cum-seed drill is available place the mixed fertilizer 3″ away and 3″ below the seed. Otherwise, follow the normal practice of spreading and mix with harrow. The remaining half dose of nitrogen should be applied 40-45 days after sowing. Final thinning must have been done by now. Apply this second dose four inches away from the rows and intercultivate to mix the fertilizer. CSH-2 can respond up to 150 kg/N per hectare.

Sowing, gap-filling and thinning. Adopt the local practice of spacing between rows (usually 18″). The time of sowing should be well within the limits of normal sowing period, usually towards the middle of July. Drill seed with a seed rate of 5 kg/hect at optimum moisture. Immediately after germination examine for any gaps and re-sow the gaps by hand dibbling.

Thin at two stages to retain one plant at every 6″. The final thinning may be done when the plants are about 30 days old. Within the row there should be no gap exceeding 12″ between plants.

Note that it is very essential to have a full stand since the hybrids can stand thick populations.

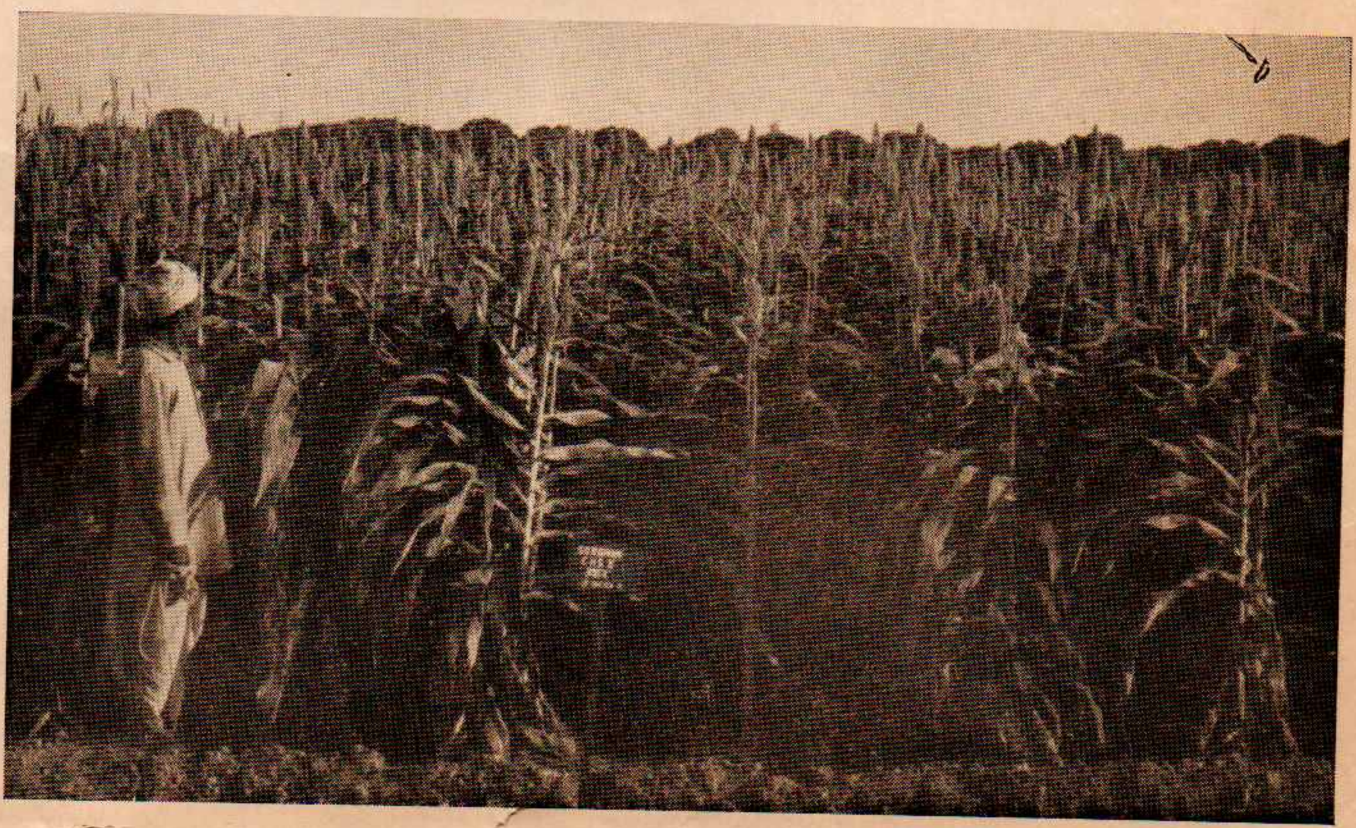
Insect control. As a rule, the following plant protection schedule is recommended: (1) On the third to the fifth day after germination an endrin spray, 0.055 at 500-800 litres/hect or any other systemic insecticide as a safeguard against attack of stemfly and moth borers. (2) After the final thinning and before the second dose of fertilization apply 0.2 per cent endrin granules at 10-20 kg/ hect to the foliage with special care to treat plant whorls. Excessive application in leaf whorls may be avoided as this may cause leaf blotching. The granules may be taken in a perforated tin and dropped in the whorls by walking along the rows. One man can cover an acre easily in a day. (3) A second application of granules about 15 days letter is highly desirable. (4) When the earheads start emerging, dust 5% DDT, 10-15 kg/hect as a safeguard against midge or earhead bugs. In case of any other pests, consult the local officers.

Weeding and interculturing. Keep the field absolutely clean through hand-weeding and intercultures. The frequency of irrigations may be so adjusted taking into account the rainfall received. Note that the greatest demand for water is at the time of flowering.

Bird scaring. If the hybrid matures earlier than the surrounding locals, birds maybe expected to play havoc. Keep a vigilant watch from the early milk stage till the harvest.

Harvest and threshing. As per local practice. The harvested produce is only for consumption and not to be used again as seed.

A commercial crop of CSH-2



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GENETICISTS RECEIVE SIR SHANTI SWARUP BHATNAGAR AWARD 1966-1967 FOR BIOLOGICAL SCIENCES.

Dr. H. K. Jain

Dr. N. G. P. Rao

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GENETICISTS RECEIVE SIR SHANTI SWARUP BHATNAGAR AWARD 1966–1967 FOR BIOLOGICAL SCIENCES

The Society and the Journal record with great pleasure the nomination by the CSIR of two members of the Society—Dr. H. K. Jain, Head of the Division of Genetics, Indian Agricultural Research Institute, New Delhi and Dr. N. Gangaprasada Rao, Project Co-ordinator (Sorghum) ICAR—to receive the Sir Shanti Swarup Bhatnagar award for biological sciences for 1966–1967.

Dr. H. K. Jain, Head of the Division of Genetics at the Indian Agricultural Research Institute, New Delhi has made extensive contributions in the field of genetic recombination including its mechanism and regulation, more particularly its control at the interchromosome level. A new hypothesis on such a control has been developed and considerable experimental evidence has been obtained in support of it. Dr. Jain's work on tomato and more recently on *Drosophila* has provided what is considered to be the first convincing evidence in support of the phenomenon of mutagen specificity. His school at IARI has shown that chemicals like hydroxylamine and hydrazine, which react with particular bases in the DNA molecule, induce non-overlapping mutations at specific gene loci. The manipulation of mutation rates and spectrum has been one of the most important objectives of contemporary mutation research and Dr. Jain's work on mutagen specificity and mutation rates has been an important contribution in this direction. His other studies relate to the synthesis of RNA in plant cells, more particularly the demonstration of hyperactive nature of the nucleolus-organising locus in this regard.

In more recent years, Dr. Jain has been interested in studies on adaptation in wheat and on problems with regard to origin of the maize plant. Some of these studies have indicated the possibilities of finding a number of cytological and other parameters for measuring adaptability. Thus, it has been found that wheat varieties marked by a high degree of adaptability, as shown by multi-location tests, are characterised by a high chiasma frequency and stability in the synthesis of their DNA under different environmental conditions. In contrast, such varieties show considerable plasticity in their RNA synthesis at different temperatures. Analysis of the primitive races of maize discovered in Sikkim has shown that this material differs from the present-day commercial varieties in many important characters, including their DNA content, genetic recombination potential and chromosome structure. These findings have suggested the possibility that maize might have been introduced in Asia in a pre-Columbian period.

During the past five years, Dr. Jain has been leading a group at IARI engaged in the diversification of the high yielding varieties programme. A number of new concepts have been extensively used in the course of these studies, including the concept of improved harvest index, in order to ensure that the current agricultural transformation is extended to crops like pulses, oilseeds and cotton.

Dr. Jain had his education at the University of Delhi and at the Indian Agricultural Research Institute, where he had a first class first academic record. Subsequently (1952–1955), he held the 1851 Science Research Scholarship of the Royal Commission, London, at the University of Wales for three years, working for his Ph.D. degree. He has been President of the Indian Society of Genetics and Plant Breeding and has presided in a number of international scientific meetings. Dr. Jain has developed an active school of research in the field of mutagenesis and cytogenetics at the IARI, and a large number of Ph.D. students who have come out of this school now occupy important positions in India and abroad.

As the Sorghum Breeder at the Indian Agricultural Research Institute, Dr. NEELAMRAJU GANGA PRASADA RAO was associated with this project right from its inception and subsequently became the co-ordinator of the All India Co-ordinated Sorghum Improvement Project during 1968.

Dr. Rao's primary contribution is in the field of sorghum breeding, resulting in the release of the first commercial sorghum hybrids, CSH-1 and CSH-2. Subsequently, a high yielding variety *Swarna* that equalled the commercial hybrid CSH-1 in yield levels was also developed and released for general cultivation. The performance of the first hybrids, following their release, amply demonstrated that the average yields of this rainfed crop could be stabilised at 2000–2500 kg./hect. as against the national average of only 400–500 kg./hect. Maximum yields of the order of 7000 kg./hect. were recorded under optimum conditions. The hybrid CSH-1 has made profound impact particularly in the dryland districts of Maharashtra and Mysore, benefiting a large section of the dryland farming community in peninsular and central India. These hybrids also performed well in several African, South-East Asian and Latin American countries. The advent of the hybrids gave rise to an organised hybrid sorghum seed industry in the public as well as private sectors.

Dr. Rao's contribution to basic biological sciences include discovery of apomixis, the production of seed without the union of male and female gametes, which has potentialities in developing perpetual hybrids. The belief that hybrids are meant for better farming conditions only was disproved by his studies on stability of hybrids and varieties under stress and non-stress conditions. Hybrids were demonstrated to have better performance under moisture stress when local varieties failed. Dr. Rao observed that the tall, late Indian *Jowars* are individually superior whereas the dwarf, early exotic *Jowars* are superior in a community. Present efforts of Dr. Rao and his associates are aimed at combining the individual superiority of Indian varieties with the community performance of exotics through exotic × Indian crosses. Dr. Rao has over 50 research publications.

As Project Co-ordinator, he has laid a sound foundation for the development of a multi-disciplinary All India Co-ordinated Sorghum Improvement

Project involving several scientists from state Departments of Agriculture and Agricultural Universities.

Dr. Rao was born in a village, Korisapadu, Ongole district of Andhra Pradesh. He had his early education at Korisapadu village and high school education at Bapatla and Ongole and later at Hindu College, Guntur. He took his B.Sc. (Ag.) from the Bapatla Agriculture College during 1949 obtaining second rank in Andhra University. He was awarded the B.V.L. Narayana's Gold Medal. He did his post-graduate studies at the Indian Agricultural Research Institute, New Delhi obtaining a first class and first rank during 1953. Dr. Rao worked as a research assistant in the Hyderabad/Andhra Pradesh Departments of Agriculture (1950–58), Lecturer in Osmania University Agriculture College (1958–60) and since then he has been with the ICAR and IARI.

He was earlier awarded the C. Subramaniam Gold Medal; the Andhra Pradesh Government presented him with a shawl in recognition of his contribution to the development of *Swarna jowar*. The Indian Society of Genetics and Plant Breeding awarded him a medal for one of the best papers written in their scientific journal. Dr. Rao is presently the Head of the IARI Regional Research Station, Hyderabad and Co-ordinator of the All India Co-ordinated Sorghum Improvement Project.

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LINE × TESTER ANALYSIS OF COMBINING ABILITY IN *SORGHUM*

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THE first commercial hybrids of *Sorghum* released for general cultivation in India had male sterile combine *Kafir* 60 as the female parent (Rao and House, 1965a, b). Since then, a number of non-restoring lines against the *milo* source of cytoplasm were converted by substitution backcrosses into male steriles to provide a wider choice of the female parents. Such male steriles developed by Vidyabhushanam (1965) together with *Kafir* 60 were crossed with a common set of testers of both exotic and Indian origin; a combining ability analysis from this line × tester mating system is presented in this paper.

MATERIALS AND METHODS

Male sterile combine *Kafir* 60 (CK60A) and three other male steriles 2219A, 3675A and 3676A were used as the female parents (lines). All the females are of the *kafir* type, the last three being derived *kafirs* with yellow endosperm. Six tall Indian varieties, M. 35-1, *Karad Local*, *Aispuri*, B.P. 53, *Nandyal*, G.M. 1-5 and five dwarf exotics, I.S. 84 (yellow endosperm *feterita* and the pollinator parent of CSH-1 the released hybrid), I.S. 3691 (yellow endosperm *hegari* and pollinator parent of CSH-2), I.S. 2031, I.S. 2938, I.S. 3922 (*kafir* type derivatives with yellow endosperm),were used as the male parents (testers).

The four female lines were crossed with the eleven testers and the resulting 44 hybrids were grown in randomised blocks replicated three times. Within a block, the tall hybrids were randomised in one portion and the dwarfs in the remaining area so as to keep competition and shading effects between talls and dwarfs to the minimum. However, for purposes of analysis, the experiment was treated as a completely randomised design. The experiment was sown on July 8, 1966. The field was fertilised with 100 kg. N and 60 kg. P_2O_5 per hectare. Cultural and plant protection operations were given as and when necessary. Individual plant observations on six random plants were recorded for grain yield, days to flower and plant height.

Combining ability analysis was based on procedures developed by Kempthorne (1957); the analysis of variance form is given in Table 1.

TABLE 1

Analysis of variance for combining ability

Source	d.f.	M.S.S.	Expectations of mean squares
Replications	(r–1)		
Hybrids	(mf–1)		
Males	(m–1)	M_1	σ^2+r[Cov. (F.S.)–2 Cov. (H.S.)] + [fr Cov. (H.S.)]
Females	(f–1)	M_2	σ^2+ r[Cov. (F.S.)–2 Cov. (H.S.)]+ [mr Cov. (H.S.)]
Males×Females	(m–1) (f–1)	M_3	σ^2+ r[Cov. (F.S.)–2 Cov. (H.S.)]
Error	(r–1) (mf–1)	M_4	σ^2

Cov. (H.S.) = $(M_1-M_3) + (M_2-M_3)/r\,(m+f)$

Cov. (F.S.) = $(M_1-M_4)+(M_2-M_4) + (M_3-M_4)/3r$ + 6r Cov. (H.S.)–r(f+m) Cov. (H.S.)/3r

$\hat{\sigma}^2$gca = Cov. (H.S.)

$\hat{\sigma}^2$sca = Cov. (F.S.)–2 Cov. (H.S.)

The combining ability effects were estimated as follows:

$\hat{\mu} = \frac{x...}{m.f.r}$ where x...=the total of all hybrids

$\hat{g}_i = \frac{x_i..}{f.r} - \frac{x...}{m.f.r}$ where x_i.. =total of *ith* male parent over all females and replications.

$\hat{g}_j = \frac{x.j.}{m.r} - \frac{x...}{m.f.r}$ where x.j.=total of the *jth* female parent over all male parents and replications.

$\hat{s}_{ij} = \frac{x(ij).}{r} - \frac{x_i..}{f.r} - \frac{x.j.}{m.r} + \frac{x...}{m.f.r}$

where x(ij). = (ij)*th* combination totals over all replications.

The combining ability variances and effects were based on plot totals.

RESULTS

(1) *Hybrid analysis.*—An examination of Table 2 reveals that the hybrids derived from the four female parents do not differ very much with respect to the mean values of grain yield, days to flower and plant height when averaged

TABLE 2

Mean values

Character	Line	Tester: M. 35–1	K. Local	Aispuri	B.P. 53	Nandy-al	G.M. 1–5	IS 84	IS 2031	IS 2938	IS 3691	IS 3922	Mean
Grain yield (Gm./plant)	CK 60A	50·26	75·93	93·46	115·26	102·48	112·68	41·80	58·23	44·09	94·09	61·87	77·28
	2219A	34·03	107·08	112·30	97·27	97·52	91·37	50·20	47·60	49·18	84·82	58·11	75·40
	3675A	55·65	85·85	109·81	101·50	105·41	81·20	50·11	61·87	46·53	110·57	57·32	78·71
	3676A	47·16	76·37	81·47	84·70	102·53	65·87	56·37	45·22	45·42	103·15	68·57	70·62
	Mean	46·77	86·30	99·26	99·68	101·98	87·78	49·62	53·23	46·30	98·15	61·46	
Days to flower	CK60A	63·22	85·83	79·50	81·88	83·27	85·22	62·16	62·66	59·94	85·33	61·33	73·66
	2219A	60·94	76·83	71·83	76·33	83·72	75·77	60·66	61·22	61·94	84·00	60·55	70·34
	3675A	63·44	95·55	82·33	89·50	84·77	88·83	61·38	62·00	61·11	87·83	62·22	76·26
	3676A	62·33	94·50	85·05	83·83	90·05	88·00	62·66	64·38	61·16	89·00	64·05	76·81
	Mean	62·48	88·17	79·67	82·88	85·45	84·45	61·71	62·56	61·03	86·54	62·03	
Plant height (Cm.)	CK60A	236·66	278·05	296·94	358·33	272·50	240·27	130·27	115·83	133·83	154·55	140·72	214·35
	2219A	204·72	235·00	295·55	284·44	262·22	182·94	127·61	131·66	128·05	145·61	129·88	193·42
	3675A	225·50	282·50	307·77	310·00	282·77	208·55	133·77	133·66	144·11	167·11	138·16	212·17
	3676A	230·27	263·88	315·00	297·77	283·22	203·83	124·66	125·77	142·44	172·27	139·22	208·93
	Mean	224·28	264·85	303·81	312·63	275·17	208·89	129·07	126·73	137·10	159·88	136·99	

S.E.m. Grain yield—36·23 S.E.m. Days to flower—1·46 S.E.m. Plant height—14·74.

over the eleven tester parents. 2219A which is the shortest and earliest among the females tends to result in hybrids of a relatively short and early nature. The hybrids with Indian varieties are generally tall, later in maturity and higher yielding than the hybrids with dwarf exotics.

The mean squares due to males is of a larger magnitude (Table 3) in comparison with those due to females or females × males indicating greater diversity among males. The mean squares due to females × males is of lower magnitude than that of both males and females indicating that the hybrids are more uniform.

TABLE 3

Analysis of variance

Source	d.f.	Mean Sum of Squares		
		Yield	Days to flower	Plant height
Blocks	2	60359·81	239·14	6099·46
Hybrids	43	66920·01	15886·72	556609·95
Females	3	14776·13**	10401·26**	106428·21**
Males	10	245023·19**	61964·67**	2304691·32**
Females × Males	30	12766·67**	1075·98**	18934·32**
Error	86	5771·92	57·00	3908·33
$\hat{\sigma}^2$ *Gca*		5205·91	1560·31	52738·90
$\hat{\sigma}^2$ *Sca*		2331·58	359·66	5008·70
Gca / Sca		2·23 : 1	4·34 : 1	10·53 : 1

** Significant at 1% level.

The relative estimates of the variance due to g.c.a. and s.c.a. (Table 3) indicate g.c.a. to be the dominant component for all the three characters under study.

(2) *Combining ability effects.*—The g.c.a. effects of females and males are presented in Table 4 and the specific combining ability effects in Table 5. Considering the g.c.a. effects the females do not seem to offer much choice. 2219A can yield earlier and dwarfish hybrids or derivatives but it is not superior with respect to yield. All the male parents of Indian origin with the exception of M. 35-1 are desirable from the point of g.c.a. for yield, but the high yields

TABLE 4

General combining ability effects

	Grain yield	Days to flower	Plant height
Females			
1. msCK 60A	10·68	–3·64*	42·81**
2. ,, 2219A	–0·60	–23·58**	–82·80**
3. ,, 3675A	–19·23	11·96**	29·69*
4. ,, 3676A	29·31*	15·26**	10·29
S.E. ($\hat{g}_i$) ±	14·25	1·41	11·72
Males			
1. M. 35–1	–172·38**	–70·76**	102·38**
2. Karad Local	64·79**	83·44*	345·79**
3. Aispuri	142·53**	32·41**	579·54**
4. B.P. 53	145·05**	51·66**	632·46**
5. Nandyal	158·87**	67·08**	407·71**
6. G.M. 1–5	73·64**	61·08**	10·04
7. I.S. 84	–155·31**	–75·34**	–468·87**
8. I.S. 2031	–133·66**	–70·26**	–482·96**
9. I.S. 2938	–175·21**	–79·42**	–420·71**
10. I.S. 3691	–135·91**	73·58**	–284·04**
11. I.S. 3922	–84·24**	–73·42**	–421·37**
S.E. ($\hat{g}_j$) ±	16·75	2·46	11·91

*Significant at 5% level. **Significant at 1% level.

are confined to the tall and late groups. The male parent G.M. 1-5 is the only one which surprisingly yields a hybrid intermediate in height between parents.

With regard to the s.c.a. effects, it is difficult to make definite statements since the high yielding combinations are confined to the tall and late groups which do not have the desirable plant type for commercial exploitation. However, parents like *Karad Local* and G.M. 1-5 may provide the basic materials for selecting suitable lines for specific combining ability. The hybrid 2219A × *Karad Local* is high yielding besides being relatively early, but some difficulties may arise in commercial production of hybrid seed since the parents differ very much in date of flowering and plant height.

DISCUSSION

Since the release of the first commercial hybrids, CSH-1 and CSH-2, in India which were based on CK60A, attempts have been in progress to develop diverse male steriles by substitution backcross programmes. Such male steriles were expected to provide wider choice of the female parents besides

TABLE 5

Specific combining ability effects

Character	Line	Tester: M. 35–1	K. Local	Aispuri	B.P. 53	Nand-yal	GM 1–5	IS 84	IS 2031	IS 2938	IS 3691	IS 3922
Grain yield (Gm./plant)	CK60A	10·24	−72·93	−45·65	82·81	−7·71	138·72†	−57·63	19·32	−23·97	−35·09	−8·27
	2219A	−75·85	125·25†	78·81	−14·18	−26·20	22·13	4·08	−33·20	17·85	−79·41	−19·56
	3675A	34·02	−21·98	44·08	−8·34	1·34	−58·73	−16·28	−0·73	−17·88	−222·59†	−321·94†
	3676A	31·59	−30·31	−77·42	−60·57	32·58	−102·13*	69·82	−18·73	24·26	59·24	71·92
Days to flower	CK60A	8·06	−9·44*	2·56	−2·36	−9·45*	8·22	6·31	4·23	−2·95	−3·61	−0·61
	2219A	14·33†	−44·50†	−23·50†	−15·75†	13·16†	−28·51†	17·25†	15·50†	28·99†	8·33	14·66†
	3675A	−6·21	32·29†	3·96	27·71†	−16·05†	14·29†	−13·96†	−15·37†	−11·55*	−4·21	−10·88*
	3676A	16·17†	22·66†	16·99†	−9·59†	12·32†	5·99	−9·59*	−4·34	−14·51†	−0·51	−3·18
Plant height (Cm.)	CK60A	31·44	36·36	−84·06*	231·36†	−58·89	145·44†	−35·65	−108·22†	−62·47	−74·81*	−20·48
	2219A	−34·62	−96·36†	33·22	−86·37*	5·05	−72·95*	73·96*	112·39†	28·47	−2·87	40·13
	3675A	−22·44	76·15*	−5·94	−45·52	15·89	−31·77	−1·53	11·90	12·31	13·64	−22·69
	3676A	25·62	−16·12	56·80	−99·46†	37·96	−40·70	−36·79	−16·04	21·71	64·04	3·04

S.E. ($\hat{S}_{ij}$) Grain yield ± 43·91

S.E. ($\hat{S}_{ij}$) Days to flower ± 4·35

S.E. ($\hat{S}_{ij}$) Plant height ± 36·13

*Significant at 5 % level.

†Significant at 1 % level.

added advantages with respect to grain quality and insect resistance which were lacking in CK60A. The choice of the non-restorers to be used in such backcross substitution programmes was made primarily on the breeder's familiarity with the material rather than pre-assessed combining ability. Most steriles thus developed in the past provided only limited diversity among A lines which was attributed to their being primarily *kafirs* or *kafir-milo* derivatives (King *et al.*, 1961). Similarly, Vidyabhushanam (1965) transferred male sterility to a number of derived yellow endosperm *kafirs* since it was thought that hybrids based on such steriles would have superior grain quality. Three such steriles, 2219A, 3675A and 3676A were crossed to a set of common testers; the resulting hybrids did not differ widely in average yields, flowering behaviour or plant height except that the earliest and the shortest female parent 2219A tended to yield earlier and shorter hybrids. The variance due to general combining ability was predominant for grain yield, flowering and height.

The Indian parents used as testers were very tall and late and had large sized panicles; the hybrids with such parents were also tall, late and high yielding in comparison with the hybrids involving dwarf, early exotic selections. However, the hybrids with Indian varieties lacked the plant type for cultivation under heavy fertilisation and population levels and were not very much superior to their respective pollinator parents. Besides, some of the combinations like msCK60 × *Karad Local* which were somewhat heterotic could not be considered for release since their threshability was poor. The yellow endosperm steriles have a shorter glume and the hybrids with Indian parents are consequently free threshing. If a tall hybrid is to be considered for release, these appear to hold promise. Yet, the problem of hybrid seed production will present difficulties on account of the wide range in flowering and plant height between the two groups of parents.

These three yellow endosperm steriles do not appear to differ very much with respect to their combining ability and may not provide any major increases in yield levels in comparison with hybrids based on CK60A. The g.c.a. effects of most Indian varieties are desirable, but they seem to be associated with the late maturity and possibly a tall habit. G. M. 1-5 is one Indian parent which yields hybrids of intermediate height. Specific combinations like 2219A x *Karad Local* with positive specific effects for yield and negative specific effects for days to flower and plant height may be of interest since they are also free threshing. The crosses do exhibit differences due to specific combining ability effects and it may be necessary to utilise varieties like *Karad Local* and G. M. 1-5 to extract semi-dwarf lines to be subsequently used in hybrid programmes. Choice of female parents on prior evaluation of combining ability before they are used in substitute backcross programme may avoid disappointments after the end of many cycles of backcrossing, particularly where major improvement in yield is sought.

The general and specific combining ability effects were based on plot totals where the number of plants was kept constant. The dwarf and early exotic hybrids are known to stand heavy populations while the tall, late hybrids may not be equally suitable for such plantings. The space planted conditions of the present experiment confer an advantage on the tall late types and the estimates for yield based on equal number of plants could be biassed, favouring the tall hybrids. Such a bias could possibly be minimised by growing the different plant types at their optimum population levels and computing the data from such plots.

Summary

A line × tester analysis of combining ability involving three yellow endosperm male steriles developed in India and male sterile combine *Kafir* 60 as female parents and a set of eleven exotic and Indian varieties as male parents was undertaken. The newly developed male steriles did not exhibit superiority over combine *Kafir* 60 with regard to the mean yields or general combining abilities. They, however, yield free threshing hybrids with Indian pollinator parents which is not the case with CK60A.

Some combinations involving Indian varieties as pollinator parents were, however, found to be markedly superior to the available commercial hybrids with respect to grain yield, but they were generally tall and late. It is visualised that some of the varieties like *Karad Local*, *Nandyal*, G.M. 1–5 and B.P. 53 may provide the basic breeding materials to derive dwarf or semi-dwarf selections to provide the necessary germ plasm for the subsequent development of high yielding hybrids. Prior assessment of the parents for combining ability before initiation of backcross programmes would enable realisation of anticipated results.

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SWARNA : The High-yielding Variety of Jowar that equals Hybrids

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THE FIRST commercial *Jowar* hybrid, CSH-1, released during the year 1964 is not only popular with farmers in several states, but also established its suitability under conditions of drought. The seed production of the second hybrid CSH-2 is gaining pace and is expected to cover the medium duration kharif areas with retentive soils and well distributed rainfall. It is now well-known that the hybrid seeds are to be produced every year since the produce from the hybrid crops cannot be used as seed. Against the vast annual area of 43 million acres under sorghum, a high-yielding variety whose seeds can be saved, thereby encouraging natural spread, will be a useful supplement to the already available hybrids. Swarna, the improved variety of *Jowar* recently released by the Central Variety Release Committee for general cultivation is one such high-yielding variety. Swarna is not a 'hybrid' but it is 'high-bred' and has the yield potentiality of the hybrid CSH-1.

Comparative grain yields and area of adaptation. The comparative performance of Swarna and CSH-1 averaged over 30 locations spread in the states of Maharashtra, Mysore, Andhra Pradesh, Madhya Pradesh, U.P., Madras, Orissa and Bihar is summarised on the next page.

TABLE 1. COMPARATIVE PERFORMANCE OF CSH-1 AND SWARNA

Variety-Hybrid	Grain yield (kg/ha)		% of CSH-1	
	Summer 1967	Kharif 1967	Summer 1967	Kharif 1967
Swarna	3850	3745	99.6	101.7
CSH-1	3864	3682	100.0	100.0
Local	2836	2358	73.4	64.0

This variety has a yield potential equalling the commercial hybrid CSH-1. Under ideal conditions Swarna has recorded yields up to 7000 kg/hectare.

Swarna is suitable for cultivation during the traditional kharif and summer seasons. It has been the general experience that Swarna tends to yield as much or even more than CSH-1, if there is adequate rainfall and the growing conditions are good. Where moisture stress is experienced, the hybrid still tends to outyield Swarna. As such the early duration kharif areas all over the country wherever the requirement is for a 110 day crop could be considered the area of adaptation for this variety. Preferably areas of assured rainfall should be chosen and where drought is more likely to be experienced CSH-1 is still the best.

The irrigated summer areas in Madras, Mysore and Andhra Pradesh are also suitable. Sowing should be done in late January or early February which is somewhat earlier than the traditional sowing of the summer *jowar*.

Distinguishing Features

The plants are medium dwarf (120-150 cm tall); the stems are juicy; a waxy bloom is very marked on the peduncle and the leaves tend to be erect, as against the horizontal arrangement in CSH-1. The ears are elongated, appear rather conical and the grains are creamy and bold. Swarna is susceptible to shootfly and, therefore, needs plant protection. Sowing periods should also be confined to periods when shootfly populations are low. The habit of the plant permits greater manipulation of plant densities. While CSH-1 did not exhibit any appreciable differences in yield under row spacings of 22.5, 45.0 and 67.5 cm, respectively, Swarna exhibited a differential response and the yields at 45 cm were the highest under favourable growing conditions.

Response to nitrogen levels. The response patterns of CSH-1 and Swarna to nitrogenous fertilisers were quite similar. The mean yields averaged over five locations at different nitrogen levels are given in table 2

TABLE 2. *COMPARATIVE RESPONSE OF CSH-1 AND SWARNA TO NITROGEN LEVELS. GRAIN YIELD QTL/HA

Variety	Level of N in kg/ha					Mean
	0	50	100	150	200	
CSH-1	21.9	33 5	38.9	44.7	45.6	36.9
Swarna	20 3	31.5	37.8	42.6	43.4	35.1

*—Data from coordinated trials

This observation is significant in the light of the earlier work where the local varieties were observed to be low in response to nitrogen in comparison with CSH-1. Thus, Swarna is not only comparable to CSH-1 in grain yields but also in response to nitrogenous fertilisation. Besides, its plant type permits high population densities.

Package of Practices

The All-India Sorghum Workshop held during May 1968 recommended the following package of practices for cultivation of Swarna, CSH-1 and CSH-2.

(A) *Agronomic recommendations*

1. *Time of planting*. *Jowar* should be planted as soon as possible after the rains begin, but late enough to assure continuous rainfall for germination. Usually sowings done before July 15 are satisfactory. Shootfly takes heavy toll of crops sown beyond July 15.

2. *Plant population*. The available data indicate that about 150,000 plants/ha is sufficient for maximum yields. This population should be obtained by spacing plants 12 cm apart in rows which are 45 cm apart.

3. *Fertiliser application*

N (a) Apply 100-120 kg N/ha in areas of assured high rainfall (400—500 mm/season or more). This should be applied one half at sowing time and one half at about 'knee-high' stage (about 30 days after sowing).

(b) Apply 80 kg N/ha in low rainfall areas. This should be applied as 40 kg N/ha at planting. The remaining 40 kg N/ha should be side-dressed at about 'knee-high' stage, if there is sufficient rainfall. If the rainfall is insufficient, no additional applications of N should be made.

P_2O_5 A soil test information be used wherever possible. If no soil test information is available, apply 60 kg P_2O_5/ha in high rainfall areas, and 40 kg P_2O_5/ha in low rainfall areas.

K_2O Research information indicates that response to potassium is very infrequent. Therefore, we recommend that no potassium be applied except in those soil areas known to be deficient in potassium. A soil test is a good indicator of potassium status of soils.

Ears of sorghum Swarna

(B) *Control of insect pests*

Though endrin has been found to be an effective insecticide for the control of stem borer, it has not been included in the package since evidence presented in the workshop has indicated a residue problem in grain and fodder. Also other equally effective insecticides are available for the control of this pest. It was, therefore, felt that the use of endrin should not be recommended for the general cultivation of sorghum.

1. *Shoot fly*. Where shoot fly is a problem use 10% phorate granules at 1.3 gm/metre row or 5% disulfoton (thiodemeton) at 3 gm/metre row in furrows at the time of sowing. Alternatively, the crop may be sprayed with carbaryl (50% W.P.) 2 kg, or phosphamidon (100%) 125 cc or dimethoate (30% E.C.) 250 cc in 450 to 500 litres of water per hectare. The crop should be sprayed twice, the first spray 3 to 5 days after emergence of seedlings and the second 5 to 7 days after the first spray.

The shoot fly damage has generally been observed in late sown kharif crop in all the sorghum growing areas, rabi areas and monsoon crop in Tamil Nadu.

2. *Stem borer*. Apply granules of 10% carbaryl or 1% lindane or 10% malathion for two to three times at 10 days interval, starting 20 days after emergence of seedlings. The rate of application for the three treatments should be about 8, 12 and 15 kg/ha, respectively.

Alternatively the crop may be treated with the spray formulations of the above mentioned insecticides at the same dose of active ingredient in 500 to 600 litres of water per hectare. With carbaryl or wherever mite is a problem, add 2 kg of wettable sulphur. The spray should be directed towards the leaf whorls.

3. *Ear pests*. For midge control spray the earheads before flowering with carbaryl (50% W.P.) 3 kg or lindane (20% E.C.) 1.25 litres or endosulfan (30% E.C.) 1 litre in 500 to 600 litres of water per hectare. (In case of continued infestation, repeat spraying after 5 to 7 days).

For ear bug and caterpillars at the milk stage treat the ears with 10% carbaryl dust with sulphur (8:2) or 1.3% lindane dust at 20 kg/ha.

(C) *Disease control*

1. *Seed treatment*

(a) Remove all ergot sclerotia, if any, before seed treatment.

(b) Treat seeds with thiram, sulphur or organo-mercurials at 1:250. When certified seeds are obtained, the seeds are already treated.

2. *Field spray*

Diseases are not generally serious in sorghum, but whenever it is a problem the following control measures are available.

(a) Spray from 45 days with zineb or wettable sulphur at 1 to 1½ kg/ha. Repeat with an interval of 10 to 15 days twice to control leaf diseases like rust, leaf blight, zonate leaf spot, etc.

(b) Wherever, sugary disease is a problem, spray with ziram 0.15% (about 1 kg/ha) at boot leaf stage, repeating 2 to 3 times at 5 to 6-day interval.

(c) Dust the ears just after emergence with a mixture of BHC plus DDT 10% at (1:1) or carbaryl (sevin) 10% plus sulphur at 10 to 15 kg/ha. This will control the insect carriers of sugary disease as well as control the midge.

3. *Field sanitation and adjustment of sowing date*

(a) Remove and burn all the plants showing downy mildew infection or whole head smut ears and also ears showing honey dew stage.

(b) Adjust sowing date so that the flowering period does not coincide with cool, moist weather.

towards the top of the Kasauli Series which attain a thickness of 2,136 mt. in this area. This is in harmony with the view held by Fiestmantel[2] and Sahni.[4]

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PHENOTYPIC STABILITY OF HYBRIDS AND VARIETIES IN GRAIN SORGHUM

AN ideal variety is one that combines high yield and stability of performance. Stability assumes added importance in breeding dry land crops, the yields of which are subject to climatic fluctuations. Since Finlay and Wilkinson[3] proposed a linear regression analysis of general adaptation, attempts have been made to analyse the stability of performance in crops like barley and wheat.[2,5] Using a model developed by Eberhart and Russel,[1] the stability of performance of two commercial sorghum hybrids CSH-1 and CSH-2, the tall improved local varieties and a recently developed improved variety *Swarna*, a hybrid derivative, is examined. Stability is described by three parameters, mean yield, regression of mean yield on an environmental index and deviations from regression.

Grain yields obtained under rainfed conditions over a period of five years at 7–12 locations per year, representing diverse environments under which *kharif* (July-November) sorghums are cultivated in India over an approximate area of 12 million hectares, are evaluated. The rainfall was normal during the years 1963, 1964 and 1967, while severe drought was experienced at several locations during 1965 and 1966. The grain yields over years and locations fluctuated from less than 200 kg./hectare to over 5000 kg./hectare, thus, providing a representative range of environments. The parameters estimated may, therefore, be expected to provide satisfactory measures of stability.

The stability parameters estimated from this study are presented in Table I. It will be seen that the mean yields of the hybrids are consistently superior under normal and stress environmental conditions over the locals, CSH-1 being superior to CSH-2. The improved variety S. 413 has shown a tendency to outyield CSH-1 under favourable environmental conditions only, a detailed performance of which was presented earlier by Rao *et al.*[7] The local checks are consistently low yielding. The size of the regression coefficients for the locals, in general, are lower than the hybrids as well as the improved variety ($b < 1 \cdot 0$). Relative to the hybrids, the regression coefficient is greater for *Swarna* ($b > 1 \cdot 0$). Although the average regression coefficients of the hybrids are of similar magnitude and near $1 \cdot 0$, the differences in *b*'s are maximum in years where the mean yields are higher as in 1965 and 1967. The deviations from regression are maximum in CSH-2 during 1963 and 1965 indicating that under certain environmental conditions the departure from linearity is substantial for CSH-2. While the high mean yields in the hybrids are associated with larger deviations from linearity, the behaviour of the locals is erratic.

It is often stated that hybrids, in general, are economically feasible in areas of adequate rainfall or under irrigation.[8] The consistency of performance of sorghum hybrids under normal and stress environmental conditions has belied the general belief that the hybrids are for favourable environmental conditions only. CSH-1 appears to be the best genotype that has consistently high performance over several environments. The hybrid CSH-2 and the improved variety *Swarna* tend to outyield CSH-1 as the environment becomes more and more favourable. The locals are consistently low yielding. The degree of heterozygosity, the diversity in the origin of alleles and the nature of gene action in the material under study could furnish the possible causes for the differential behaviour. The local checks are pure lines selected under low fertility conditions and most of them are late maturing.

TABLE I

Stability parameters for hybrids and varieties

Year	CSH-1			CSH-2			*Swarna* (S. 413)			Local check			Grand mean
	Mean Q./ha.	*b*	Deviation	Mean Q./ha.	*b*	Deviation	Mean Q./ha.	*b*	Deviation	Mean Q./ha.	*b*	Deviation	Q./ha.
1963 (7)*	23·37	1·15	14·64	18·30	1·11	38·03	—	—	—	13·02	0·73	72·64	18·23
1964 (8)	26·76	0·95	15·63	23·75	1·04	13·91	—	—	—	18·66	1·01	16·97	23·06
1965 (11)	30·40	0·96	52·55	23·28	1·35	104·16	—	—	—	19·17	0·69	25·17	24·26
1966 (12)	21·66	1·17	19·05	15·21	1·08	9·47	—	—	—	12·93	0·75	57·35	16·60
1967 (12)	32·72	0·75	46·45	25·48	0·98	39·55	30·74	1·25	39·27	20·46	1·01	36·18	27·35
Average ..	26·98	0·996	—	21·20	1·112	—	30·74	1·25	—	16·85	0·838	—	21·90

* Number of locations. – Data not available.

The improved variety *Swarna* has in its parentage an early *kafir* and a late maturing African yellow endosperm type. The hybrids besides being early and completely heterozygous, have a common female parent, male sterile Combine *Kafir* 60, and the male parents are a derived *feterita* and a derived *hegari* respectively. The effective components of yield heterosis in CSH-1 are additive and additive × additive epistasis while in CSH-2, dominance and dominance × dominance components are significant and are in the same direction.[6] Whatever may be the precise cause, hybridity as observed in *Arabidopsis thaliana* by Griffing and Langridge[4] together with the earliness and quicker rate of growth appear to confer greater phenotypic stability as observed in CSH-1. Development of suitable hybrids could, therefore, provide the genetic tool to stabilise the unpredictable and chronically low yield levels of rainfed tracts.

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COMPARATIVE PERFORMANCE OF HYBRIDS AND SOME IMPROVED VARIETIES IN GRAIN SORGHUM

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IN spite of the predominance of additive genetic variance in sorghum populations (Kambal and Webster, 1965; Niehaus and Pickett, 1966; Beil and Atkins, 1967 and Rao, Rana and Tripathi, 1968), it has been observed that half a century of intensive selection had failed to produce pure lines that could compete with commercial hybrids (Allard and Hansche, 1964). Recent work on line improvement in sorghum resulted in the development of promising varieties, some of which could possibly compete with commercial hybrids. Considering grain yield and response to nitrogen as measures of fitness, the question of hybrids *vs.* varieties in grain sorghum is examined in relation to the environmental conditions and some of the available findings on fitness of heterozygotes and homozygotes in self-fertilized species.

MATERIALS AND METHODS

Ten improved selections, viz., 11 (I.S. 84), 46 (I.S. 511), 113 (I.S. 815), 133 (I.S. 2031), 217 (I.S. 2944), 361 (I.S. 3796), 370 (I.S. 3797), 393 (I.S. 3922), 405 (I.S. 3922) and 413 (I.S. 3924) were tested in regional trials all over the country during the 1967 summer (January–May) and *kharif* (July–October) seasons. The two commercial hybrids CSH-1 and CSH-2, their pollinator parents, I.S. 84 and I.S. 3691, the fertile counterpart of the common female parent, Kafir B and an improved local variety as a check were included in the same trial. During the *kharif* season the trial was conducted at 48 locations representing nine States; during summer it was conducted at 5 locations representing the States of Madras, Andhra Pradesh and Mysore. The experiment was laid out at each location as randomized blocks replicated four times. The gross plot size was 243 sq. ft. and net plot 150 sq. ft. The summer trials were grown under irrigated conditions and the *kharif* trials were rainfed. Most of the improved selections and CSH-1 mature in 100–110 days; CSH-2 in 120–130 days and the locals are variable maturing in 120–160 days. All the improved lines were the result of intensive selection from early generation segregating yellow-endosperm derivatives introduced from U.S.A.

RESULTS

1. VARIETAL PERFORMANCE OVER ALL THE LOCATIONS TESTED (*KHARIF* 1967)

The grain yields of the varieties at all locations tested is summarized in Table 1. This includes all the 48 trials for some of which the coefficients of variation were high and the yield levels were low. This does not take into account the areas of adaptation. It is seen that the early hybrid CSH-1 is by far the most consistent and superior entry. Selection 413 is next in order of superiority and the grain yields are 93 per cent. of CSH-1. Amongst others, selections 11, 46, 361 yielded 83, 83 and 84 per cent. respectively of the grain yield of CSH-1.

2. COMPARATIVE PERFORMANCE OF 413*, CSH-1 AND LOCAL IN SELECTED LOCATIONS (*KHARIF* AND SUMMER 1967)

The comparative grain yields of 413, CSH-1 and local at 25 locations during *kharif* where the difference between CSH-1 and 413 are not very marked are presented in Table 2 and the performance in summer season in Table 3. It is seen that the average grain yields for CSH-1 and 413 are almost on par and both of them are superior to the available improved varieties of the respective regions. The hybrid is generally superior in locations where the yield levels were relatively low and the environmental conditions not very conducive to high yields.

3. AGRONOMIC ATTRIBUTES OF 413, CSH-1 AND LOCALS

Selection 413 has creamy, bold seeds and could be considered for general cultivation in *kharif* and summer seasons where CSH-1 is presently recommended; within this area, the assured rainfall tracts during the *kharif* season may be considered more suitable for selection 413. This variety matures about a week later than CSH-1. The plant type of this variety is also ideal in that it has semi-erect leaves in the middle and somewhat erect leaves at the top. The stems are thin and juicy. Prominent waxy bloom is present on the peduncle and leaf sheaths. The glumes are red purple. Some of the agronomic attributes of 413, CSH-1 and local are summarized in Table 4.

DISCUSSION

The phenomenon of heterosis has provided the most important genetic tool in improving yields of self- as well as cross-fertilized species. In contrast to the consistency of evidence of heterozygote superiority in outbreeding species, the evidence for inbreeding species has been conflicting. Commercial exploitation of heterosis in a mostly self-pollinated crop like grain sorghum through the employment of cytoplasmic-genetic male sterility, and recent experiments with *Arabidopsis thaliana* (Griffing and Landridge, 1963) and lima bean (Allard and Workman, 1963) suggest that self- and cross-fertilized plants are essentially similar in their heterotic response and the use of heterosis should carefully be considered

*413 has since been released under the name *Swarna*.

TABLE 1

Summary of the varietal performance over all the locations tested (kharif, *1967*)

State	No. of locations		Variety/Hybrid 11	46	113	133	217	361	370	393	405	413	I.S. 84	I.S. 3691	Kafir	CSH-1	CSH -2	Local Check
Maharashtra	13	1	3064	3132	2996	2641	2790	3016	2828	2745	2868	3398	2644	1748	2712	3803	3002	2913
		2	80	82	79	69	73	79	74	72	75	89	69	46	71	100	79	76
Mysore	6	1	3362	3069	3114	3244	3180	3389	3243	2889	3025	4147	3037	2431	3291	3688	3512	3069
		2	91	83	84	88	86	92	88	78	82	112	82	66	89	100	95	83
A.P.	7	1	3104	3031	3070	2913	2840	3447	2962	2844	3039	3321	2713	2731	2827	3755	2757	2178
		2	83	81	82	77	76	92	79	76	81	88	72	73	75	100	73	58
M.P.	5	1	1895	1614	1801	1585	1681	1758	1832	1837	1731	2077	1423	865	1424	2439	1562	2216
		2	78	66	74	65	69	72	75	75	71	85	58	35	58	100	64	91
Madras	3	1	2063	3312	1978	1653	2420	3324	2785	3954	3184	3293	3223	1427	2466	3766	2378	2185
		2	55	88	52	44	64	88	74	104	84	87	85	38	65	100	63	58
Gujarat	5	1	1039	886	1110	639	816	871	940	724	735	1175	990	376	836	1564	896	968
		2	66	57	71	41	52	56	60	46	47	75	63	24	53	100	57	62
U.P.	3	1	2395	2111	2405	1627	1843	1966	1929	1462	1256	2633	1894	838	1380	2265	2814	1632
		2	105	93	106	77	81	87	85	64	55	117	84	37	61	100	124	72
Orissa	5	1	2811	2742	2216	2849	2470	2804	2553	2065	2668	2905	2622	1996	2474	3440	3379	1583
		2	82	80	64	83	72	81	74	60	77	84	76	58	72	100	98	46
Bihar	1	1	3109	2679	1818	1866	2057	2248	1674	1148	1196	2296	1913	1339	1674	2535	2296	1674
		2	123	106	72	74	81	89	66	45	47	90	75	53	66	100	90	66
All India	48	3	2538	2508	2279	2124	2233	2536	2305	2308	2189	2805	2273	1528	2120	3028	2511	2046
		2	84	83	75	70	74	84	76	76	72	93	75	50	70	100	83	68

1—Average grain yield (kg/ha). 2—% of CSH-1 3—Mean over all locations.

TABLE 2

Comparative performance of 413, CSH-1 and Local at 25 locations (kharif, 1967)

State	Location	Grain yield (kg./ha)			S.E.M.	Fodder yield (kg./ha)		
		413	CSH-1	Local		413	CSH-1	Local
Maharashtra	Parbhani	4352	4945	3582	252	13452	8309	23202
,,	Nanded	4520	4734	2410	270	9324	7410	16438
,,	Somnathpur	4468	5064	3490	159	10285	12737	16026
,,	Akola	5140	3935	2582	201	11388	8790	17282
,,	Buldhana	2637	3084	1746	240	3229	4783	10046
,,	Yeotmal	3983	4150	2201	299	7893	6458	9329
,,	Karad	2215	1937	1650	239	4485	5561	10225
,,	Kolhapur	3032	4084	1650	320	7843	12027	14704
Mysore	Dharwar	3961	3564	3799	254	5143	6040	13454
,,	Siruguppa	3707	4126	3169	206	4784	4784	5262
,,	Raichur	3535	3480	2115	344	4521	4521	10261
,,	Bailhongal	4092	3107	2780	321	6004	4389	4783
,,	Bagalkot	6551	4040	3268	237	6996	6518	11242
A.P.	Warangal	2562	2971	1528	170	10094	11290	10859
,,	Rudrur	3683	4066	2296	241	9089	9918	15260
,,	Amberpet	4285	4463	3570	—	—	—	—
,,	Rajendranagar	5045	4282	1099	277	12387	9300	23907
M.P.	Khargone	2936	3976	1118	192	4604	6578	11661

U.P.	Jhansi	2758	1834	—	—	—	—	—
,,	Pant Nagar	4072	3738	2121	174	17000	23200	34700
Madras	Coimbatore	4403	3885	3885	364	—	—	—
Orissa	Rajgangpur	3450	3392	1859	143	11685	11393	23215
,,	Bhawanipatna	3074	3681	1208	387	13735	18594	34892
,,	Phulbani	2858	2978	1794	213	5501	7774	15308
Bihar	Kanke	2296	2535	1674	329	9807	15403	36118
	Average	3744·60	3682·04	2358·08		8602·22	9353·50	16735·18
	% of CSH-1	101	100	64		92	100	179
	% of Local	158	156	100		51	56	100

TABLE 3

Comparative varietal performance, Grain yield kg./ha—Summer, 1967

Locations	Variety/Hybrid															
	11	46	113	133	217	361	370	393	405	413	I.S. 84	I.S. 3691	Kafir B	CSH -1	CSH -2	Local Check
Madras																
Coimbatore	2356	1936	2550	3572	2368	2580	2276	3260	4441	4062	2705*	1883	2267	4060	3100	2241
Bhavanisagar	1818	2631	1483	2488	1435	1914	1914	2009	2105	4066	2057	1770	2631	3827	2775	3349
A.P.																
Rudrur	3588	3301	3253	2392	3157	3971	3397	3444	3397	5214	4305	3492	3779	5167	2727	4066
Chandragiri	1722	3014	1148	1650	1363	3081	1937	2153	1794	2583	2224	789	1292	2727	2081	1507
Mysore																
Siruguppa	1594	2520	1283	1872	863	2000	1740	1315	1751	3324	1671	1523	2173	3541	2739	3014
Average	2216	2680	1943	2395	1837	2509	2253	2436	2697	3850	2592	1891	2428	3866	2684	2835
% of CSH-1	57	69	50	62	48	65	58	63	70	99·6	67	49	63	100	69	73

TABLE 4

Some agronomic attributes of S. 413, CSH-1 and Local

Character	S. 413	CSH-1	Local
Days to 50% bloom	60–70	60–64	65–95
Plant height (cm.)	120–170	120–160	200–300
Lodging percentage	0–1	0–1	0–90
Fodder quality	Juicy, stem rather thick, high proportion of leaf to stem	Juicy, stem relatively thin, high proportion of leaf to stem	Juicy to pithy
Grain colour	Light yellow endosperm, pearly	Cream, pearly	White pearly, yellow, red, white chalky
Threshability	Good	Good	Good
Reaction to shootfly	Susceptible	Susceptible	Susceptible

in all crop plants irrespective of their breeding system. Further, commercial experience with sorghum hybrids suggests that the individual buffering commonly associated with heterosis has substantial contribution to make in increasing and stabilizing yields in self-pollinated species also (Allard and Hansche, 1964).

CSH-1 is the first commercial hybrid developed in India (Rao and House, 1965) and it was not only superior to several introduced commercial hybrids tested in India, but also performed well in many African and South Asian countries. The comparative performance of CSH-1 and 413 over 25 locations in *kharif* and 5 locations in summer (Table 5) clearly indicates that the variety

TABLE 5

Comparative performance of CSH-1 and S. 413

Variety/Hybrid	Grain yield (kg./ha.)		% of CSH-1	
	Summer 1967	Kharif 1967	Summer 1967	Kharif 1967
413 (IS 3924)	3850	3745	99·6	101·7
CSH-1	3864	3682	100·0	100·0
Local	2836	2358	73·4	64·0

Summer: Average of 5 locations
Kharif: Average of 25 locations

is almost as good as the hybrid. A location-wise examination of grain yields, however, revealed that the variety is superior to the hybrid in locations where the conditions for growth were more favourable and the yield levels were also consequently high. The hybrid, on the other hand, is superior in locations where the yield levels were relatively low and the environmental conditions not very conducive to high yields. Recent studies with self-fertilized species indicated that under optimum conditions heterozygotes and homozygotes differ little in fitness, but under unfavourable conditions the superiority of heterozygotes is often striking (Griffing and Langridge, 1963 and Allard and Workman, 1963). These findings are very well substantiated in the present investigation based on multilocation testing.

Further, the response of CSH-1 and the improved variety 413 to varying rates of nitrogen (0, 40, 80, 120, 160 kg/ha.) was also studied in five locations during the 1967 *kharif* season. The response patterns were found to be quite similar at all locations. The pooled response functions of the hybrid and variety are as follows:

$$\text{CSH-1}: Y = 2220 + 23\cdot7\ N - 0\cdot060N^2$$
$$413: Y = 2050 + 24\cdot2\ N - 0\cdot064N^2$$

The yield levels conformed to the pattern of the varietal trials in that where yields were of a higher order 413 was superior to the hybrid and where the yields were generally low the hybrid was superior. This finding is significant in the light of the earlier work where the tall local varieties were observed to be not only lower in yield levels but also low in response to nitrogen in comparison with the commercial hybrid CSH-1. The linear response averaged over six locations was higher in the hybrids by three times as compared to locals (Murty, 1967). The response to fertility could also be considered as a measure of fitness since the increased yields were reflected in increased grain numbers.

The superior performance of the variety is possibly due to the diverse parents involved in hybridization and possibly to a better plant type. It has somewhat erect leaves and also responded to higher populations manipulated through different row spacings.

In India sorghums are cultivated in both *kharif* and *rabi* (October–February) seasons primarily as rainfed crops. During the *rabi* season, the moisture stress is more keenly felt as the crop thrives on residual soil moisture and practically no rain is received during crop growth. Presently, we do not have a suitable hybrid for the *rabi* season due to certain specific insect and other problems. Varieties like 413 and a few others in various stages of development could possibly compete with hybrids in *kharif* and summer seasons. Suitable hybrids if developed may have greater scope during *rabi* season which represents the stress environment. Capitalizing on the heterozygote advantage may thus provide the means to raise the low yields of some of the rainfed sorghum tracts, while under irrigated or assured rainfall conditions, suitable varieties if developed could be expected to perform as well as commercial hybrids.

Summary

Considering grain yield and response to nitrogen levels as measures of fitness, the question of hybrids *vs.* varieties in grain sorghum is examined in relation to the environmental conditions and some of the available findings on fitness of heterozygotes and homozygotes in self-fertilized species. The performance with respect to grain yields and response to nitrogen levels of a commercial sorghum hybrid CSH-1 and an improved variety 413 indicated that the hybrid and the variety were comparable in both respects.

Further, in more favourable environments, as reflected by higher mean yields, the variety was superior while in locations where the yield levels are generally low, obviously on account of moisture stress and other unfavourable environmental conditions, the commercial hybrid CSH-1 was superior. Capitalizing on heterozygote advantage is, therefore, expected not only to provide the genetic means to raise the low yields of some of the rainfed tracts but could also stabilize production levels.

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GENOTYPE × ENVIRONMENT INTERACTION IN GRAIN SORGHUM HYBRIDS

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The best genotype is the one that has consistently high performance over several environments. Studies on genotype-environment interaction over years involving many crop plants (Allard and Bradshaw, 1964) have aided delimitation of distinct regions of adaptability, development of suitable testing procedures and elimination of the upward bias in the estimation of genetic variances which lead to discrepancies between expected and realised responses to selection. Indian sorghums, in particular, have been considered to be highly localized in their adaptation and breeding for each of the many small regions was considered necessary (Chavan and Shengde, 1957). Such ideas were, however, not based on any critical data. The adaptability of the two recent hybrids over a wide area including the above regions, where approximately a hundred varieties were hitherto cultivated, necessitated a re-examination of the existing notions to develop suitable testing procedures.

Materials and Methods

The experimental design was randomised complete blocks with three replications. The gross plot size was 375 sq. ft. and the net plot size 300 sq. ft. The experiment was laid out at seventeen locations during the years 1963 and 1964. Data on plant height and days to flower were available only from sixteen locations while grain and fodder yields were obtained from all locations.

Results

Five hybrids and a local check of the respective tract were grown at 18 locations during the *kharif* season of the years 1963 and 1964. The locations were the same during both the years.

(1) Mean performance of hybrids vs local checks

Mean yields of grain and fodder per plot, days to 50 per cent. bloom and average plant heights are presented in Table 1. The hybrids msCK6O × IS 84 and msCK60 × IS 3691, which have been released as CSH-1 and CSH-2 respectively, are obviously the best performers. CSH-1 is an early and dwarf hybrid, and CSH-2 is slightly later and taller. The hybrids with Indian parents

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TABLE 1

Mean values of the hybrids and the local checks tested over 18 *locations*

Sl.No.	Hybrid/Variety	Grain yield Kg./plot	Fodder yield Kg./plot	Days to 50% Bloom	Plant height (Cm.)
1.	msCK60 × IS 84 (CSH-1)	8·182	16·510	59·6	141·7
2.	,, × IS 3687	7·775	27·029	67·9	233·2
3.	,, × IS 3691 (CSH-2)	8·161	28·304	70·6	162·5
4.	,, × M. 35-1	5·819	28·304	62·9	241·5
5.	,, × Karad Local	7·260	36·627	74·0	222·7
6.	Local Check	5·694	27·961	78·4	254·4

are very tall and do not compare with CSH-1 and CSH-2 in yield performance. Their threshability is also poor.

TABLE 2

Combined analysis of variance of grain yield, fodder yield, days to flower and plant height

Source	Mean sum of squares					
	d.f.	Grain yield	Fodder yield	d.f.	Days to 50% bloom	Plant height
Years	1	84·00	0·02	1	224·0	115·0
Locations	16	4303·00	286·52	15	948·5	44697·7
Years × Locations	16	3040·69	76·97	15	513·7	11612·9
Reps./Years/Locations	68	44·12	2·76	64	2·8	500·8
Genotypes	5	4198·60**	129·69**	5	4662·6**	203085·4**
Genotypes × Years	5	44·60(NS)	7·49 (NS)	5	183·0*	1668·6 (NS)
Genotypes × Locations	80	281·29**	18·74**	75	248·3**	3278·0**
Genotypes × Years × Locations	80	121·29**	6·86**	75	71·9**	1254·9**
Error	340	20·11	1·73	320	2·8	271·3

**Significant at 1% level. *Significant at 5% level. NS Not significant.

From the analysis of variance (Table 2), it will be seen that the second order $g \times y \times l$ interaction and the first order $g \times l$ interaction are significant in all cases whereas the $g \times y$ interaction is not significant except for days to bloom.

(2) ESTIMATES OF VARIANCE COMPONENTS

The estimates of variance components obtained from the combined analysis are presented in Table 3.

TABLE 3

Estimates of components of variance for various characters from the combined analysis

Character	$\sigma^2 g$	$\sigma^2 gl$	$\sigma^2 gy$	$\sigma^2 gly$	$\sigma^2 e$
Grain yield	1·08	1·98**	0·01	1·71**	1·73**
(Kg./plot)	±0·68	±0·52	±0·08	±0·36	±0·13
Fodder yield	39·16	26·67**	−1·50	33·73**	20·11**
(Kg./plot)	±22·00	±7·97	±0·60	±6·33	±1·54
Days to 50%	44·83	29·40**	2·32	23·03**	2·80**
bloom	±25·98	±6·96	±2·05	±3·86	±0·22
Plant height (cm.)	2077·02	337·18**	8·62	327·87**	271·30**
	±1130·82	±94·28	±19·05	±67·79	±21·38

**Significant at 1%.

The magnitudes of these components indicate the relative importance of the corresponding sources of variation. The genotype × location interaction for almost all the characters is of sizeable magnitude and statistically significant. Next to this in magnitude is the second order interaction of genotype × location × year which is also significant at both the levels. The genotype × year interactions are of the lowest magnitude and statistically not significant.

Relative to the estimates of g, the size of the estimates of $g \times l$, $g \times l \times y$ and e are larger for grain yield. For all other characters estimate of g is the largest component.

The error component is always larger than $g \times y$ interaction. Except for yields, the error estimate is only next in magnitude after genotype, $g \times l$ and $g \times l \times y$ interactions.

DISCUSSION

The relative magnitude of the first order interactions such as variety × location and variety × year and the second order interaction variety × location × year have frequently permitted delimitation of States into subareas for development and evaluation of varieties of crop plants. They further provided data to decide the relative emphasis to be laid on locations, years or replications in regional testing.

The lack of a sizeable variety × location interaction enabled Miller, Williams and Robinson (1958) to conclude that it was not necessary to divide the State of North Carolina into subareas for variety evaluation. Even when the testing was extended to Texas (Miller, Robinson and Pope, 1962). the conclusions were more or less similar, and testing varieties over an adequate sample of environments likely to be encountered in the breeding area would increase precision of evaluation. The significant variety × location × year interactions also lead to the conclusion that it was essential to test cotton varieties over a number of different environments. In India, Gandhi, Nathawat and Bhatnagar (1964) also recorded a large second order interaction in wheat variety tests conducted over locations and years.

With particular reference to the breeding and testing procedures of sorghum in India, it has been stated that the indigenous varieties which are the outcome of prolonged natural selection represent genic combinations with a capacity to adapt and withstand the seasonal fluctuations of a given tract and do not normally perform well when transported into a different region (Chavan and Shengde, 1957). Consequently, breeding for many small regions within a state was considered necessary and resulted in the development of over hundred improved varieties with local adaptation.

The present study involving replicated trials with five sorghum hybrids and a varietal check was conducted at 18 locations over a two-year period. The locations were spread all over the sorghum growing regions of India during the *kharif* season. The first order interaction $g \times l$ and the second order interaction $g \times l \times y$ were highly significant whereas the $g \times y$ interaction was not significant. The estimates of components of variance for yield also point out to σ^2_{gl} (1·98), σ^2_{gly} (1·71) and σ^2_e (1·73) as the major sources of variation affecting yield. Year fluctuations were unimportant (σ^2_{gy}=0·01).

The relative changes in the error component with a change in the number of locations or years or replications will be as follows:

y	l	r	σ^2_e	σ_e	Relative σ^2_e
2	17	3	·189	·435	100
1	17	3	·261	·510	117
2	17	2	·197	·444	102
2	10	3	·317	·563	178
3	10	3	·278	·527	121
3	10	2	·288	·537	123
2	20	3	·161	·401	92
2	20	2	·168	·409	94
1	20	3	·217	·468	108
1	20	2	·233	·483	111

The changes in the error component indicate that maximum precision could be obtained by increasing the test locations. With an increase in the number of locations, the number of replications could be reduced. From recent studies on soybean tests, Schutz and Bernard (1967) suggested that locations may be effectively substituted for years in regional tests to permit a rapid turnover of breeding material and this holds good to sorghum in India, at least within a season.

The performance of the individual hybrids in these trials and other studies (Rao and House, 1966 and Rao, House, Mohan and Ayengar, 1966) over different locations in the *kharif* season indicated that the early hybrid CSH-1 was the best under relatively low rainfall conditions and where traditionally early maturing varieties were cultivated irrespective of the geographic location of the test centre. Similarly CSH-2, the medium duration hybrid was the top entry at all locations where better rainfall conditions prevailed and traditionally late maturing varieties were under cultivation. The performance of the hybrids coupled with the data on genotype-environment interaction leads us to the conclusion that sorghum could be bred for maturity zones, which are in turn determined by soil and climatic factors, rather than for areas limited by state or other geographic barriers. Growing material over adequate number of locations within a maturity zone in preference to a geographical zone would, therefore, be appropriate in breeding and testing of sorghums. This could eliminate the artificial barriers to adaptability a least during a season and enable development of fewer hybrids with wider adaptability. Further work will be needed before varieties adapted to the *rabi* as well as *kharif* could be developed.

Summary

Genotype × location × year interactions indicated that the first order interaction $g \times l$ and the second order interaction $g \times l \times y$ are highly significant whereas the $g \times y$ interaction was non-significant. These studies further pointed out that sorghum could be bred for few large maturity zones rather than several small regions limited by state and geographic barriers. The implications of genotype-environment interactions in the development of testing procedures have been discussed.

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COMPONENTS OF HETEROSIS IN TWO SORGHUM HYBRIDS

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The finding that the first generation hybrids showing non-allelic interactions were in general superior to non-interacting crosses pointed to non-allelic interactions as a major source of heterosis. Jinks and Jones (1958) expressed heterosis in terms of genetic parameters, *d*, *h*, *i*, *j* and *l* of Hayman and Mather (1955). Evaluating data on *Nicotiana rustica*, they established a correlation between the presence or absence of heterosis and the presence or absence of non-allelic interactions. While heterosis can arise in the absence of non-allelic interactions, it does so with a lower frequency and a lower mean expression. Further, it was observed that non-allelic interactions play a major role in environments which allowed a fuller expression of the heterotic potential of a cross. Among interactors, absence of heterosis for certain characters could be attributed to internal cancellation of the components of heterosis. In the present study an effort is made to examine the components of heterosis in two commercial sorghum hybrids in terms of gene effects.

Materials and Methods

Parents, F_1, F_2 and F_3 generations of two released hybrids, CSH-1 (msCK60×IS 84) and CSH-2 (msCK60×IS 3691) were chosen for obtaining the estimates of the components of heterosis from generation means. The experiment was laid out as randomised blocks replicated three times during the 1965 *kharif* season. There were three rows of 15′ in each plot and individual plant observations on 15 random plants per plot were recorded for (1) days to flower, (2) plant height, (3) ear length, (4) number of secondary branches and (5) grain weight per panicle. Thus, each family mean was based on a total of 45 plants.

Based on the generation means, five of the six genetic parameters *m* (F_2 mean), *d* (additive), *h* (dominance), *i* (additive×additive), *j* additive× dominant) and *l* (dominant×dominant) gene effects and their standard errors were obtained as outlined by Hayman (1958) and Jinks and Jones (1958). Since backcross data were not available estimates of $d'=d-j$ component were calculated.

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Results

ANALYSIS OF FAMILY MEANS

The mean values for the different generations under study are presented in Table 1. While none of the F_3 families equal the F_1's in yield, some of the families are superior to the corresponding F_1 with respect to components of yield. The F_3 family 26 has greater mean panicle length than the F_1. The families 9 and 17 have higher number of secondary branches. From the analysis of variance (Table 2) it is seen that the treatment differences are highly significant.

TABLE 1

Mean values of parents, F_1, F_2 and F_3 generations

Family No.	Pedigree		Days to flower	Plant height (Cm.)	Earhead length (Cm.)	Number of secondaries	Grain weight per head (Gm.)
1	Kafir B		61	108	22·2	55	35·1
2	IS 84		66	124	28·1	60	37·3
3.	IS 3691		57	80	22·1	94	28·9
4.	msCK60×IS84	F_1	61	139	29·3	66	65·0
5.	,,	F_2-1	62	137	29·6	69	48·7
6.	,,	F_2-2	64	133	30·5	66	51·2
7.	,,	F_2-3	63	135	28·5	66	45·7
8.	,,	F_2-4	63	136	28·5	64	45·6
9.	,,	F_3-1	64	123	25·6	73	40·7
10.	,,	F_3-2	64	120	28·1	66	26·1
11.	,,	F_3-3	64	96	27·0	53	18·4
12.	,,	F_3-5	62	96	28·3	53	32·6
13.	,,	F_3-7	67	120	27·0	63	31·4
14.	,,	F_3-9	67	127	26·7	61	31·5
15.	,,	F_3-11	61	102	26·9	55	14·9
16.	,,	F_3-12	61	96	23·6	61	28·4
17.	,,	F_3-13	67	115	22·5	104	30·8
18.	,,	F_3-14	66	114	32·3	66	23·6
19.	,,	F_3-15	63	140	28·7	65	45·2
20.	msCK60×IS3619	F_1	77	172	26·3	88	89·6
21.	,,	F_2-1	75	141	24·9	92	51·0
22.	,,	F_2-2	77	188	25·6	80	51·9
23.	,,	F_2-3	73	127	24·7	85	49·8
24.	,,	F_3-1	68	141	23·8	87	45·5
25.	,,	F_3-2	64	112	24·1	72	40·0
26.	,,	F_3-3	68	120	28·7	88	50·3
27.	,,	F_3-4	65	113	23·7	72	38·5
28.	,,	F_3-6	67	108	22·7	66	33·0
	S. Em±		0·744	3·623	0·486	2·493	2·968

TABLE 2

Analysis of variance—parents, F_1, F_2 and F_3 for the two crosses

S.V.	d.f.	Days to flower	Plant height	No. of condaries	Earhead length	Grain weight
Blocks	2	223·71	192·91	15·00	42·65	1264·45
Treatments	27	1051·34**	22970·48**	8258·31**	332·79**	10089·33**
Blocks × treatments	54	24·93	590·62	279·63	10·61	396·47
Intra plot	1176	15·12	514·63	197·96	10·98	239·39

**Significant at 1 %.

HETEROSIS AND INBREEDING DEPRESSION

The generation means, heterosis and inbreeding depression for the two crosses are given in Tables 3 and 4. Heterosis for yield as well as other characters is greater than the corresponding inbreeding depression. It may be noted here that in F_2 and F_3, when steriles were come across, the next fertile plant was taken as the random plant.

GENE EFFECTS AND INTERACTIONS

The gene effects were estimated from the generation means according to the procedure of Hayman (1958). Since back cross generations were not available, only d', a combined estimate of d-j, could be obtained and heterosis was estimated from its components d', h, i, and j. The data together with their respective standard errors are presented in Table 5.

In CSH-1, all the characters excepting flowering exhibit positive heterosis. The negative heterosis with respect to flowering is also commercially desirable. Heterosis for all characters except number of secondary branches is of greater magnitude for the second cross, namely CSH-2. There is no heterosis for the number of secondary branches in this cross.

The d' and i components together in case of CSH-1 are of considerable magnitude for grain yield, ear length and plant height. In case of CSH-2, the components d' and i together are high for number of secondary branches and plant height. Considerable gain for these traits may be realised in a true breeding state by selection.

The estimates of the component h are fairly high and with the exception of secondary branches it is many times that of d'. This is indicative of presence of overdominance or non-allelic interaction. But it may be noted that the high estimates of h and epistatic interactions have been found to be together.

In CSH-1 excepting for days to flower, the l and h components have opposite signs for all other characters and the magnitude of l exceeds that of h for plant height, number of secondary branches and ear length; for grain weight

TABLE 3

Generation means of parents, F_1, F_2 and F_3 of two crosses

Character	msCK60×IS 84					msCK60×IS 3691				
	Kafir B	IS 84	F_1	F_2	F_3	Kafir B	IS 3691	F_1	F_2	F_3
Days to flower	61·17	65·80	60·67	63·07	64·08	61·17	57·44	77·07	74·88	66·31
Plant height (Cm.)	107·64	123·91	139·33	135·11	113·48	107·61	80·27	171·62	152·13	118·67
No. of secondaries	55·18	59·49	65·58	66·26	65·33	55·18	94·02	88·36	85·48	76·69
Panicle length (Cm.)	22·18	28·14	29·33	29·29	26·97	22·18	22·14	26·29	25·06	24·60
Grain weight (Gm.)	35·14	37·31	64·96	47·78	29·40	35·14	28·94	89·60	50·87	41·45

TABLE 4

Heterosis and inbreeding depression in two released hybrids, CSH-1 and CSH-2

Character	Heterosis		Inbreeding depression	
	CSH-1	CSH-2	CSH-1	CSH-2
1. Grain yield/plant	42·6	60·8	26·5	43·2
2. Days to flower	–0·8	25·5	–4·0	2·8
3. Plant height	22·7	53·2	3·0	11·4
4. Number of secondaries	9·3	–6·4	–1·0	3·3
5. Panicle length	4·1	15·6	0·1	4·7

Heterosis= $(\bar{F}_1 - \bar{SP}/F_1)100$; In breeding depression= $(\bar{F}_1 - \bar{F}_2/F_1)$ 100

TABLE 5

Estimates of main genetic and interaction components based on generation means in msCK60×IS 84 (CSH-1) and msCK60×IS 3691 (CSH-2)

Character	m	$d'=d-\hat{j}$	h	i	l	Heterosis $(h-i)-(\hat{d}-j)$
		msCK60×IS 84 (CSH-1)				
1. Grain weight	47·78	1·09	60·47**	31·73**	–52·21**	27·65
		1·63	3·33	12·53	11·69	
2. Days to flower	63·07	2·32**	–4·29**	–1·49	–1·01	-0·48
		0·41	0·84	3·15	2·99	
3. Plant height	135·11	8·14**	60·49**	36·94*	–104·11**	15·41
		2·39	4·89	18·38	13·92	
4. No. of secondaries	66·26	2·16	2·03	—6·22	–6·77	6·09
		1·48	3·03	11·40	10·63	
5. Ear length	29·29	2·98**	6·21**	2·05	–12·27**	1· 18
		0·35	0·71	2·68	2·50	
		msCK60×IS 3691 (CS-2H)				
1. Grain weight	50 ·87	3 ·10*	50 ·94**	—6 ·62	53·04**	54 ·46
		1 ·63	4 ·12	14 ·43	13 ·48	
2. Days to flower	74·88	1·87**	24·31**	6·55**	–39·87**	15·89
		0·41	1·04	3·63	3·39	
3. Plant height	152·13	13·69**	102·22**	24·55	–126·48**	63·98
		2·39	6·05	21·17	19·76	
4. No. of secondaries	85·48	19·42**	25·36**	11·60	–39·20**	–5·66
		1·48	3·75	13·12	12·25	
5. Earlength	25·06	0·02	2·05*	–2·08	0·83	4·11
		0·35	0·88	3·09	2·88	

*Significant at 5%. **Significant at 1%.

it is almost equal to *h*. This indicates considerable duplicate epistasis for most characters. In spite of this the crosses are heterotic in the *kharif* season. In the second cross also *h* and *l* have opposite signs for most characters. For grain yield, however, they are in the same direction and are of considerable magnitude.

In case of CSH-1 due to internal cancellation of *h* and *l*, the magnitude of heterosis was not upto expectations based on these interactions, and the effective components of heterosis in F_1 are *d'* and *i* which are available for selection. Therefore, the inbreeding depression was also less in F_2. In CSH-2, the second cross, the magnitude of *d'* and *i* are much less than in the first and heterosis for yield is the result of favourable gene interactions.

Discussion

As pointed out earlier, mere presence or absence of heterosis does not indicate the presence or absence of any particular type of gene action or interaction and heterosis can result from a whole range of combinations of gene effects (Jinks and Jones, 1958). One approach to a study of heterosis is in terms of the additive (*d*), dominance (*h*) and interaction (*i*, *j* and *l*) components which would reveal the type of association between heterosis and these genetic parameters. Liang and Walter (1968) estimated gene effects based on parental, F_1, F_2 and backcross generations. Additive gene effects seemed to have a minor contribution to the inheritance of grain yield, head weight and kernel weight. However, the additive × additive interaction effects formed a major component. The dominance × dominance gene effects were also of considerable magnitude.

Positive heterosis for yield, as well as for most components of yield, is marked in the two released hybrids CSH-1 and CSH-2, the latter being more heterotic for yield. Heterosis is negative for the number of secondary branches in CSH-2. The dominace component *h* is high in both crosses and appears to be the major contributing factor to heterosis. The complementary interaction component is positive and of considerable magnitude in CSH-1 for most components, while for CSH-2 such interactions are not that important. It is also interesting to note that the interaction component dominant × dominant (*l*) is of considerable magnitude in both crosses and is generally in the negative direction. In the case of CSH-1, *h* and *l* are almost of the same magnitude and are in opposite direction cancelling each other. It is the additive (*d*) and additive × additive (*i*) interactions which effectively contribute to yield heterosis. In CSH-2, *h* and *l* are in the same direction and are of considerable magnitude and are responsible for marked heterosis. Favourable non-allelic interactions, therefore, play a greater role in the yield increases obtained in CSH-2. The *h* and *l* components for most characters are in opposite directions and the magnitude of *l* exceeds that of *h* in some cases indicative of duplicate epistasis.

Thus, the hybrids CSH-1 and CSH-2 have shown considerable differences in yield with divergent mechanisms as evident from the components of heterosis.

This appears to have been achieved by different developmental mechanisms with superior capacity for nitrogen accumulation and transfer of energy in one hybrid and similar superior capacity for phosphorus ussimilation in the other (Rao, 1967).

Summary

The nature of gene interactions in two heterotic hybrids CSH-1 and CSH-2 show that heterosis for yield could result from divergent mechanisms. In CSH-1 it is the additive (d') and additive $\times$ additive (i) components which were effective in contributing to increased yields. In CSH-2 the components h and l are in the same direction and are of considerable magnitude. The implications of the differences in the nature of gene action in influencing developmental mechanisms and selection procedures are discussed.

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GENETIC ANALYSIS OF SOME EXOTIC×INDIAN CROSSES IN SORGHUM. 1. HETEROSIS AND ITS INTERACTION WITH SEASONS

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THE nature of diversity in *Eu-sorghums*, particularly the cytoplasmic-genic interactions betwteen *milo* and *kafir* groups, enabled development of cytoplasmic-genetic male steriles and the commercial exploitation of heterosis. Utilising such a source of male sterility from combine *kafir* 60, it has been possible to develop and release the first grain sorghum hybrids for general cultivation in India (House and Rao, 1966; Rao, House, Mohan and Ayengar, 1966).

During the initial stages of the hybrid breeding project, it was expected that the already well adapted Indian varieties would furnish the pollinator parents for the first hybrids, but the successful hybrids were only exotic ×exotic combinations. Thus the indigenous material, in spite of providing the well adapted base and being genetically more diverse from the exotic female parent, remained unutilised. It, therefore, became necessary to analyse the factors responsible for this failure to exploit the indigenous wealth of material and examine their potentialities as parental material for future breeding work.

The available genetic information in sorghum is limited and pertains to the manifestation of heterosis (Quinby, 1963; Kambal and Webster, 1966; Kirby and Atkins, 1968) and studies on combining ability (Kambal and Webster, 1965; Niehaus and Pickett, 1966; Beil and Atkins, 1967; Malm, 1968). The material handled by most of these workers with the exception of Neihaus and Pickett and Malm was confined to *kafirs*, *milos*, *kafir-milo* derivatives and *feteritas* grown in the U.S. summer season. Further, lack of variability among the female parents, which are *kafirs* or *kafir-milo* derivatives only, was considered to be a major impediment in realising further yield increases (King *et al.*, 1961). Thus, the extensive germ plasm furnished by the Indian sub-continent and the continent of Africa remained unutilised in the development of hybrids and in obtaining basic genetic data. As such, studies on heterosis and combining ability involving diverse sources of germ plasm are essential for the Indian work in particular and the sorghum breeding work at large.

The results of experiments conducted to evaluate Indian and exotic varieties as pollinator parents, with male sterile combine *kafir* 60 as the common female parent, for developing commercial sorghum hybrids in India are reported in this paper.

Materials and Methods

Ten hybrids with male sterile combine *kafir* 60 (msCK60), their pollinator parents and *kafir* B, the fertile counterpart of the common female parent, constituted the experimental material for a preliminary study of the expression of heterosis in the two main seasons of India, namely *kharif* (July–December) and *rabi* (October-January). The hybrids furnished a representative sample of *kafir*×exotic and *kafir*×Indian crosses being evaluated as potential commercial hybrids and combine good grain quality and yield. The particulars of the parents are as follows:

IS. 532: A selection from a dwarf yellow endosperm type introduced from Nebraska.

IS. 2930: A selection from a double dwarf yellow endosperm *hegari* introduced from Texas.

IS. 2046: Another dwarf introduction from Texas.

IS. 3574: A tall African variety *Zerazera* classified as *S. caudatum* var. *durum* (Snowden, 1936).

Nandyal: A tall local variety grown in the *kharif* season in the Dharwar region of Mysore State; described as *Sorghum subglabrescens* var. *irunguforme* by Snowden (1936).

Improved Ramkel: An improved variety grown in the light soil areas of the Vidarbha region of Maharashtra State in the *kharif* season and described as *Sorghum cernum* var. *orbiculatum* (Snowden, 1936).

Aispuri: Another *kharif* improved variety of Maharashtra State, grown in the heavy rainfall and deep black cotton soil areas of Khandesh region. Panicles are more compact than *Improved Ramkel.* Snowden (*loc. cit.*) grouped this variety also under *S. cernuum* var. *orbiculatum.*

M. 35-1, PJ4R, Tamri Maldandi: Varieties from the local *maldandi* sorghums cultivated in the *rabi* season of Maharashtra and described as *Sorghum cernuum* var. *globosum* by Snowden (*loc. cit.*).

Kafir 60: Male sterile combine *kafir* 60 was the common female parent and its fertile counterpart *kafir B* was grown in the yield trial.

The experiment was laid out in a randomised complete block design replicated three times. A single row of 750 cm. was the plot size with 90 cm. spacing between rows and 12·5–15 cm. between plants. The experiment was carried out in two seasons, *kharif* and *rabi*, in 1962–63. The *kharif* trial had 13 entries while the *rabi* trial had 15; seven of the entries were common in both seasons. The same hybrids with Indian parents could not be repeated as some of the parents are photosensitive and do not grow in both seasons. The following individual plant observations were recorded on fifteen random plants in each replication: (1) grain weight, (2) length of panicle, (3) number of secondary branches, (4) mean length of secondary branches (based upon six branches situated in different positions), (5) mean number of tertiary branches per secondary branch, (6) weight of 100 seeds, (7) days to flower, and (8) plant height at maturity.

Results

The choice of the pollinator parents in this study had to be limited to certain groups of materials like the selected yellow endosperm types, the improved Indian *kharif* and *rabi* varieties with white pearly seeds and the African *zerazeras*, since combining white pearly grain type with high yields is a prerequisite of the Indian hybrid breeding programme with msCK60 as the common female parent. Among a large number of such crosses attempted as part of general breeding programme, only ten hybrids and their parents representing the three groups mentioned above, were chosen for a critical analysis of the manifestation of heterosis.

In India, grain sorghums do not tiller and it is essentially the main stalk that contributes to yield. Therefore, observations were confined to: (1) expression of heterosis for yield and yield components in relation to genetic diversity among parents and (2) genotype-environment (season) interaction of parents and hybrids with respect to the various components under study.

EXPRESSION OF HETEROSIS IN RELATION TO DIVERSITY AMONG PARENTS

The mean values and the analysis of variance for the characters under study are presented in Tables 1 to 4. The treatment sums of squares were partitioned orthogonally into s.s. due to hybrids, males, hybrids *vs.* males and female *vs.* rest. The s.s. due to hybrids and males was further partitioned into s.s. due to exotic, indigenous and exotic *vs.* indigenous males or hybrids. Heterosis $(\overline{F_1}-\overline{SP})$ is expressed as percent. of $\overline{F_1}$ for the individual crosses and is summarised in Table 5. The following observations may be made from the data presented in these tables.

TABLE 1

Analysis of means of parents and hybrids (kharif, 1962)

Sl. No.	Hybrid/Parent	Grain weight (Gm.)	Length of panicle (Cm.)	No. of secondaries	Mean length of secondaries (Cm.)	Mean No. of tertiaries per secondary	Wt. of 100 seeds (Gm.)	Days to flower	Plant height (Cm.)
1.	msCK60 × IS 532	47·4	24·6	63	6·8	7·9	3·04	54	131
2.	IS 532	17·1	22·1	57	6·1	6·8	2·87	61	114
3.	msCK60 × IS 2930	45·2	26·7	69	6·8	7·5	3·05	53	139
4.	IS 2930	21·5	21·9	70	4·6	5·4	2·70	63	131
5.	msCK60 × IS 2046	39·6	27·1	59	8·3	7·1	2·76	60	135
6.	IS 2046	27·2	27·5	68	8·2	6·7	2·61	64	138
7.	msCK60 × Nandyal	58·7	25·0	78	5·9	6·8	3·47	86	322
8.	Nandyal	39·0	21·8	57	5·9	8·5	2·56	112	328
9.	msCK60 × Imp. Ramkel	68·4	22·9	82	5·9	7·0	3·77	90	369
10.	Imp. Ramkel	74·7	20·5	82	5·6	6·8	3·38	98	329
11.	msCK60 × Aispuri	55·0	21·6	69	5·3	6·6	3·69	76	356
12.	Aispuri	105·6	16·8	57	5·9	9·2	4·13	100	315
13.	Kafir B	25·9	22·4	54	6·2	6·9	2·48	60	116
	S.Em.±	3·92	0·64	2·32	0·30	0·38	0·11	0·91	7·21

TABLE 2

Analysis of variance—parents and hybrids (kharif, 1962)

Source of variation	Degrees of freedom	Mean sums of squares							
		Grain weight	Panicle length	No. of secondaries	Length of secondaries	Days to flower	Plant height	No. of+ tertiaries	100+ seed weight
Blocks	2	1171·30	2·99	597·58	8·66	8·39	6614·58	4·67	0·46
Treatments	12	27562·77**	403·03**	4250·11**	48·65**	17619·51**	530795·19**	13·36**	4·15**
Hybrids	5	4891·88**	199·62**	3444·81**	48·95**	11862·17**	628321·31**	3·39	2·46**
Exotic	2	722·02	79·47**	1159·70*	30·39**	5780·02**	708·07	2·95	0·41
Indigenous	2	2149·33	127·27**	1884·28**	4·80	2364·80**	26298·68**	0·53	0·36
Exo. *vs.* Ind.	1	18716·69**	584·61**	11136·13**	174·40**	53425·20**	3087593·07**	10·00*	10·79**
Males	5	55810·34**	538·07**	4624·50**	62·02**	23415·31**	522212·55**	28·33**	5·62**
Exotic	2	1163·56	454·21**	2457·62**	146·70**	67·70	7110·37	9·38*	0·26
Indigenous	2	49942·45**	311·05**	9102·29**	1·20	2390·95**	2468·94	22·44**	9·29**
Exo. *vs.* Ind.	1	176839·70**	1159·82**	2·70	14·28	112159·29**	259104·13**	78·03**	8·99**
Hybrids *vs.* Males	1	3223·24*	1120·61*	2797·12**	28·89*	23562·02**	34800·41**	0·19	2·90**
Female *vs.* rest	1	24019·00**	27·37	7857·60**	0·14	11484·68**	582072·63**	1·55	6·49**
Block × Treatments	24	690·19	18·65	241·32	3·98	37·66	2338·09	2·13	0·17
Intraplot	546	144·91	4·25	70·15	0·79	3·02	298·22	0·67	0·11

+Individual plant observations for these two characters were confined to only 5 plants for replication and hence the d.f. for intraplot will be 156.

TABLE 3

Analysis of means of parents and hybrids (rabi, 1962–63)

Sl. No.	Hybrid/Parent	Grain weight (Gms)	Panicle length (Cms)	No. of secondaries	Mean length of secondaries (Cms)	Mean No. of tertiaries	Weight of 100 seeds (Gms)	Plant height (Cms)
1.	msCK60 × IS 532	28·6	20·9	48	5·1	6·7	2·95	127
2.	IS 532	18·4	18·5	41	4·9	6·6	3·14	92
3.	msCK60 × IS 2930	28·3	24·8	52	5·8	6·4	2·58	135
4.	IS 2930	19·3	22·0	55	4·3	5·0	2·58	98
5.	msCK60 × IS 2046	35·1	25·2	52	6·5	6·8	2·49	127
6.	IS 2046	19·8	25·5	46	6·3	8·9	2·11	113
7.	msCK60 × IS 3574	31·9	18·3	39	4·7	6·1	2·56	181
8.	IS 3574	20·7	12·4	34	3·1	4·4	2·16	124
9.	msCK60 × M. 35–1	34·8	17·8	54	4·7	5·8	3·49	224
10.	M. 35–1	32·8	17·3	59	5·2	5·8	3·87	217
11.	msCK60 × PJ4R	43·9	20·2	68	4·9	6·6	3·71	243
12.	PJ4R	29·6	14·0	60	3·6	5·0	3·71	225
13.	msCK60 × Tamri Maldandi	41·5	20·0	67	5·3	6·6	3·44	234
14.	Tamri Maldandi	29·3	15·8	57	4·5	5·6	4·00	206
15.	Kafir B	26·3	21·5	49	5·1	6·7	2·47	114
	S.Em±	2·87	0·83	2·58	0·31	0·74	0·18	4·51

(a) The yield levels of the parents as well as hybrids are generally low in the *rabi* season in comparison to *kharif*.

(b) In *kharif* season, the late Indian varieties have a comparatively higher yield level than the exotic parents. The hybrids with improved Indian varieties are not heterotic. On the other hand, crosses with exotic pollinator parents are more heterotic than hybrids with Indian parents.

(c) During the *rabi* season, the hybrids with Indian varieties adapted for *rabi* are slightly more heterotic. The local pollinator parents in this group are also at a higher yield level but do not compare favourably with Indian *kharif* varieties.

(d) The extent of heterosis for individual characters in both seasons was substantial and in the desired direction for grain weight, seed weight and length of secondaries in 11, 9 and 7 of the 13 cases respectively. For length of panicle and number of secondary branches, heterotic response as observed in less than half of the hybrids under study. Least heterosis was observed for number of tertiary branches per secondary (Table 5).

(e) Heterosis is negative in msCK60×Indian variety crosses for length of secondary branches and mean number of tertiaries per secondary during

TABLE 4

Analysis of variance—parents and hybrids (rabi, 1962–63)

Source of variation	Degrees of freedom	Mean sum of squares						
		Grain weight	Panicle length	No. of secondaries	Length of Secondaries	Plant height	No. of+ tertiaries	100+ seed weight
Blocks	2	446·32	9·39	42·62	0·34	56·92	21·84	0·0102
Treatments	14	2694·41**	686·83**	4203·56**	34·80**	138457·11**	16·85	6·2501**
Hybrids	6	1643·89**	379·00**	4725·89**	19·29**	123082·85**	1·79	3·9304**
Exotic	3	475·84	477·11**	1792·74**	27·05**	29480·92**	1·38	0·6380
Indigenous	2	1013·90	79·95	2886·96**	4·38	3859·76*	3·07	0·3362
Exotic *vs.* Ind.	1	6407·97**	682·75**	17203·20**	25·85**	642334·83**	0·47	20·9960**
Males	6	1639·96**	941·84**	4519·38**	47·84**	159160·33**	34·53**	9·8232**
Exotic	3	43·37	1410·18**	3518·49**	75·19**	9453·70**	62·40**	3·4382**
Indigenous	2	173·52	124·36*	133·43	28·52**	4192·07*	2·64	0·3155
Exotic *vs* Ind.	1	9362·59**	1171·78**	16293·93**	4·40	918216·78**	14·70	47·9934**
Hybrids *vs* Males	1	17582·40**	1523·20**	2888·58**	82·88**	124068·13**	14·46	0·1451
Female *vs* Rest	1	436·33	167·42*	489·60	1·58	120872·21**	3·55	4·8356**
Blocks × Treatments	28	370·31	31·32	299·75	4·41	914·55	8·32	0·4675
Intra Plot	674	120·67	4·38	79·96	0·85	117·39	1·77	0·0468

*Significant at 5% **Significant at 1%

+Individual plant observations for these two characters were confined to only 5 plants per replication and hence the d.f. for intraplot will be 180.

kharif season, while in the *rabi* season the panicle length and seed weight also show negative heterosis.

TABLE 5

Heterosis expressed as values of (F_1—superior parent) expressed as per cent. of F_1 for some characters

Sl. No.	Hybrid		Grain weight	Panicle length	No. of Secondaries	Mean length of secondaries	Mean No. of tertiaries per secondary	Wt. of 100 seeds
1.	msCK60 × IS 532	K	45·4	8·9	9·5	8·8	12·7	5·6
	,,	R	8·0	−2·9	−2·1	0·0	0·0	6·4
2.	msCK60 × IS 2930	K	42·7	16·1	−1·5	8·8	8·0	11·5
	,,	R	7·1	11·3	−5·8	12·1	−4·7	0·0
3.	msCK60 × IS 2046	K	31·3	−1·5	−15·3	1·2	2·8	5·4
	,,	R	25·1	−1·2	5·8	3·1	−30·9	0·8
4.	msCK60 × Nandyal	K	33·6	1·0	26·9	0·0	−25·0	26·2
5.	,, × Imp. Ramkel	K	−9·2	2·2	0·0	−5·1	1·4	10·3
6.	,, × Aispuri	K	−92·0	−3·7	17·4	−17·0	−39·4	−11·9
7.	,, × IS 3574	R	17·6	−17·5	−25·6	−8·5	−9·8	3·5
8.	,, × M. 35–1	R	5·8	−20·8	−9·3	−10·6	−15·5	−10·9
9.	,, × P. J. 4R	R	32·6	−6·4	11·8	−4·1	−1·5	0·0
10.	,, × Tamri Maldandi	R	29·4	−7·5	14·9	3·8	−1·5	−16·3

K—*Kharif* R—*Rabi*

(f) During the *kharif* season, a comparison of hybrids *vs.* parents has revealed substantial differences for panicle length, length of primary axis, number of secondary branches, days to flower and plant height while for grain weight and length of secondary branches the differences were significant only at 5 per cent. This is in contrast to the substantial S.S. due to the female *vs.* rest comparison for all characters except panicle length and length of secondary. The pattern of the comparisons in the data obtained from *rabi* season is different from that of *kharif.* During *rabi*, the S.S. for the comparison female *vs.* rest was negligible in relation to the S.S. due to hybrids *vs.* males. The differences between parents and hybrids in *rabi* are highly significant for all characters. An examination of the S.S. due to exotic *vs.* indigenous hybrids in both *kharif* and *rabi* seasons has indicated greater differences in *kharif* as compared to *rabi.*

(g) The proportion of S.S. accounted for by exotic *vs.* indigenous is less in hybrids than in male parents. This is attributable to a greater stability of the hybrids than the parents. The female parent msCK60 is non-photosensitive and the hybrids also tend to be less sensitive to photoperiod.

(h) Further, during the *kharif* season, a greater proportion of the S.S. is accounted for by msCK60 × Indian varieties than msCK60 × exotic varieties. The situation is generally similar with respect to males also except for the flowering time. On the other hand, during the *rabi* season the proportion of S.S. accounted by msCK60 × Indian varieties is only slightly greater with respect to grain yield and number of secondary branches whereas for all other components a greater proportion of the S.S. is accounted by msCK60 × exotic combinations.

(i) Among the two seasons, it is seen that during the *kharif* most components of yield are significant for msCK60 × Indian combinations and among Indian males, whereas during the *rabi* season the differences among the msCK60 × exotic varieties as well as among exotic parents, are generally significant. This indicates that the behaviour of exotic hybrids and parents is in opposite directions during the *kharif* and *rabi* seasons.

(j) A study of the components of variance for males and hybrids (Table 6) indicates that the characters like the length of panicle, and number of tertiary branches per secondary are stable. The number of secondary branches is highly variable over seasons.

INTERACTION OF PARENTS AND HYBRIDS WITH SEASONS

Three hybrids along with their exotic parents were common in both *kharif* and *rabi* seasons. Table 7 presents the analysis of variance. In this analysis not only the treatment differences were not significant but the differences among the parents and among the hybrids were also not significant due to the large magnitude of M.S.S. for the interaction, treatment × season. This could be partly due to the very few hybrids that could be raised in both the seasons.

The treatment sums of squares were partitioned into hybrids, males, hybrids *vs.* males and female *vs.* rest. The treatment × season interaction was partitioned into hybrids × seasons, males × seasons and female in seasons.

The treatment × season interactions are significant for grain yield and number of secondary branches and plant height.

Among the treatments the proportion of S.S. due to males is greater than hybrids *vs.* males for yield components such as panicle length, number of secondary branches, length of secondaries, number of tertiaries and seed weight. The S.S. due to hybrids is generally lower than the rest of the components.

The S.S. due to hybrid × season interaction for yield and number of secondary branches is more than the male × season interaction while the reverse is true for other components. The number of secondary branches on the panicle is most influenced by seasons; in the *rabi* there is a tendency for the panicle to become loose and contribute to lower yields. Such interactions indicate that the stability of some characters is not necessarily related to heterozygosity.

TABLE 7

Combined analysis of variance for hybrids and parents grown in two seasons

Source of variation	Degrees of freedom	Mean squares						
		Grain yield	Panicle length	No. of secondaries	Mean length of secondaries	Mean No. of tertiaries	100 seed weight	Plant height
Reps/Seasons	4	10529·55	354·62	19189·41	151·64	60·96	1·16	14915·4
Treatments	6	100769·77	8164·71	32130·49	1387·64	97·56	9·19	188660·6
Hybrids	2	474·37	4513·37	11781·17	726·32	8·10	5·06	23713·8
Males	2	11381·84	13889·00	66804·05	2610·38	258·14	15·78	171546·7
Hybrids *vs* Males	1	571687·22	7746·94	2055·11	1397·48	52·57	4·60	653672·2
Females *vs* rest	1	9218·99	4436·05	33557·40	254·94	0·33	8·88	87770·6
Seasons	1	111972·35	9297·63	432694·50	3828·51	6·25	7·43	461790·8
Treatments × Seasons	6	22201·89*	641·09	12023·67**	115·68	49·54	2·75	320379·1**
Hybrids × seasons	2	20657·28	344·63	9140·06	60·37	9·20	1·37	1757·4
Males × seasons	2	6445·83	1245·76	4026·06	237·64	81·64	5·61	12785·3
Female in seasons	1	61·43	280·17	7704·17	405·08	1·22	0·01	886·6
Error	24	6068·73	348·85	3231·04	87·98	42·40	2·03	10165·9

*Significant at 5% **Significant at 1%

An examination of the components of variance obtained from this study (Table 8) reveals that the t×s component for number of secondary branches and plant height is larger than the estimates for treatments and seasons indicating that these interactions are of maximum importance in influencing the yields either way in different seasons. Mean number of tertiaries and seed weight are less influenced by the season or seasonal interaction, and therefore, these may be considered to be stable over seasons.

TABLE 8

Components of variance obtained from genotype × season interaction study

Character	$\hat{\sigma}^2 t$	$\hat{\sigma}^2 s$	$\hat{\sigma}^2 ts$	$\hat{\sigma}^2$
Grain yield	13094·6	4274·8	5377·7	6068·7**
Length of panicle	1253·9**	412·2	97·4	348·9**
No. of secondaries	3351·1	20031·9	2930·9	3231·0**
Mean length of secondaries	212·0*	176·8	9·2	88·0**
Mean No. of tertiaries	8·0	2·1*	2·4	42·4**
Weight of 100 seeds	1·1	0·2	0·2	2·0**
Plant height	21953·1	6733·9	103404·0	10165·9**

t–treatments; s–seasons; ts–treatments × seasons
*Significant at 5% **Significant at 1%

The large estimate of $\hat{\sigma}^2_t$ as compared to $\hat{\sigma}^2$ for all the characters might have not permitted the detection of t×s interaction, There is also considerable magnitude of seasonal effect on varieties which is evident from a comparison of $\hat{\sigma}^2_t$ and $\hat{\sigma}^2_s$.

Thus, the combined analysis has revealed that the hybrids *vs.* males comparison is not significant for any one of the characters, while evidence of interaction with seasons is present to some extent. While it is likely that the high residual error component could have prevented the detection of differences, the differential interaction of the hybrids during the two seasons cancels out the advantage of the hybrids. This will lead to a spurious conclusion that the hybrids may not be superior to the parents. Thus, it appears to be necessary to evaluate separate groups of hybrids for *kharif* and *rabi.*

DISCUSSION

The most basic comparison that is of importance to plant breeders is that of parental *vs.* hybrid performance. On account of the adaptability and greater genetic diversity from the exotic female (msCK60) furnished by the Indian sorghums, it was expected that the msCK60 × Indian variety crosses would be high yielding and of immediate value to the Indian farmer. Studies on inter-varietal crosses of maize also point out to a positive relationship between genetic diversity of parents and expression of heterosis (Moll, Salhauna and Robinson, 1962). Crosses of adapted and exotic varieties out-yielded crosses of two adapted varieties in maize indicating the potential utility of genes in exotics.

Available results on the manifestations of heterosis in grain sorghums indicate that the yield advantage of the hybrids resulted mainly from an increase in the number of seeds per head and to a certain extent from the number of stalks per plant (Quinby, 1963; Kambal and Webster, 1966; Kirby and Atkins, 1968). Since grain sorghums under study did not tiller under Indian conditions, and the major contribution to yield was provided primarily by the panicle, an examination of the heterotic response for yield and yield components, particularly those concerning the panicle in msCK60 × exotic and msCK60 × Indian varieties, was expected to provide useful information.

Some of the improved varieties of India which are very late maturing have excellent white pearly grains and in spite of their being tall, are capable of bearing a large ear under widely spaced conditions, whereas under thick populations they resemble forage sorghums and bear only small sized panicles. The Indian parents involved in the study are representative of such improved varieties grown in the *kharif* and *rabi* seasons. Under the experimental conditions, where wide spacing between rows as well as plants was provided, the improved Indian varieties (pollinator parents) were at a higher level of yield per plant in comparison with their exotic counterparts and the resulting hybrids were definitely less heterotic for yield per plant in the *kharif* season. Lack of heterosis or negative heterosis was marked for mean length of the secondary branches and the number of tertiary branches per secondary which bear grain.

The compact headed Indian varieties have their panicle length reduced but bear longer secondaries which are adpressed and with greater number of tertiaries which give the panicle increased girth. On the other hand, the emphasis is on the length rather than the girth of the panicle in the exotic *kafir*. Since length and girth seem to have evolved in opposite directions, there seems to be lack of reinforcement between genes or gene complexes for length of the primary axis and those contributing to girth. Heterotic response seems to be greater for characters evolved in the same direction as observed in the *kafir* × *Nandyal* cross where the panicles of both exotic and Indian types are of the elongate type. Thus, during the *kharif* season, the reduced heterotic response of the hybrids coupled with a tall plant type and difficulties in threshability of the hybrids contributed to the non-desirability of hybrids with indigenous pollinator parents normally grown in the *kharif* season. But developing commercial hybrids with msCK60 × exotic lines was a definite possibility; these have since been released to farmers.

On the other hand, during the *rabi* season, hybrids involving *kafir* 60 and *rabi* varieties of India as pollinator parents are slightly more heterotic for yield than the hybrids with the same exotic parents studied in the *kharif*. But during this season, due to the greater susceptibility of hybrids to shootfly and relatively inferior grain quality compared to the improved varieties, chances of development of a commercial hybrid with Indian or exotic pollinator parents appears to be rather limited.

An examination of the estimates of components of variance in respect of parents and hybrids (Table 6), indicates that during the *kharif* season, the estimates for most such components for hybrids are smaller than the parental estimates and in many cases smaller than the estimates for sampling and experimental errors indicating that the hybrids are much more stable than the parents. Similar estimates during the *rabi* season indicate that the magnitude of the hybrid estimates for grain yield and number of secondary branches are almost as large as the male estimates and the estimates due to sampling error are even larger than the parental and hybrid estimates. The most stable components in both seasons appear to be the length of the secondary and the number of grain bearing tertiary branches which they bear, whereas the number of secondary branches is the least stable.

That genotype-environment interactions can be a major factor in the expression of heterotic characters is known. Internal cancellation of the components of heterosis, can also be equally important (Jinks and Jones, 1958; Rao and Murty, 1970). A study of the interaction of the exotic parents and their hybrids and the common female parent with these two main seasons *kharif* and *rabi* was, therefore, undertaken. An examination of the relative sums of squares for treatments × seasons which were further partitioned into hybrids × seasons, males × season and female in seasons indicated that the S.S. due to hybrid × season interactions for grain yield and number of secondary branches were far in excess of the male × season interaction. These interactions were statistically significant. The expression of the heterosis in these hybrids, therefore, appears to be limited by the genotype-environment interaction. The exotic pollinator parents are heterogenous in the *rabi* environment, thereby indicating their interaction with this season, but they were non-interactors in the *kharif*. The reverse is true for Indian types and the common female parent, msCK60 is a non-interactor in both environments. Maximum heterosis was observed when this non-interacting parent was crossed with types which did not interact in that environment. Genotype-environment interactions, therefore, seem to have acted in a direction opposite to that of heterosis resulting in limited or no heterosis. Evidence for internal cancellation of components of heterosis depending on the genetic background has also been obtained in this study. The first hybrids released in India, CSH-1 and CSH-2 (Rao *et al.*, 1966) are msCK60 × exotic combinations and their utility was confined to the *kharif* and summer seasons, but not the winter. The number of secondary branches is most susceptible to change during the *rabi* season. Reduction in the means for this component results in loosening of the panicle and a fall in the total number of spikelets resulting in low yields. Selection of parents stable for this character could enhance yields of hybrids in *rabi* season.

Thus, the acceptance of msCK60 as the common female parent for the first hybrids imposed a limitation on the choice of the pollinator parents. As has been discussed, the hybrids with the Indian parents, were characterised by (1) lack of marked heterosis, (2) difficulties in threshability and (3) too tall a habit not amenable for increasing the plant population per unit area. On the other hand, they undoubtedly possess a higher potentiality for yield on an individual plant basis, present less of pest problems and are of known adaptation to certain major regions of sorghum in this country. To capitalise on these advantages, further studies involving exotic × exotic, exotic × Indian and Indian × Indian varieties in a diallel mating system providing for greater diversity on the male as well as female sides have been taken up.

Summary

When msCK60 was used as the common female parent, the improved indigenous sorghum varieties used as pollinator parents inspite of their adaptability to some agroclimatic regions of India, did not result in hybrids of commercial value. This could be attributed mainly due to lack of heterosis in *kharif* season, an undesirable plant type and difficulties in threshability. During the *rabi* season, in spite of limited heterosis with both exotic and Indian parents, greater susceptibility of hybrids to shoot-fly and relatively inferior grain quality compared to the local *rabi* varieties did not enable the development of any commercial hybrid for this season. The first hybrids released for *kharif* and summer seasons were, therefore, exotic × exotic combinations.

An examination of the heterotic response of the components of yield revealed that heterosis was generally negative for the length of the secondary branches and the number of tertiary branches. Considering panicle morphology, the emphasis in compact headed Indian varieties is on girth which is due to relatively longer secondary branches with more number of tertiaries, while in exotics panicle length was generally pronounced. When such varieties were combined, there seems to be lack of reinforcement between genes or gene complexes for length of primary axis and those contributing to girth, resulting in limited or no heterosis for ultimate yield. Heterosis for panicle components seems to be maximum for characters evolved in the same direction irrespective of their geographic origin.

The estimates of the components of variance for parents and hybrids reveal that hybrids are more stable than parents during *kharif* season. During the *rabi* season the magnitude of such estimate is as large for hybrids as for males indicating that heterozygosity is not necessarily related to stability. The number of secondary branches is the least stable character, whereas the length of the secondary branches and the number of tertiaries are most stable. These stable characters are observed to be least heterotic.

The limitations imposed by the genotype-environment (season) interactions on the magnitude of heterosis are well brought out. In spite of the common

female parent msCK60 being a non-interactor in both seasons, the hybrids behaved differently. While the exotic×exotic combinations were most heterotic in the *kharif* environment, genotype-environment interactions acted in a direction opposite to that of heterosis resulting in limited heterosis during *rabi*. It, therefore, appears necessary at least in the immediate future to develop different groups of hybrids for *kharif* and *rabi* seasons. Development of parental stocks which are stable for the number of secondary branches in both seasons may enable development of commercial hybrids common for both the seasons.

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GENETIC ANALYSIS OF SOME EXOTIC×INDIAN CROSSES IN SORGHUM. II. COMBINING ABILITY AND COMPONENTS OF GENETIC VARIATION

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THE limitations of using indigenous varieties of sorghum in the development of commercial hybrids with male sterile combine *kafir* 60 as the female parent were analysed earlier (Rao, 1970). Increased knowledge of the nature of gene action in yield heterosis provides a basis for reappraisal of breeding methods and aids in developing new breeding procedures. A diallel analysis of heterosis and combining ability in crosses involving tall, long duration Indian parents and dwarf, early exotics is reported in this paper.

MATERIALS AND METHODS

All possible crosses (without reciprocals) were made among five dwarf exotic parents and four tall imporved Indian varieties. Brief description of the parental material is given below.

Kafir 60: Male sterile Combine *Kafir* 60 is the common female parent of first commercial hybrids in India; the fertile counterpart *Kafir* B was grown as parent in yield trial.

IS 84 : A selected yellow endosperm *feterita* and the pollinator parent of CSH-1, the first sorghum hybrid released in India for general cultivation.

IS 3691 : A selected yellow endosperm *hegari* and the pollinator parent of CSH-2, the second sorghum hybrid developed and released in India.

IS 2031 : A *kafir* type, originally introduced as SA 8491-1 (D.D.) and has undergone considerable selection for yield improvement. The particular line used as the parent is selection 133.

IS 3922 : Another yellow endosperm *kafir* which has been considerably improved at Delhi for yield. The line used is selection 393.

Karad Local : A variety cultivated in southern parts of Maharashtra State in Western India.

Aispuri : An improved variety grown in Northern Maharashtra with very big and compact ears. Snowden (1936) classified this variety under *S. cernuum* var. *orbiculatum*.

Nandyal : A tall *kharif* variety grown in the Dharwar region of Mysore State described as *Sorghum subglabrascens* var. *irunguforme* (Snowden, 1936).

G.M. 1-5 : A selection from *Gidda Maldandi*, a comparatively shorter variety among the Indian types, cultivated in parts of Mysore State.

Since three crosses were missing in the 9×9 diallel-set, the data were analysed as two diallel experiments, one with seven parents (1, 2, 3, 4, 6, 8 and 9) and the other involving six parents (1, 3, 5, 6, 7 and 8), so as to obtain the general and specific combining ability effects of all the parents involved. There were three replications and individual plant observations were recorded on five random plants in each replication. Within the blocks the tall parents and hybrids were randomised and kept together while the dwarfs were similarly randomised and kept together. This restriction on randomisation was resorted to avoid unequal competition between lines of widely different growth habits. A uniform border of *kafir* was provided at the end of all experimental plots. The experiment was planted on July 19, 1966 under high fertility conditions of 100 N and 60 P_2O_5 and necessary field operations were carried out at appropriate times. Combining ability analysis of the two sets of diallel experiments was carried out according to Griffings (1956) model II and method 2.

One of the diallel experiments (7 × 7) was utilised for graphic analysis and for estimation of the components of genetic variation using the methodology of Hayman (1954) and Jinks (1954).

Results

For purposes of presentation of data, the material is grouped as exotic parents, Indian parents, exotic × exotic, exotic × Indian and Indian × Indian cross combinations. The same order is maintained throughout the presentation.

ANALYSIS OF MEANS AND EXPRESSION OF HETEROSIS

The mean values for grain yield, days to flower and plant height are presented in Table 1. Heterosis $(\overline{F_1}-\overline{SP})$ expressed as percentage of $\overline{F_1}$ is also given in the same table. It will be seen that the heterosis for yield ranged from 3·0 to 67·8 per cent. among exotic × exotic combinations, –3·8 to 45·0 per cent. among exotic × Indian and from –8·9 to 20·9 per cent. among Indian × Indian crosses.

TABLE 1

Analysis of means and expression of heterosis

Sl. No.	Parent/Hybrid	Grain yield Gm./plant	Days to flower	Plant height (Cm.)	Heterosis: Grain yield	Heterosis: Days to flower	Heterosis: Plant height
	Parents—Exotic						
1.	IS 84	47·1	66·6	122			
2.	IS 3691	33·1	58·6	78			
3.	IS 2031	55·8	88·1	123			
4.	Kafir 60	34·8	62·1	104			
5.	IS 3922	57·8	79·9	129			
	Mean	45·7	71·1	111·2			
	Parents—Indian						
6.	Karad Local	83·3	109·0	239			
7.	Nandyal	78·0	107·6	284			

(Contd.)

TABLE 1 (Contd.)

Sl. No.	Parent/Hybrid	Grain yield Gm./ plant	Days to flower	Plant height (Cm.)	Heterosis		
					Grain yield	Days to flower	Plant height
8.	G.M. 1-5	84·1	113·1	226			
9.	Aispuri	98·8	99·5	283			
	Mean	86·5	107·3	258·0			
	Hybrids—Exotic × Exotic						
10.	IS 84 × IS 3691	87·6	85·4	181	46·2	31·4	56·9
11.	IS 84 × IS 2031	85·5	62·4	144	34·7	6·7	15·3
12.	IS 3691 × IS 2031	102·7	87·8	161	45·7	33·3	51·6
13.	IS 3691 × IS 3922	112·8	86·7	157	48·8	32·4	50·1
14.	Kafir 60 × IS 3691 (CSH-2)	108·2	85·3	156	67·8	27·2	50·0
15.	Kafir 60 × IS 84 (CSH-1)	63·5	63·4	133	25·8	2·1	21·8
16.	Kafir 60 × IS 2031	57·5	62·1	116	3·0	0·0	10·3
17.	Kafir 60 × IS 3922	67·1	62·2	140	13·9	0·2	25·4
	Mean	85·6	74·4	148·5	35·7	16·7	35·2
	Hybrids—Exotic × Indian						
18.	IS 84 × Karad Local	135·7	86·1	211	38·6	22·7	42·2
19.	IS 84 × Nandyal	128·4	87·9	249	39·3	24·2	51·0
20.	IS 84 × G.M. 1-5	123·6	84·7	180	32·0	21·4	32·2
21.	IS 3691 × Karad Local	98·0	92·8	240	15·0	36·9	67·5
22.	IS 3691 × Nandyal	103·9	89·3	225	24·9	34·4	65·3
23.	IS 3691 × G.M. 1-5	102·5	88·1	222	18·0	33·5	64·9
24.	IS 3691 × Aispuri	120·8	85·4	270	18·2	31·4	85·3
25.	IS 2031 × Karad Local	141·6	87·4	234	41·2	–0·8	47·4
26.	IS 2031 × Nandyal	141·8	88·5	245	45·0	0·5	49·8
27.	IS 2031 × G.M. 1-5	96·7	89·8	184	13·0	1·9	33·2
28.	Kafir 60 × Karad Local	77·0	83·3	275	–8·2	25·5	62·2
29.	Kafir 60 × Nandyal	106·7	83·9	269	26·9	26·0	61·3
30.	Kafir 60 × G.M. 1-5	81·1	86·8	226	–3·8	29·4	45·4
31.	Kafir 60 × Aispuri	90·8	82·0	293	–8·8	24·3	64·5
32.	IS 3922 × Karad Local	149·1	91·1	241	44·1	12·3	46·5
33.	IS 3922 × Nandyal	114·7	88·3	259	32·0	9·5	50·2
34.	IS 3922 × Aispuri	105·7	83·9	288	6·5	4·8	55·2
	Mean	112·8	87·0	241·8	22·0	19·9	54·3
	Hybrids—Indian × Indian						
35.	Karad Local × Nandyal	103·0	108·4	297	12·4	–0·6	19·5
36.	Karad Local × G.M. 1-5	99·0	108·8	253	15·1	–4·0	10·7
37.	Nandyal × G.M. 1-5	99·6	109·3	281	15·6	–3·5	19·6
38.	Aispuri × Karad Local	90·7	97·3	305	–8·9	–1·2	21·6
39.	Aispuri × Nandyal	124·9	97·5	301	20·9	–1·0	6·0
	Mean	103·4	104·3	287·4	11·0	–2·1	15·5
	S.Em±	3·94	0·60	5·39			

The mean yields for tall and late Indian parents are at a higher level than for the exotic parents. Consequently, the yield levels of the exotic × Indian cross combinations are at a higher level even though the magnitude of heterosis is not greater than the exotic × exotic crosses. The Indian × Indian crosses exhibit least heterosis and the plant type is also not desirable.

The hybrids with IS. 3691 × exotic parents are unique combinations in that two dwarf and early parents interact to give a tall and late hybrid. These are the most heterotic hybrids. Such a degree of complementary action is not found in the other crosses. If this hybrid is left out, expression of heterosis is of the same order in both exotic × exotic and exotic × Indian crosses. The Indian parent G.M. 1–5 tends to yield hybrids of an intermediate height with all parents.

The analysis of variance for grain yield, flowering and plant height is presented in Tables 2 and 3. The treatment sums of squares for yield are further partitioned to provide comparisons among and between exotic and Indian parents as well as hybrids. Most of the comparisons are significant. The proportion of sums of squares accounted by the source, exotic *vs.* Indian parents is of a large magnitude indicating that they are genetically diverse.

It is also of interest to note that several hybrids have much higher mean values for grain yield in comparison with the released hybrids CSH-1

TABLE 2

Analysis of variance for grain yield for the two sets of diallel crosses

Source	Diallel set 1		Diallel set 2	
	d.f.	Mean square	d.f.	Mean square
Blocks	2	455·90	2	1342·15
Treatments+	27	12831·52**	20	12091·60**
Among exotic parents	3	1717·70**	2	2853·19**
Among Indian parents	2	163·05	2	1745·01**
Among exotic × exotic hybrids	5	6212·72**	2	9499·27**
Among Indian × Indian hybrids	2	71·10	2	4506·31**
Among exotic × Indian hybrids	11	7523·14**	8	6141·19**
Exotic *vs.* Indian parents	1	39325·7**	1	45118·08**
Exotic *vs.* Indian hybrids	1	8063·3**	1	2360·40**
Exotic *vs.* Exotic × Indian hybrids	1	44533·8**	1	4393·61**
Indian *vs.* Exotic × Indian hybrids	1	4237·6**	1	46·03
Blocks × Treatments	54	232·32	40	273·62
Sampling error	336	239·40	252	259·76

+The break up of comparisons is not orthogonal
**Significant at 1 % *Significant at 5 %

TABLE 3

Analysis of variance for flowering time and plant height for the two sets of diallel experiments

Source	Mean square (Diallel set 1)			Mean square (Diallel set 2)		
	d.f.	Days to flower	Plant height	d.f.	Days to flower	Plant height
Blocks	2	1·10	978·20	2	5·25	1218·85
Treatments	27	3755·68**	57004·79**	20	2965·52**	76957·22**
Blocks × Treatments	54	5·45	436·35	40	5·99	560·11
Sampling error	336	0·77	202·23	252	1·18	241·45

**Significant at 1%.

(msCK60×IS. 84) and CSH-2 (msCK60×IS. 3691). Crosses with the improved exotic lines, IS. 2031 and IS. 3922 resulted in hybrids with maximum yields.

ANALYSIS OF COMBINING ABILITY

The analysis of variance for combining ability for the two diallels is presented in Table 4. A comparison of the variance due to general and specific combining ability indicates that both general and specific combining abilities are important for yield. For flowering and plant height, additive gene action is predominant.

COMBINING ABILITY EFFECTS

Estimates of general combining ability effects are given in Table 5 which reveal wide differences between exotic and indigenous parents. The magnitude and direction of the effects point to IS. 2031 and IS. 3922 as excellent among exotic parents. The differences among indigenous parents are not very marked.

Even though the two diallel sets were created from the same experiment, the gca effects for *Karad Local* are different in the two sets. There are also similar differences in the estimates of standard errors, which indicate that the genetic background as well as cytoplasmic effects play a role in influencing the general as well as specific effects.

Estimates of specific combining ability effects are presented in Table 6 which reveal the cross msCK60×IS. 3691 (CSH-2) to be a unique specific combination with maximum heterosis. All the crosses with IS. 84 which is the male parent of the released hybrid CSH-1, and the crosses IS. 2031×*Karad Local*, IS. 2031×*Nandyal*, IS. 3922×*Karad Local* are excellent specific combiners.

The cross IS. 2031×G.M. 1–5 has low specific effect. The gca effects of the parents are also in the desired direction. Similarly the crosses IS. 3922×*Nandyal* and IS. 3922×*Aispuri* also have low specific effects and the parents are

TABLE 4

Analysis of variance for combining ability for the two sets of diallel crosses

Source	Diallel set 1				Diallel set 2			
	d.f.	m.s. Grain yield	m.s. Days to flower	m.s. Plant height	d.f.	m.s. Grain yield	m.s. Days to flower	m.s. Plant height
General combining ability	6	989·99**	915·13**	13455·85**	5	750·03**	631·50**	15640·15**
Specific combining ability	21	817·35**	60·16**	1043·76**	15	825·09**	52·79**	1627·45**
Error (M'e)	336	15·96	0·06	13·48	314	17·32	0·08	16·10

**Significant at 1 %

TABLE 5

Estimates of general combining ability effects for the two sets of diallel crosses

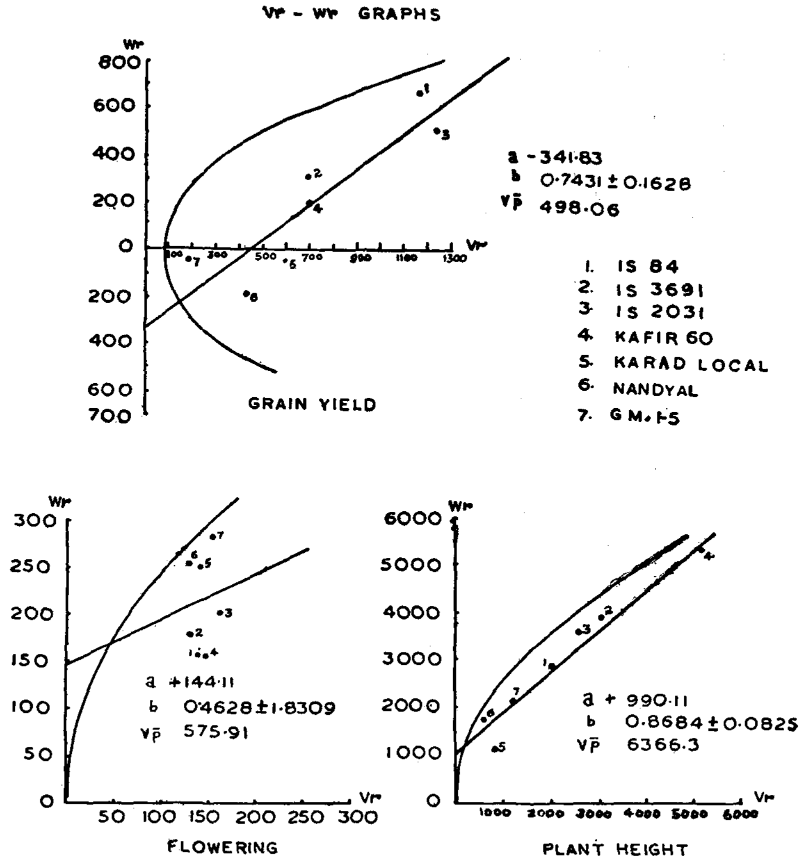
Parents	Grain yield	Days to flower	Plant height
Diallel set 1			
I.S. 84	–1·43	–10·14**	–30·51**
IS. 3691	–6·92**	–5·25**	–30·61**
IS. 2031	+0·67	–4·33**	–31·84**
Kafir 60	–18·64**	–11·57**	–25·95**
Karad Local	+9·95**	+10·18**	+41·27**
Nandyal	+12·00**	+9·93**	+57·49**
G.M. 1–5	+4·37**	+11·17**	+20·16**
S.E. ($\hat{g}_i$) ±	1·23	0·07	1·13
Diallel set 2			
IS. 3922	+1·49	–4·92**	–33·50**
IS. 3691	–5·40**	–6·83**	–50·88**
Kafir 60	–16·71**	–11·31**	–33·75**
Karad Local	+3·92**	+9·94**	+28·31**
Nandyal	+7·02**	+8·91**	+38·50**
Aispuri	+9·68**	+4·22**	+51·50**
S.E. ($\hat{g}_i$) ±	1·34	0·09	1·30

**Significant at 1%.

desirable from the point of view of gca. As such, these crosses may result in desirable recombinations of true breeding nature.

GRAPHIC ANALYSIS OF DIALLEL DATA

The Vr–Wr graphs for the three characters under study are presented in Figs. 1, 2 and 3. The slope of the regression line is 0·7431 for grain yield, 0·8684 for height and 0·4628 for days to flower. These data suggest gene interaction, and the assumption that gene action is additive is not valid. The regression line for yield cuts the Wr-axis below the origin indicating overdominance, which cannot be distinguished from non-allelic interaction at this stage. Dominant alleles for yield and height are present in the Indian parents while the exotics have recessive alleles for these characters. On the other hand, the situation is reversed for flowering time with the exotics having mostly dominant alleles. The Wr+Vr values are the highest for grain yield for IS. 2031 which is a selected exotic variety for yield; for days to flower for G.M. 1–5 and for plant height for *Kafir* 60. These parents, therefore, appear to carry highest number of dominant genes for these characters.



ESTIMATES OF COMPONENTS OF GENETIC VARIATION

The estimates of the components of variation with their standard errors are presented in Table 7. Certain other statistics computed from these estimates are also presented therein. The additive component for yield is of a comparatively low magnitude and is not statistically significant. For plant height and flowering, the additive component is of sizeable magnitude and statistically significant. The average degree of dominance $(\hat{H}_1/\hat{D})^{0\cdot 5}$ for yield is in the range of overdominance; for flowering and plant height it is partially dominant.

The proportion of genes with positive and negative effects in the parents for yield and plant height appear to be similar since H_1 and H_2 are of the same magnitude and $\hat{H}_2/4\hat{H}$ is 0·25 and 0·22 respectively. On the other hand,

TABLE 6

Estimates of components of variance in respect of parents and hybrids

Sl. No.	Character	Kharif				Rabi			
		$\hat{\sigma}^2$m	$\hat{\sigma}^2$h	$\hat{\sigma}^2$w	$\hat{\sigma}^2$e	$\hat{\sigma}^2$m	$\hat{\sigma}^2$h	$\hat{\sigma}^2$w	$\hat{\sigma}^2$e
1.	Grain yield	1224·89*	93·37	144·91**	36·35**	28·21	28·30	120·67**	16·64**
2.	Panicle length	11·54*	4·02*	4·28**	0·96**	20·23*	7·73*	4·38**	1·80**
3.	No. of secondaries	97·40*	71·19*	70·15**	11·41**	93·77*	98·36*	79·96**	14·65**
4.	Mean length of secondary	1·16*	1·00*	0·79**	0·21**	0·97*	0·33	0·85**	0·24**
5.	Mean no. of tertiaries	1·75**	0·08**	0·67**	0·29**	1·75**	−0·44**	1·77**	1·31**
6.	Weight of 100 seeds	0·36**	0·15	0·01	0·36**	0·62**	0·23**	0·08**	0·05**
7.	Plant height	11552·77*	139107·38*	298·22**	135·99**	3516·57**	2714·85**	117·39**	53·14**
8.	Days to flower	519·50**	262·77*	3·02**	2·31**				

m—males; h—hybrids; w—sampling error; e—experimental error
*Significant at 5% **Significant at 1%

TABLE 6

Estimates of specific combining ability effects

Hybrid		Diallel set 1			Diallel set 2		
		Grain yield	Days to flower	Plant height	Grain yield	Days to flower	Plant height
IS 84	× IS 3691	+4·53	+14·15**	+40·05**	—	—	—
,,	× IS 2031	-5·16	-9·78**	+4·27	—	—	—
IS 3691	× IS 2031	+17·53**	+10·73**	+21·39**	—	—	—
,,	× IS 3922	—	—	—	+23·41**	+11·11**	+11·23**
Kafir 60	× IS 84	-7·85**	-1·53**	-12·62**	—	—	—
,,	× IS 3691	+42·34**	+15·48**	+10·50**	+37·01**	+16·10**	+10·48**
,,	× IS 2031	-15·95**	-8·64**	-28·28**	—	—	—
,,	× IS 3922	—	—	—	-10·98**	-8·91**	-22·89**
IS 84	× Karad Local	+35·77**	-0·59**	-1·84	—	—	—
,,	× Nandyal	+26·41**	+1·47**	+19·94**	—	—	—
,,	× G.M. 1–5	+29·24**	-2·98**	-11·73**	—	—	—
IS 3691	× Karad Local	+3·55	+1·20**	+27·27**	+6·18	+2·35**	+32·61**
,,	× Nandyal	+7·40*	-2·02**	-3·95	+8·98*	-0·11	+7·23**
,,	× G.M. 1–5	+13·63**	-4·47**	+30·38**	—	—	—
,,	× Aispuri	—	—	—	+23·22**	+0·68**	+39·23**
IS 2031	× Karad Local	+39·57**	-5·10**	+22·49**	—	—	—
,,	× Nandyal	+37·71**	-3·74**	+17·27**	—	—	—
,,	G.M. 1–5	+0·24	-3·69**	-6·40	—	—	—
Kafir 60	× Karad Local	-5·72	-1·95**	+57·60**	-3·51	-2·68**	+50·48**
,,	× Nandyal	+21·92**	-1·10**	+39·08**	+23·09**	-1·04**	+34·11
,,	× G.M. 1–5	+3·95	+0·56**	+29·72**	—	—	—
,,	× Aispuri	—	—	—	+4·53	+1·75**	+45·11**

TABLE 6 (Contd.)

Hybrid	Diallel set 1			Diallel set 2		
	Grain yield	Days to flower	Plant height	Grain yield	Days to flower	Plant height
IS 3922 × Karad Local	—	—	—	+50·39**	−1·26**	+16·23**
,, × Nandyal	—	—	—	+12·90**	−3·03**	+23·86**
,, × Aispuri	—	—	—	+1·23	−2·74**	+39·86**
Karad Local × Nandyal	−10·37**	+1·65**	−3·84	−1·23	+2·21**	+0·23
,, G.M. 1–5	−6·73	+0·80**	−10·51**	—	—	—
,, × Aispuri	—	—	—	−16·19**	−4·20**	−4·77
Nandyal × G.M. 1–5	−8·19*	+1·56**	+1·27	—	—	—
,, × Aispuri	—	—	—	+14·91**	−2·96**	−19·14**
S.E. $\hat{S}_{(ij)} \pm$	3·59	0·20	3·30	3·69	0·25	3·56

*Significant at 5% **Significant at 1%

genes for flowering are asymmetrically distributed. The proportion of dominant to recessive genes in the parents for yield is less than unity while for flowering it is much greater than unity. The distribution of dominant and recessive genes governing these two characters is asymmetric and in opposite directions. For plant height the distribution is symmetric.

TABLE 7

Estimates of components of variation from a 7×7 diallel (set 1) cross

Parameter estimated	Grain yield	Days to flower	Plant height
$\hat{D}$	265·74 ±126·40	570·46** ±38·19	5929·98** ±290·25
$\hat{F}$	–100·89 ±303·22	302·67* ±91·62	299·82 ±696·30
$\hat{H}_1$	1972·04** ±304·30	292·16* ±91·95	2410·99* ±698·76
$\hat{H}_2$	1935·16** ±268·13	78·94 ±81·02	2138·62* ±615·70
$\hat{h}^2$	5223·97** ±180·08	–2·24 ±54·41	5839·12** ±413·53
$\hat{E}$	232·32** ±44·69	5·45 ±13·50	436·35** ±102·63
$(\hat{H}_1/\hat{D})^{\frac{1}{2}}$	2·72	0·72	0·64
$(\hat{H}_2/4\hat{H}_1)$	0·25	0·07	0·22
$\frac{(4\hat{D}\hat{H}_1)^{\frac{1}{2}} + \hat{F}}{(4\hat{D}\hat{H}_1)^{\frac{1}{2}} - \hat{F}}$	0·87	2·18	1·08
$\hat{h}^2/\hat{H}_2$	2·70	–0·03	2·73
r (between Wr + Vr and Yr)	–0·6217	+0·9480**	–0·8316*

*Significant at 5% **Significant at 1%

The values of $\hat{h}^2/\hat{H}_2$ is of the same magnitude for yield and plant height indicating a similarity of gene action between these characters. The value for flowering time is nearly equal to zero indicating that the number of genes with dominance are in a very low proportion, as compared to the total number of loci involved for this character.

The co-efficients of correlation (r) between parental order of dominance (Wr+Vr) and the parental measurements (Yr) for yield and plant height is not significant but highly significant for flowering time. This is indicative that the negative genes are dominant for yield and height while positive genes are dominant for flowering.

Discussion

Earlier studies revealed that the msCK60×Indian combinations were not as heterotic as msCK60×exotic combinations (Rao, 1970). However, the present study has shown that crosses involving diverse exotic females and Indian pollinators are as heterotic as exotic×exotic combinations. The only exception is the exotic ×exotic (msCK60×IS. 3691) CSH-2, which is the most heterotic cross recorded. It is again to be noted that pollinator parents of Indian origin for the most heterotic crosses were furnished by *Karads* and *Nandyals* which have an elongated panicle as against the compact types which were not as heterotic. The exotic parents involved in the study were also characterised by similar panicle morphology. The Indian×Indian varieties were relatively less heterotic. The range of yields and heterotic responses obtained from this study are summarized below:

TABLE 8

Range of yield levels and heterotic responses from diallel crosses

Character		Exotic × Exotic	Exotic × Indian	Indian × Indian
1. Grain yield (Gm./plant)	Mean	58 to 113	81 to 149	91 to 125
	Heterosis	3 to 68	-9 to 45	-9 to 21
2. Days to flower	Mean	62 to 88	82 to 93	97 to 109
	Heterosis	0 to 50	-1 to 37	-4 to -1
3. Plant height (Cm.)	Mean	116 to 181	180 to 298	253 to 305
	Heterosis	10 to 57	32 to 85	6 to 22

What is of greater importance at a practical level than the magnitude of heterosis is the range of yield levels in these three groups of crosses. The highest yields on individual plant basis are recorded for some of the exotic × Indian combinations, IS. 3922 × *Karad Local*, IS. 2031 × *Karad Local*, IS. 2031 × *Nandyal*, and IS. 84 × *Karad Local*. The yield levels of these crosses are one-and-half to two times that of the released hybrids CSH-1 and CSH-2. The answer to a major genetic improvement in yield performance of future hybrids lies in developing these known combinations into males and females and correcting the drawback of excessive height of the Indian parents (Rao, Rana and Tripathi, 1968). Since the above evidence has indicated substantial heterosis in some cross combinations, it will be of interest to examine its components in relation to combining ability for a rational choice of parents in a hybridization programme.

Recent studies on diallel analysis of combining ability in yield heterosis in sorghum (Niehaus and Pickett, 1966; Chiang and Smith, 1967; and Liang, 1967) are in general agreement indicating that the general combining ability effects are predominant for yield and yield components, such as seeds per head, heads per row and also days to flower. Since general combining ability is attributable to additive gene action and additive × additive epistasis, which is theoretically fixable, it appears that conventional breeding methods would be rewarding and should receive greater emphasis than at present. It may be noted here that the female parents involved in the above studies were essentially *kafirs* or *kafir-milo* derivatives and did not provide for adequate diversity. Even the choice of male parents was restricted to mostly *kafirs*, *feteritas* and their derivatives.

Since the nature of gene action is known to vary with the genetic architecture of the parental populations involved, the diallel set of crosses involved in the present study were built up from *kafir*, *hegari* and *feterita* types of U.S. and the *subglabrascens* and *cernuum* types which are cultivated in India for grain purposes. Results of combining ability analysis from such a mating system indicated that the magnitude of the variances due to general and specific combining ability for yield are equally important (σ^2 gca=990, σ^2 sca=817 in one case, and σ^2 gca=750, σ^2 sca=825 in the other) suggesting that non-additive genetic variances also play a significant role in yield heterosis. The results of Malm (1968) involving diverse germ plasm also indicate the importance of both general and specific effects in yield heterosis. However, it should be noted that the g × e interaction was not taken into account in the present study. The gene action for days to flower and plant height which are major components of wide adaptation, was essentially additive.

Graphic analysis and the estimates of the components of genetic variation are also in general agreement with the combining ability analysis. The regression line for yield cuts the Wr axis below the origin indicating overdominance. But, this cannot be distinguished from the effect of non-allelic interactions as observed in the study as in maize, tobacco, flax and *Galeiopsis* (Jinks, 1955). The apparent overdominance could, therefore, be spurious and this brings to the fore the importance of non-allelic interactions in influencing yield.

An examination of the general combining ability effects reveals *kafir* 60 to be a poor general combiner. This has been one of the widely used females in the hybrid breeding programmes and the present evidence is contrary to the earlier findings and the results could be attributed to the diversity of parents involved in the present study. Among exotics the improved selections IS. 2031 and IS. 3922 developed recently give not only higher yields, but are also good general combiners. These selections are presently undergoing yield evaluation all over the country (Rao *et al.*, 1969). The Indian varieties on the other hand, do not show such wide differences in their general combining ability.

The specific combining ability effects for the crosses *kafir* 60 × IS. 3691 (CSH-2), IS. 84 × *Karad Local*, IS. 2031 × *Nandyal*, IS. 3922 × *Karad Local* are very high and they are also the highest yielders indicating that these combinations are eminently suited to a hybrid programme. The crosses IS. 2031 × *G.M. 1–5* and IS. 3922 × *Aispuri* have low specific effects while the parents are desirable from the point of view of general combining ability. These crosses could be expected to yield promising material in segregating generations combining the desirable features of the exotic and Indian parents.

The graphic analysis further reveals that the distribution of dominant and recessive alleles governing yield and flowering is asymmetric and is in opposite directions. The Indian varieties possess the dominant alleles for yield and plant height, while the exotics have the dominant alleles for flowering. From a breeding point of view, it is necesary to bring together the recessive alleles for height together with the dominant alleles for flowering and yield in a homozygous condition. The crosses which exhibited high general and low specific effects may provide the basic material for realising such homozygous segregates.

Summary

An examination of the mean values and heterotic response of crosses involving a wide range of parents of both exotic and Indian origin from a diallel mating system reveal that some exotic × Indian combinations were at a higher yield level in spite of comparable heterosis to exotic × exotic combinations. This was not possible when msCK60 was used as the female parent. Combinations which yield one-and-half to two times the present commercial hybrids have been identified. The development of the parents of these known combinations into males and females can result in future hybrids representing marked increases of yield over the first hybrids.

Results of analysis of combining ability from a diallel mating system involving exotic and Indian parents indicate that both general and specific combining ability variances for yield are of equal magnitude, thereby indicating the importance of non-allelic interactions in influencing yield. The gene action for days to flower and plant height was essentially additive. Graphic analysis and estimates of components of genetic variation are also in general agreement with the combining ability analysis.

Crosses with high specific and low general and high general and low specific effects have been identified, which could be useful for hybrid and conventional breeding methods respectively. Performance of line *per se* together with its nature of combining ability is expected to furnish the guide line in the choice of parents.

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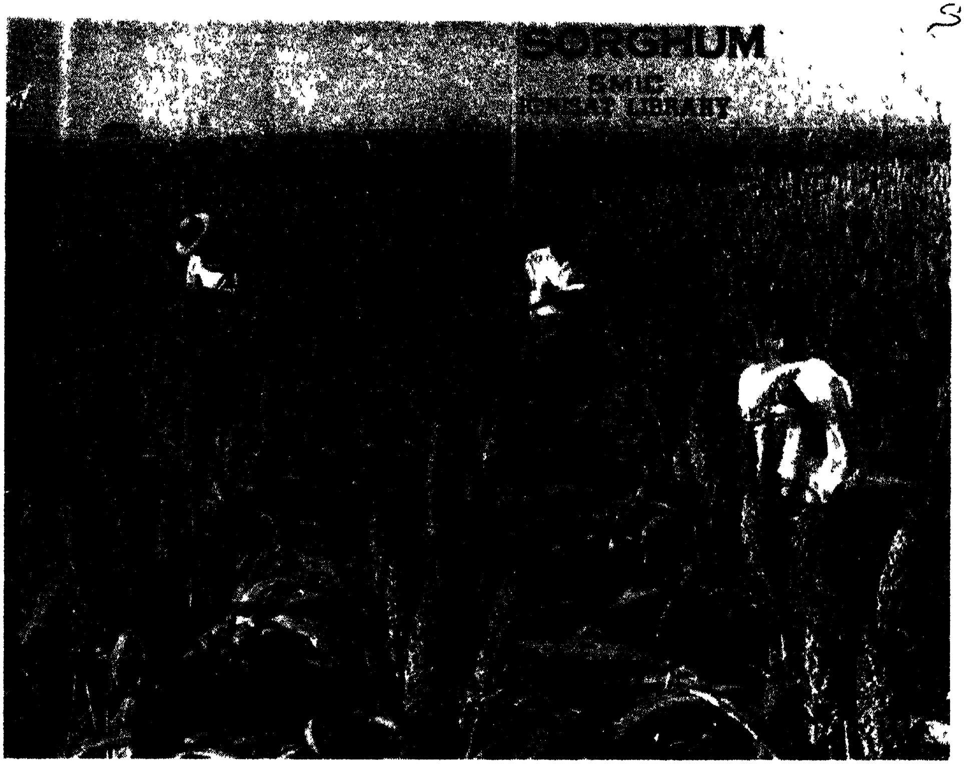

Newer varieties of sorghum under development

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SORGHUM CULTURE

DRY TO IRRIGATED FARMING

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SORGHUMS in India are almost wholly grown as rain-fed crops and the yields have remained a gamble with the fluctuating monsoons. Cultivation of tall, long duration varieties over a vast proportion of the area, the yields of which were most affected in years of drought, almost the total absence of the practice of fertilizer application and the tradition of growing sorghums only under low populations have been the major limiting factors in realising higher yields. The availability of over a hundred improved strains, which were also tall and late and were essentially pure line selections from local varieties, did not influence the yield levels since they suffered from the same genetic as well as management limitations. The recently released hybrids and high-yielding varieties are acting as catalysts not only in elevating the chronically low yield levels of this rain-fed crop but also helping to stabilise the yield levels in spite of fluctuating rains. The role of the recent developments in elevating and stabilising yield levels of sorghum under rain-fed farming as well as under irrigation is examined.

Variety Recommendations

The development and release of the first sorghum hybrids, Coordinated Sorghum Hybrids 1 and 2 (CSH-1 and CSH-2) during 1964 and 1965 respectively and the release of a true breeding variety Swarna in 1968 provided the material basis for the high-yielding varieties programme pertaining to sorghum. With increased yields of the order of 60-100 per cent over the available improved varieties and maximum yields of 6000-7000 kg/ha under optimal conditions of cultivation, the first hybrids marked a genetic break-through in the yield levels.

CSH-1. The first commercial hybrid, CSH-1 was released for general cultivation in the early and medium duration *kharif* (July-October) areas and the irrigated summer tracts (February-May) all over the country during 1964. This high-yielding hybrid is the product of hybridization between male sterile Combine Kafir 60 and a yellow endosperm *feterita* (IS 84). The hybrid is dwarf (120-140 cm), early, matures in 90-100 days and gives an average 60-80 per cent increase in grain yields over the improved local varieties.

Even in years like 1965 and 1966 when vast areas were drought hit, CSH-1 yielded an average yield of 2500 kg/ha. During the six year period CSH-1 was tried in yield trials, national demonstrations, farmers' fields and also in scarcity rainfall areas like the Bellary District of Mysore State. In no year the yields averaged less than 2000 kg/ha. This is a considerable improvement over the national average of only about 450-500 kg/ha. Under optimal conditions of moisture and fertility grain yields of the order of 8000 kg/ha were recorded.

CSH-2. The second hybrid CSH-2 released during 1965 is suitable for vast mid-late areas during the *kharif* season. CSH-2 has been developed by crossing male sterile Combine Kafir 60 with a yellow endosperm *hegari* (IS 3691). It has a 70-90 per cent superiority with respect to grain yields while the forage yields are almost equal to the locals. Unlike CSH-1, this hybrid is medium late (150-200 cm) and matures in 110-120 days.

Swarna. This is the first high-yielding variety that equals the commercial hybrid CSH-1 in yield levels besides being comparable to it in height and maturity. Swarna has a dwarf kafir and a tall late yellow endosperm African type in its parentage. The comparative performance of the hybrid and the variety is summarised below.

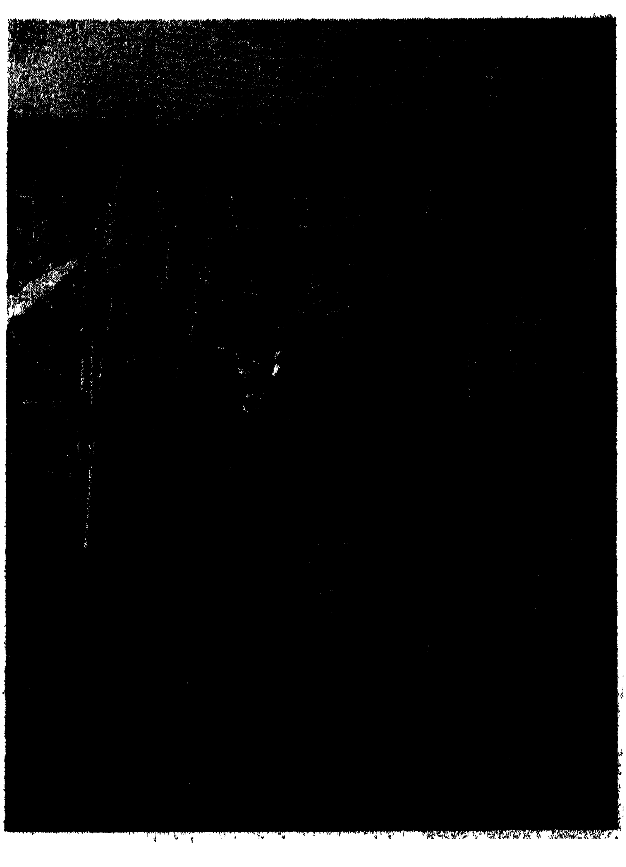
COMPARATIVE PERFORMANCE OF CSH-1 AND SWARNA

Variety/ hybrid	Grain yield (kg/ha)		% of CSH-1	
	Summer 1967	*Kharif* 1967	Summer 1967	*Kharif* 1967
Swarna	3850	3745	99 6	101 7
CSH-1	3864	3682	100 0	100 0
Local	2836	2358	73 4	64.0

The plants of Swarna are medium dwarf (120-150 cm) and mature in 110 days. Swarna is particularly characterised by an erect leaf habit. Unlike CSH-1, it exhibited a differential response to population levels. Yields of Swarna were superior to the hybrid under close spacing and thick populations possibly due to its *erectophile* habit. Unlike the hybrids, where the farmer has to procure hybrid seed every year, he can save his seed of Swarna and use again. Swarna is ideal for cultivation in areas where growing conditions are favourable.

Certified seed. As a rule it is better to purchase certified seed every year. Particularly, seeds of hybrids need to be obtained each year since genetic breakdown occurs during the second year. Where certified seed is not available, seed

Swarna—the high-yielding variety that equals hybrids



should be treated with a fungicide. Sulphur, Agrosan GN, Thiram, Captan, etc. are some of the fungicides commonly available. Treatment of the seed with the chemical carbofuran (Furadan) will control shoot fly, but the chemical is not presently available in India.

Seed-bed preparation. A good seed-bed needs to be prepared to destroy weeds, conserve moisture, warm the soil and provide favourable soil conditions for germination and to obtain a good stand. Whatever may be the equipment used in preparing the seed-bed, it is essential to see that the seed-bed is firm, mellow and moist.

Fertilizers

Grain sorghum is a heavy feeder of nitrogen; it also responds to phosphatic fertilizers in many soils; potash deficiencies are rarely came across. The following fertilizer recommendations generally hold good in several instances, but it is always better to have the recommendation based on soil analysis.

N (a) Apply 100-120 kg N/ha in areas of assured high rainfall (400-500 mm/season or more). This should be applied one half at sowing time and one half at about 'knee-high' stage (about 30 days after sowing).

(b) Apply 80 kg N/ha in low rainfall areas. This should be applied as 40 kg N/ha at planting. The remaining 40 kg N/ha should be side-dressed at about 'knee-high' stage, if there is sufficient rainfall. If the rainfall is insufficient, no additional application of N should be made.

A soil test information be used wherever possible. If no soil test information is available, apply 60 kg P_2O_5/ha in high rainfall areas, and 40 kg P_2O_5/ha in low rainfall areas.

K_2O Research information indicates that response to potassium is very infrequent. Therefore, no potassium should be applied except in those soil areas known to be deficient in potassium. A soil test is a good indicator of potassium status of soils

Placement. When fertilizers are applied in direct contact with sorghum seeds, injury to germination frequently occurs The best placement of fertilizer for sorghums is in a band along the row, two inches to the side and at least two inches deep. This is best done with a seed cum fertilizer seed drill.

Date of planting. Jowar should be planted as soon as possible after the rains begin usually during the first fortnight of July. Late *kharif* plantings generally suffer heavy shoot fly attack. The planting dates with local varieties in different zones generally coincide with the shoot fly free periods. As a rule it is preferable to be well within these planting dates. Planting from late September to early October for *rabi* and late January to early February for summer seasons could be generally practised.

Rate of planting. Available data indicate that about 150,000 plants/ha are sufficient for maximum yields. This is obtained by spacing plants 12 cm apart in rows which are 45 cm apart. Swarna responds to heavier populations than CSH-1. Swarna is erect-leaved.

Sorghum seeds are small and should not be planted deep. The depth of planting should not exceed 1 to 2 inches.

Cultivation. The primary reason for cultivating sorghums is to control weeds. Cultivations should not be deep as this injures the roots of the feeder roots which are near the soil surface.

Irrigation. Jowar is drought-tolerant, but responds well to favourable moisture conditions. With optimum moisture, fertility and population levels yields of the order of 8000-9000 kg/ha are obtained. For maximum yields, a plant should never show drought stress. A very heavy pre-planting irrigation to wet the sub-soil is most useful. The plant requires most water at boot leaf and heading stages and watering before these periods is essential. When fertilizers are applied, it is necessary to irrigate so that the nutrients are available to the young growing plants. After the dough stage, application of water is not necessary. Irrigation water is best applied through graded furrows.

Control of Insect Pests

Shoot-fly, stem-borer and midge are the serious pests of sorghum; earhead bug also causes heavy damage in some years in South India. The following control measures will be useful.

Shoot-fly. Where shoot-fly is a problem use 10 per cent phorate granules at 1.5 gm/metre row or 5 per cent disulfoton (Thiodemeton) at 3.0 gm/metre row in seed furrows at the time of sowing. If phorate and disulfoton are not available, some control may be obtained in early *kharif* season by spraying the crop with carbaryl (50% W.P.), 2 kg or endrin (20% E.C.) 1 litre, or a mixture of endrin (20% E.C.) 375 cc and methyl demeton (25% E.C.) 250 cc in 450 to 500 litres of water per hectare. The crop should be sprayed twice, the first spray after 3 to 5 days of emergence of seedlings and the second 5 to 7 days after the first spray. Addition of a wetting agent in the sprays may give better results.

The shoot-fly damage has, generally been observed in late sown *kharif* in all the sorghum-growing areas, normally sown crops in *rabi* areas and monsoon crop in Tamil Nadu. Where two crops of sorghum are taken in a year the damage is likely to be heavy in both the crops.

Stem-borer

(i) Uprooting the stubbles and burning them will reduce the possibilities of infestation.

(ii) Apply granules of 1 per cent lindane, 10 per cent malathion, 4 per cent carbaryl or 4 per cent endosulfan two to three times at 10 days interval, starting 20 days after emergence of seedlings. The rate of application for the three treatments should be 8, 12 and 15 kg/ha.

(iii) Alternatively the crop may be treated with spray formulations of the above insecticides at the same dose of active ingredients in 500 to 600 litres of water per hectare. Wherever mite is a problem, add 2 kg of wettable sulphur. Both the granules and the sprays should be directed toward the leaf whorls.

For midge control spray the ears before flowering (about three days after panicle emergence) with carbaryl (50% W.P.) 3 kg or lindane (20% E.C.) 1.25 litre or endosulfan (30% E.C.) 1 litre in 500 to 600 litres of water per hectare. (In case of continued infestation, repeat spraying after 5 to 7 days). A 10 per cent carbaryl dust may also be used for midge control applied at the rate of 20 kg/ha.

For earhead bug and caterpillars at the milky stage, treat the ears with 10 per cent carbaryl dust with sulphur (18 :2) or 1.3 per cent lindane dust at 20 kg/ha.

Note. 1. The quantity of spray mentioned is for bucket type sprayers, if back-packed mist blower is to be used the quantity of water required will be about one-third, the quantity of insecticide added per hectare should be the same.

2. Proper precautions should be taken in using these poisonous chemicals.

Disease Control

Seed treatment. (a) Treat seeds with Thiram, at 2 gm per kilogram of seed. When certified seeds are obtained, the seeds are already treated.

Field spray. Diseases are not generally serious in sorghum, but whenever it is a problem the following control measures are available.

(a) Spray from 45 days with zineb or wettable sulphur at 1 to 1½ kg/ha. Repeat with an interval of 10 to 15 days twice to control leaf diseases like rust, leaf blight, zonate leaf spot, etc.

(b) Wherever, sugary disease is a problem, spray with ziram 0.15 per cent (about 1 kg/ha) at boot leaf stage, repeating 2 to 3 times at 5 to 6 day interval.

(c) Dust the ears just after emergence with a mixture of BHC plus DDT 10 per cent (1:1) or carbaryl (sevin) 10 per cent plus sulphur at 10 to 15 kg/ha. This will control the insect carriers of sugary disease as well as control the midge.

Field sanitation and adjustment of sowing date.

(a) Remove and burn all the plants showing downy mildew infection or whole head smut ears and also ears showing honey dew stage.

(b) Adjust sowing date so that the flowering period does not coincide with cool, moist weather.

Harvesting and storing. The moisture content of sorghum should not be more than 12 per cent when it is placed in storage. This is important if the grain is to remain in storage for several months. Storage is not normally difficult in the dry areas, but is difficult in the humid areas. The storage bins should be cleaned and sprayed with a satisfactory insecticide. Fumigation will also keep the insects under check.

Multiple cropping. Most improved varieties of sorghum are late and are grown as single crops during *kharif* or *rabi*. The availability of relatively early and photoinsensitive hybrids and varieties like CSH-1 and Swarna enable practise of several multiple-cropping patterns. Rice could be followed by sorghum in late January or early February. Sorghum hybrids and varieties also stand ratooning. The growing of early hybrids in *kharif* could be followed by a winter crop. While the new hybrids and varieties are tailored to fit into multiple cropping patterns under irrigation, they could also enable conversion of the traditional long duration *kharif* and *rabi jowar* tracts of Maharashtra, Mysore, Andhra Pradesh, Madhya Pradesh and Gujarat and Rajasthan, etc. into two crop areas per year.

Conclusion. Stabilisation of yield levels of grain sorghum, which are presently at a low level of 450-500 kg/ha, is the imminent problem. With the available hybrids and varieties and adoption of the recommended package of practices, it is feasible to stabilise the average yields at 2000-2500 kg/ha under rain-fed farming. This could be done only if the recommended fertiliser and insect control measures are similarly applied. Under irrigation, average yield levels could rise up to 6000-7000 kg of grain per hectare and under exceptionally good conditions up to 9000 kg/ha. Besides, the new varieties would permit multiple cropping patterns both under irrigated and rain-fed farming.

GENETIC ANALYSIS OF SOME EXOTIC×INDIAN CROSSES IN SORGHUM

III. HETEROSIS IN RELATION TO DRY MATTER PRODUCTION AND NUTRIENT UPTAKE

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As crop yields reach a plateau detailed attention to the metabolic functions related to yield is required. The fact that a new crop variety must yield more than the variety it replaces implies that a large measure of selection for metabolic efficiency must occur. In recent years there has been increasing interest in studying differences in net photosynthesis within a species which is of obvious significance in crop improvement (Curtis, Ogren and Hageman 1969; Dornhoff and Shibles, 1970). That differential accumulation of nutrients is under partial genetic control and that this is established early in the life of the plant is also understood (Thomas, Baker and Gorsline, 1963). Sorghum hybrids involving improved Indian varieties as pollinator parents and Kafir 60 as the female did not exhibit marked heterosis (Rao, 1970a). Since crop yields are related to both total assimilation and nutrient uptake during the growing season and to the way the material acquired is partitioned between harvestable storage structures and the rest of the plant (Heslop-Harrison, 1969), an analysis of growth and nutrient uptake in heterotic and non-heterotic crosses of sorghum was undertaken. The results are presented in this paper.

MATERIALS AND METHODS

The experimental material consisted of the following hybrids and their parents.

msCK60×IS 84.—An early and heterotic hybrid released for commercial cultivation in India :SH-1.

msCK×IS 3691.—A medium duration and highly heterotic hybrid released as CSH-2.

msCK60×Aispuri and msCK 60×B.P. 53.—Medium duration hybrids whose grain yields are inte- ediate between parents.

I.S. 84.—Pollinator parent for CSH-1; a selection from yellow endosperm *feterita*.

I.S. 3691.—Pollinator parent for CSH-2; a selection from yellow endosperm *hegari*.

Aispuri and B.P. 53.—Improved Indian varieties cultivated in Western India, classified by Snowden 36) as *S. cernuum*.

Kafir B.—Fertile counterpart of the common female parent msCK60.

The hybrids and their parents were grown during the 1965 *kharif* season in a randomized complete ck design replicated four times. The plot was 10 rows 6 m. long and 75 cm. apart with a spacing of

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15 cm. between plants. The experiment was grown under adequate fertility conditions (100 N; 60 P_2O_5); cultural operations and irrigations were provided as and when necessary.

Five plants per replication were sampled at random from each of the entries at four different stages of growth, namely, 35 days after planting, at flag leaf stage, at flowering and at harvest. While taking the second and subsequent samples, widely spaced plants occurring as a result of the previous samplings were avoided. The plants were watered profusely to avoid any root damage while uprooting. The roots were carefully washed to remove the sticking soil. For determining the leaf area, the length and maximum width of all the green leaves of each plant were measured and the product of the length × breadth values for each plant were determined; the mean values for replications were calculated from the mean values of individual plants. The overall mean value was multiplied by the factor 0·747, as determined for sorghum by Stickler, Wearden and Pauli (1961).

The fresh samples were weighed and dried at 70°C in a draft-air oven to constant weight. The samples were powdered in a Wiley grinding mill. Representative samples were drawn from powdered material and dried at 105°C before taking suitable weights for analysis.

Nitrogen was estimated by the modified Kjeldahl's method. Phosphorus was determined by vandomolybdophosphoric method. Potassium was estimated by using a flame photometer (Model 52C of Perkin Elmer) using lithium as internal standard. The methods of estimation were as described by Jackson (1958).

The particulars of the hybrids and their respective parents involved in the study are detailed in Table 1.

Results

(1) Dry matter production

The data on production of total dry matter are presented in Table 2 and that for different plant parts in Table 3. Growth curves relating to the total dry matter and its rate of production are in Fig. 1.

The total dry matter production of the two heterotic hybrids, CSH-1 and CSH-2, is greater than that in their parents at all stages while the two non-heterotic hybrids msCK60 × *Aispuri* and ms CK60 × B.P. 53 were superior to their respective pollinator parents upto about 90 days only. This stage corresponded with the flowering of the male parents, *Aispuri* and B.P. 53, and from this time onwards their total dry matter was more than the corresponding hybrids; and the parental superiority was maintained till the harvest time.

The peaks for the rate of production of total dry matter generally corresponded with the period that immediately followed flowering in all cases. The slight discrepancy in case of CSH-2 could be attributed to its occasional tillering habit. IS. 3691, the parent of CSH-2 had 2·15, 1·45, 1·15 and 0·70 tillers per plant at S_1, S_2, S_3 and S_4 stages respectively while CSH-2 had 1·30, 0·90, 0·40 and 0·35 tillers per plant at these stages. The weight of the leaves increased upto flowering time in all parents except in IS. 3691. There was a general loss in leaf weight between flowering and harvest. In case of IS. 369 the increase in leaf weight after flowering could be attributed to its tillerin habit. In contrast to this, all the hybrids attained a slight increase in weigh at harvest over the weight at flowering time, indicating that there was a consis tent gain. It is also of interest to note that in heterotic hybrids the increas in leaf weights over their parents was manifest at all stages of growth, while i non-heterotic hybrids the leaf weights of male parents were superior to thos of their hybrids indicating that there was no heterosis for leaf weight. The two non-heterotic hybrids had an increased leaf area over their male parent in the seedling stage but even this advantage was lost as the growth progresse

TABLE 1

Particulars of the parents and hybrids in the study

Parent/Hybrid	Days at sampling				Plant height (cm.)				Leaf area (cm^2)			
	S_1	S_2	S_3	S_4	S_1	S_2	S_3	S_4	S_1	S_2	S_3	S_4
1. Kafir B	35	55	64	103	32	77	120	121	1775	3316	3606	2264
2. IS 84	35	60	68	110	30	96	141	138	2445	4204	4719	3244
3. IS 3691	35	52	60	100	27	64	82	84	1590	3483	2876	2237
4. Aispuri	35	82	90	140	42	311	353	337	2616	6861	7539	5155
5. B.P. 53	35	82	90	140	50	315	349	345	3146	6974	7248	4591
6. msCK60 × IS 84	35	56	65	110	39	100	154	152	2948	4514	5139	3984
7. ,, × IS 3691	35	71	80	130	39	156	185	181	2706	7168	7389	5150
8. ,, × Aispuri	35	67	75	125	57	307	350	348	3481	6609	6484	4794
9. ,, × B.P. 53	35	67	75	125	62	317	349	350	3630	7307	6782	4230
S.Em±					2·7	16·2	3·9	2·9				

*Leaf area on main plant only.
S_1=35 days after sowing; S_2=At the flag leaf stage; S_3=At 50% flowering; S_4=At harvest.

TABLE 2

Total dry weight (gm./plant) and uptake of N, P, K (mgm./plant)

Parent/Hybrid	Total dry weight				Nitrogen				Phosphorus				Potash			
	S_1	S_2	S_3	S_4	S_1	S_2	S_3	S_4	S_1	S_2	S_3	S_4	S_1	S_2	S_3	S_4
1. Kafir B	16·0	52·2	94·4	140·9	381·1	792·8	1198·7	1887·8	43·8	118·6	220·5	279·7	342·3	786·7	1174·0	1613·9
2. IS 84	18·2	67·2	108·0	152·7	396·2	914·9	1397·2	1949·4	50·4	132·2	262·2	290·5	346·3	710·3	1310·5	1403·6
3. IS 3691	17·3	62·4	91·2	148·2	401·8	1015·7	1206·0	2022·2	44·8	118·6	191·2	302·0	378·1	854·8	1410·2	1762·2
4. Aispuri	24·3	209·3	318·0	438·8	496·8	1849·6	2648·4	3700·2	57·9	309·4	480·3	587·1	602·3	1981·1	3550·2	3522·8
5. B.P. 53	28·7	223·0	283·6	442·7	576·5	2012·8	2312·2	3748·7	74·1	296·9	405·3	561·1	683·4	2606·4	4109·7	3322·7
6. msCK60 „ ×IS 84	24·6	81·1	136·0	225·5	578·0	1116·7	1594·3	2733·4	67·5	156·8	315·0	425·9	628·0	1214·3	2035·8	2122·9
7. „ ×IS 3691	25·7	215·7	242·7	383·8	613·4	2407·8	2287·8	4219·5	64·0	390·2	441·5	663·9	562·1	2171·9	3040·6	3910·1
8. „ × Aispuri	27·9	182·1	260·9	426·0	557·5	1661·4	2042·2	3547·0	70·1	241·2	370·3	555·7	685·5	1728·4	2706·2	3309·9
9. „ ×B.P. 53	31·9	201·2	252·3	419·5	621·4	1934·5	1989·3	3374·3	78·1	246·9	320·1	486·4	816·2	1854·8	2516·5	2794·4
SEm±	1·40	7·97	8·34	23·33	29·1	69·6	88·0	108·9	10·0	11·4	15·4	22·0	36·0	88·0	129·4	111·9

TABLE 3

Periodical dry weight of leaf, stem, root and ear (gm./plant)

Parent/Hybrid	Leaf				Stem				Root				Ear		
	S_1	S_2	S_3	S_4	S_1	S_2	S_3	S_4	S_1	S_2	S_3	S_4	S_2	S_3	S_4
1. Kafir B	8·2	17·3	22·6	20·4	,5·4	26·3	46·8	48·8	2·4	7·0	11·4	10·7	1·6	13·6	61·0
2. IS 84	8·4	22·8	30·6	27·0	6·0	31·2	51·9	53·3	3·8	11·5	14·3	20·4	1·7	11·2	52·0
3. IS 3691	8·5	24·0	25·9	27·4	5·9	26·7	44·5	58·5	3·0	10·1	10·8	12·0	1·6	10·1	50·4
4. Aispuri	11·5	45·1	57·9	53·6	8·8	138·2	204·9	213·9	4·0	20·4	30·8	37·4	5·7	24·5	134·0
5. B.P. 53	13·4	50·8	51·2	44·9	10·2	141·5	186·6	219·9	5·1	22·3	24·5	34·7	8·5	21·4	143·2
6. msCK60 × IS 84	11·4	26·0	29·4	31·6	8·9	40·2	73·7	75·3	4·3	12·0	16·9	25·0	2·9	16·1	93·6
7. ,, × IS 3691	12·2	66·2	61·1	63·9	9·7	124·3	141·6	156·0	3·9	21·1	22·5	29·4	4·0	17·4	134·5
8. ,, × Aispuri	12·6	37·5	41·6	43·7	9·7	121·1	176·6	251·8	5·5	20·1	25·9	37·7	3·4	17·5	92·8
9. ,, × B.P. 53	13·7	42·5	41·6	43·6	11·5	134·7	171·2	246·0	6·8	21·3	23·5	40·7	2·8	16·0	89·2
SEm±	0·48	2·00	1·58	8·21	0·61	3·90	5·41	5·95	0·43	1·44	1·22	2·11	1·73	1·04	5·04

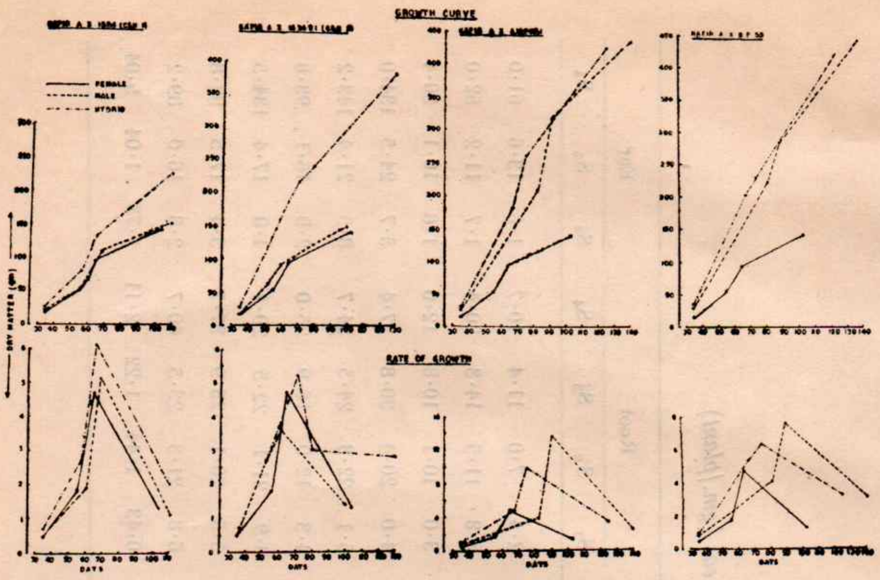

FIG. 1. Growth curves relating to the total dry matter and its rate of production.

TABLE 4

Percentage of dry weights of different plant parts at maturity in hybrids and parents

Sl. No.	Parent/Hybrid	Leaf as % of total dry weight	Stem as % of total dry weight	Root as % of total dry weight	Ear as % of total dry weight	Ear as % of shoots only
1.	Kafir B	14·5	34·6	7·6	43·3	46·9
2.	IS 84	17·7	34·9	13·4	34·1	39·3
3.	IS 3691	18·5	39·5	8·1	34·0	37·0
4.	Aispuri	12·2	48·8	8·5	30·5	33·4
5.	B.P. 53	10·1	49·7	7·8	32·4	35·0
6.	msCK60 ×IS 84(CSH-1)	14·0	33·4	11·1	41·5	46·7
7.	,, ×IS 3691 (CSH-2)	16·7	40·7	7·7	35·0	38·0
8.	,, × Aispuri	10·3	59·1	8·9	21·8	23·9
9.	,, × B.P. 53	10·4	58·6	9·7	21·3	23·5

The weight of the stalks follows the same pattern with increased weights over their parents for heterotic hybrids at all stages, whereas the non-heterotic hybrids are superior to the pollinator parents only in the early stages of growth. Subsequently, the pollinator parents attained increased weights in comparison with their hybrids. The root weights also followed a similar pattern.

There was marked heterosis for ear weights in heterotic crosses while the two non-heterotic hybrids were inferior to their pollinator parents.

The weights of leaf, stem, root and ear at harvest expressed as a percentage of the total dry weight is presented in Table 4. The exotic parents and their hybrids are characterised by relatively high leaf weights. The Indian parents and the hybrids with them, on the other hand, have relatively low leaf percentages and high percentage of stem. The harvest index expressed as ear/shoot ratio is highest for *kafir* B and CSH-1 and lowest for the non-heterotic hybrids with Indian parents.

(2) NITROGEN ACCUMULATION

The accumulation of nitrogen in the entire plant is given in Table 2, and its uptake by the different plant parts, leaf, stem and ear in Table 5.

The accumulation of nitrogen in the parents and hybrids followed the general pattern of the growth curves (Fig. 2). The rate of accumulation in case of the two non-heterotic hybrids and the heterotic CSH-1 is intermediate between that of the parents. But in case of CSH-2, which is the most heterotic hybrid, the rate of uptake at the peak period exceeds that in the superior parent. It is only in the case of this hybrid that there are two peak periods of uptake which can be attributed, at least in part, to its tillering habit. The rate of uptake of N between flowering and harvest is also considerable for this hybrid. The fall in the uptake during the 70–80 day-period for this hybrid may be attributed to sampling errors, consequent on irregular tillering habit. It is also interesting to note that msCK60, the common female parent is characterised by higher rates of uptake of N in comparison to all the pollinator parents except I.S. 84, the male parent of CSH-1.

The accumulation of nitrogen in the leaf during the first 35 days is more in all hybrids indicating seedling heterosis for this character. From this stage onwards till the flag leaf emerges, the leaf nitrogen in heterotic hybrids is considerably more than in their parents, whereas the hybrids tend to approach the high parent in the non-heterotic crosses. However, at flowering, the accumulation of N in the two non-heterotic hybrids is much less than in their pollinator parents, while in case of heterotic hybrids the superiority in total nitrogen is maintained throughout the life of the plants. At harvest stage, the non-heterotic hybrids have slightly more nitrogen in their leaves than their pollinator parents. This could be attributed to the relatively quicker drying of leaves at maturity in Indian varieties.

In the stem, heterosis for nitrogen accumulation during the first 35 days is common to all hybrids and the heterotic hybrids maintain the superiority at all stages over their parents. The non-heterotic hybrids lose the advantage between 35 days and flowering. But between flowering and harvest there is increased accumulation of N in the stem in comparison with their pollinator parents indicating that the N does not move to the grain.

In case of ear, nitrogen accumulation is more in heterotic hybrids than in their parents, whereas the non-heterotic hybrids have lower amounts in comparison to their pollinator parents at all stages.

The percentage of N in the different plant parts shows marked varietal differences (Table 6). In general, the per cent. of leaf nitrogen is highest in *kafir*, the common female. The exotic parents have a generally higher percentage of N in leaf, stem and grain in comparison with the tall Indian varieties. The per cent of N in the hybrid tissues is intermediate and within parental limits. The only exception is CSH-2, the most heterotic hybrid, which shows the highest per cent of N in leaf, higher than the superior parent during the first 35 days of growth, but this superiority is not maintained during subsequent stages of growth.

The percentage of N in the stem is less than in the leaf, but the pattern is more or less similar to leaf N. There was no marked heterosis at any stage. The ear nitrogen also follows the same course as the leaf and stem.

(3) PHOSPHORUS ACCUMULATION

The total uptake of P (Table 2) as well as its rate of uptake (Fig. 3) follow the general pattern of the growth curve and nitrogen uptake. The amount of P in the plant at all stages, excepting the seedling stage, is within the parental limits for the non-heterotic crosses, whereas the heterotic CSH-1 and CSH-2 have greater amounts of P than their parents. Seedling heterosis was common to all cases for the amount of P. It is interesting to note that in respect of the rate of uptake, CSH-2 exceeded its superior parent for nitrogen while CSH-1 exceeded its superior parent for the rate of P uptake. CSH-1 as well as its pollinator parent IS. 84 are also characterised by a heavier root system. The rate of uptake is at its peak between the flag leaf stage and completion of flowering.

In case of the amount of P in the leaf heterotic hybrids (Table 7) are markedly superior to their parents at all stages of growth. The non-heterotic hybrids are superior to high parents ony during the early stages of growth.

The behaviour of P in the stem follows the course similar to nitrogen. In the case of non-heterotic crosses the accumulation of P is maximum in the stems at the harvest stage and is higher than the amount for the pollinator parents indicating that there is a restriction on its movement into the grain.

Regarding the ear, the heterotic hybrids have greater amounts of P than the high parents, whereas the accumulation is less than high parents for non-heterotic crosses at all three stages of study.

Varietal differences for the percentage of phosphorus are also marked, the exotics being generally characterised by higher percentages of P in their tissues at all stages, particularly in the leaves and stems. The per cent of P in grain does not exhibit major differences (Table 8). It is interesting to note the percentage of leaf P, and to a certain extent the stem P also exhibit negative heterosis in CSH-2 at all stages of growth for leaf and in most stages for stem. The per cent of P for the rest of the crosses is generally in between the parents.

TABLE 5

Uptake of nitrogen by leaf, stem and ear (mgm./plant)

Parent/Hybrid	Leaf				Stem				Ear				
												S_4	
	S_1	S_2	S_3	S_4	S_1	S_2	S_3	S_4	S_2	S_3	S_4	Grain	Chaff
1. Kafir B	254·2	466·3	560·1	434·3	126·9	267·6	435·3	297·4	58·9	203·3	1156·1	1003·8	152·3
2. IS 84	255·5	556·0	707·2	485·2	140·7	306·0	486·3	433·3	52·9	203·7	1030·9	930·6	100·3
3. IS 3691	251·5	605·8	593·7	518·5	150·3	359·8	467·0	557·9	50·1	145·4	945·7	819·0	126·7
4. Aispuri	312·5	847·8	996·3	656·5	184·3	856·0	1291·7	937·6	145·8	360·4	2106·1	1856·7	249·4
5. B.P. 53	361·2	942·8	892·5	618·2	215·3	896·8	1087·0	905·7	173·2	332·7	2224·9	2017·6	207·3
6. msCK60 × IS 84	348·7	687·8	731·5	603·7	229·3	342·1	598·4	477·2	86·8	264·4	1652·5	1492·1	160·4
7. ,, × IS 3691	381·4	1401·8	1142·4	1037·5	232·0	898·2	870·6	853·9	107·8	274·8	2328·0	2203·8	124·2
8. ,, × Aispuri	353·5	813·3	846·7	693·3	204·0	754·8	916·2	1191·6	93·3	279·3	1662·0	1509·4	152·6
9. ,, ×BP 53	377·6	926·8	878·5	682·2	243·9	888·9	861·5	1141·5	82·8	249·4	1550·6	1436·9	113·7
SEm±	16·5	51·3	38·9	35·3	16·7	31·3	47·1	33·4	8·7	18·1		76·8	12·5

TABLE 6

Percentage of nitrogen in the different plant parts at four physiological stages

Parent/Hybrid	Leaf				Stem				Ear			
											S_4	
	S_1	S_2	S_3	S_4	S_1	S_2	S_3	S_4	S_2	S_3	Grain	Chaff
1. Kafir B	3·0989	2·6931	2·4823	2·1300	2·3431	1·0302	0·9290	0·6094	3·7365	1·4942	2·0273	1·3269
2. IS 84	3·0319	2·4323	2·3076	1·7941	2·3559	0·9800	0·9363	0·8125	3·2289	1·8195	2·1249	1·2162
3. IS 3691	2·9610	2·5366	2·3004	1·8903	2·5650	1·3494	1·0471	0·9550	3·1119	1·4339	2·0326	1·2597
4. Aispuri	2·7174	1·8780	1·7183	1·2212	2·0925	0·6190	0·6302	0·4379	2·5888	1·4749	1·6831	1·0724
5. BP 53	2·7030	1·8556	1·7412	1·3731	2·1189	0·6343	0·5820	0·4116	2·0798	1·5515	1·6725	0·9286
6. msCK60 × IS 84	3·0558	2·6494	2·4932	1·9098	2·5942	0·8518	0·8134	0·6345	3·0230	1·6441	1·8756	1·1489
7. ,, × IS 3691	3·1477	2·1094	1·8726	1·6240	2·3977	0·7277	0·6122	0·5474	2·6875	1·5693	1·8572	0·7862
8. ,, × Aispuri	2·7922	2·1672	2·0377	1·5878	2·0980	0·6259	0·5181	0·4736	2·7707	1·5947	1·9904	0·8982
9. ,, BP 53	2·7518	2·2659	2·1112	1·5641	2·1272	0·6747	0·5037	0·4643	3·0428	1·5552	1·9218	0·7901

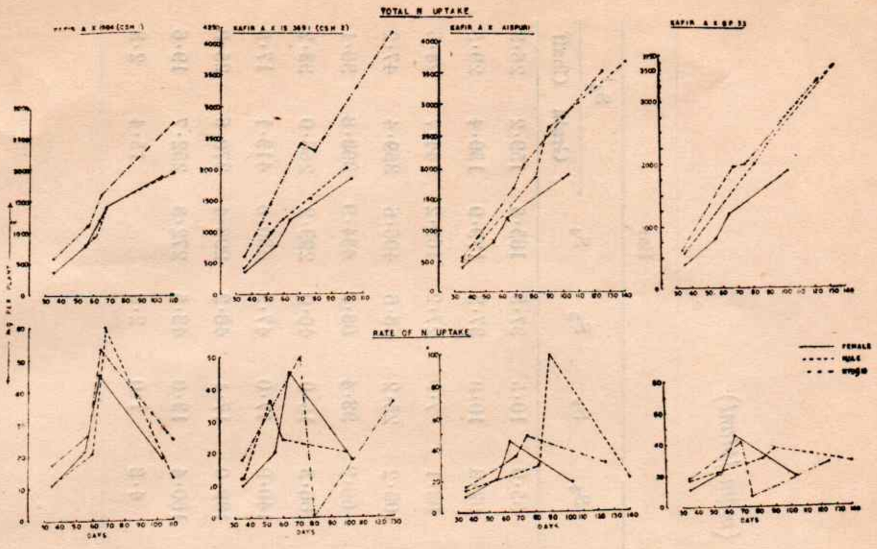

FIG. 2. Total uptake and rate of accumulation of nitrogen.

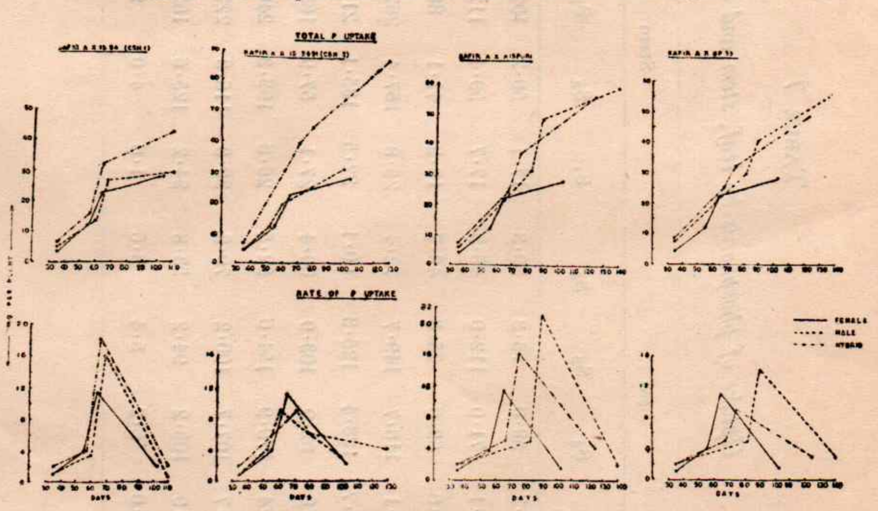

FIG. 3. Total uptake and rate of uptake of phosphorus.

(4) POTASSIUM ACCUMULATION

Data on accumulation of total K are presented in Table 2 and graphically in Fig. 4. The pattern of accumulation of K closely follows the growth curve and that of N and P up to the flowering. There are some varietal differences for uptake of K after flowering.

CSH-2, the most heterotic hybrid, has a marked uptake even after flowering. Seedling heterosis was common to all crosses for the uptake of K. The heterotic hybrids have generally more amount of K than their parents at

TABLE 7

Uptake of phosphorus by leaf, stem and ear (mgm./plant)

Parent/Hybrid	Leaf				Stem				Ear				
												S_4	
	S_1	S_2	S_3	S_4	S_1	S_2	S_3	S_4	S_2	S_3	S_4	Grain	Chaff
1. Kafir B	26·7	58·0	73·3	39·3	17·1	50·2	109·8	55·0	10·5	37·5	185·5	159·2	26·3
2. IS 84	33·1	71·0	112·0	48·3	17·7	50·4	112·9	62·3	10·8	37·3	179·9	150·4	29·5
3. IS 3691	26·6	69·6	75·8	49·7	18·2	41·1	88·2	83·1	7·9	27·2	169·2	144·7	24·5
4. Aispuri	32·1	116·7	149·7	72·4	25·8	167·4	262·0	108·2	25·2	68·6	406·6	359·4	47·2
5. B.P. 53	41·7	128·4	125·3	60·1	32·5	135·1	217·0	66·2	33·4	63·0	434·9	398·8	36·1
6. msCK60 × IS 84	40·8	82·9	103·9	60·4	27·1	57·9	165·1	66·3	16·0	46·0	299·2	266·0	33·2
7. ,, × IS 3691	37·4	179·9	154·0	92·5	26·6	193·3	240·4	140·9	17·0	47·2	430·6	413·1	17·5
8. ,, × Aispuri	39·7	107·7	100·2	70·3	30·3	116·3	222·0	189·0	17·1	48·2	296·4	270·6	25·8
9. ,, × B.P. 53	43·9	108·2	94·2	53·8	34·2	125·6	182·5	160·4	13·0	43·5	272·3	252·7	19·6
SEm±	2·0	6·2	5·4	3·6	1·6	4·0	9·3	4·8	1·0	2·9		15·4	2·3

TABLE 8

Percentage of phosphorus in plant parts at four physiological stages

Parent/Hybrid	Leaf				Stem				Ear			
	S_1	S_2	S_3	S_4	S_1	S_2	S_3	S_4	S_2	S_3	S_4	
											Grain	Chaff
1. Kafir B	0·3253	0·3357	0·3246	0·1927	0·3154	0·1910	0·2344	0·1130	0·6493	0·2755	0·3218	0·2286
2. IS 84	0·3930	0·3109	0·3658	0·1782	0·2870	0·1615	0·2176	0·1171	0·6487	0·3322	0·3438	0·3576
3. IS 3691	0·3114	0·2911	0·2934	0·1811	0·3119	0·1545	0·1979	0·1417	0·4919	0·2680	0·3594	0·2437
4. Aispuri	0·2784	0·2593	0·2587	0·1354	0·2952	0·1215	0·1279	0·0505	0·4427	0·2807	0·3247	0·2026
5. B.P. 53	0·3113	0·2529	0·2448	0·1331	0·3200	0·0955	0·1163	0·0301	0·3947	0·2940	0·3299	0·1620
6. msCK60 × IS 84	0·3542	0·3195	0·3536	0·1910	0·3067	0·1435	0·2240	0·0880	0·5509	0·2853	0·3345	0·2390
7. ,, × IS 3691	0·3079	0·2703	0·2512	0·1447	0·2749	0·1557	0·1696	0·0903	0·4242	0·2708	0·3478	0·1106
8. ,, × Aispuri	0·3148	0·2870	0·2408	0·1609	0·3114	0·0961	0·1255	0·0750	0·5052	0·2755	0·3571	0·1511
9. ,, × B.P. 53	0·3206	0·2547	0·2263	0·1233	0·2980	0·0932	0·1065	0·0653	0·4740	0·2714	0·3380	0·1360

TABLE 9

Uptake of potash by leaf, stem and ear (mgm./plant)

Parent/Hybrid	Leaf				Stem				Ear				
	S_1	S_2	S_3	S_4	S_1	S_2	S_3	S_4	S_2	S_3	S_4	S_4 Grain	S_4 Chaff
1. Kafir B	125·7	306·3	476·9	307·8	216·7	447·4	611·2	660·5	33·1	85·9	645·6	471·4	174·2
2. IS 84	124·0	359·2	610·3	393·1	222·3	312·9	628·3	411·4	38·2	71·8	599·2	475·2	124·0
3. IS 3691	148·3	398·1	553·0	432·8	229·8	428·2	733·0	735·3	28·6	124·2	594·1	380·7	213·4
4. Aispuri	231·1	555·9	1051·2	460·7	31·1	1332·0	2189·7	1794·1	93·2	309·3	1268·0	829·6	438·4
5. B.P. 53	247·7	714·1	876·9	522·5	435·7	1790·2	3032·0	1487·2	102·1	200·8	1313·0	982·7	330·3
6. msCK60 × IS 84	244·8	491·6	613·2	414·9	383·2	661·2	1230·2	822·3	61·5	192·4	885·8	690·1	195·7
7. „ × IS 3691	187·3	855·1	1029·3	794.0	374·7	1260·5	1807·6	1863·0	56·3	203·8	1253·2	944·7	308·5
8. „ × Aispuri	254·2	451·1	816·7	542·2	431·4	1218·2	1742·7	1937·7	59·2	146·9	830·0	615·9	214·1
9. „ × B.P. 53	280·4	558·1	793·6	450·2	535·8	1254·9	1591·0	1471·9	41·8	132·0	872·3	665·6	206·7
SEm±	12·2	32·6	39·4	25·5	27·0	60·2	98·8	58·7	8·8	13·2		43·1	19·5

TABLE 10

Percentage of potash in plant parts at four physiological stages

Parent/Hybrid	Leaf				Stem				Ear			
											S_4	
	S_1	S_2	S_3	S_4	S_1	S_2	S_3	S_4	S_2	S_3	Grain	Chaff
1. Kafir B	1·5313	1·7500	2·1094	1·5078	4·0000	1·7031	1·3039	1·3563	2·0625	0·6328	0·9531	1·5156
2. IS 84	1·4688	1·5781	1·9922	1·4532	3·7031	1·0000	1·2110	0·7750	2·2813	0·6407	1·0860	1·5000
3. IS 3691	1·7344	1·6563	2·1407	1·5782	3·9375	1·6094	1·6485	1·2563	1·7969	1·2266	0·9453	2·1172
4. Aispuri	2·0000	1·2344	1·8204	0·8594	4·2188	0·9688	1·0703	0·8438	1·6406	1·2657	0·7500	1·8828
5. B.P. 53	1·8438	1·4063	1·7110	1·1641	4·2969	1·2656	1·6250	0·6750	1·2188	0·9375	0·8125	1·4844
6. msCK60 × IS 84	2·1563	1·8906	2·0781	1·3125	4·3438	1·6406	1·6719	1·0938	2·1250	1·1953	0·8594	1·4063
7. ,, × IS 3691	1·5469	1·2969	1·6875	1·2422	3·8906	1·0156	1·2735	1·1938	1·4063	1·1641	0·7969	1·9532
8. ,, × Aispuri	2·0156	1·2031	1·9688	1·2422	4·4375	1·0000	0·9766	0·7688	1·7500	0·8360	0·8125	1·2578
9. ,, × B.P.	2·0469	1·3125	1·9063	1·0313	4·6719	0·9375	0·9297	0·6000	1·5313	0·8282	0·8906	1·4375

all stages, whereas the advantage is lost after flowering in non-heterotic crosses. With regard to the rate of uptake also, both CSH-1 and CSH-2 are heterotic while the hybrids with Indian parents are intermediate.

The accumulation of K in leaves, stems and ear follows the same path as that of N and P (Table 9). At harvest the non-heterotic hybrids are characterised by greater accumulation of K in their stems.

The Indian varieties have a relatively higher percentage of K in their leaves and stems at the seedling stages, whereas the percentage in exotics was higher for N and P (Table 10). But as growth progresses the percentage of K in the exotics is more than in the Indian varieties. All the hybrids except CSH-2 exhibit marked interaction for the percentage of leaf and stem K at 35 days exceeding the percentage in the superior parents. But during subsequent stages of growth the percentage of K in leaf tends to be intermediate and the percentage of stem K exhibits negative heterosis in msCK60 × Indian crosses, whereas it is intermediate for the heterotic hybrids CSH-1 and CSH-2. The percent of K in the grain of the Indian varieties is also less than in exotics whereas the hybrids do not show any marked differences.

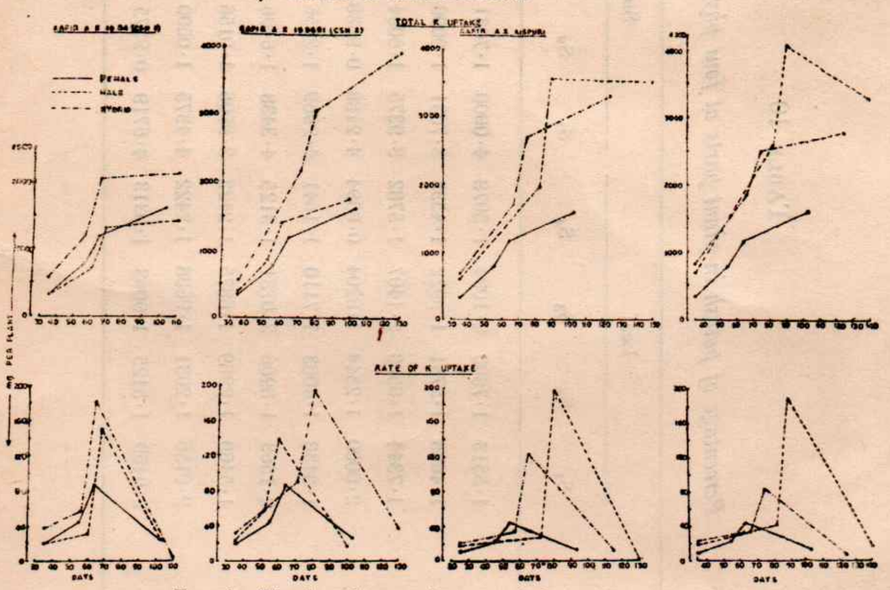

FIG. 4. Total and rate of accumulation of potassium.

DISCUSSION

While the nature of gene action in heterosis for yield and its relation to the development of suitable breeding procedures in crop plants have been extensively investigated, there appears to be relatively little effort to understand the physiological basis for the heterosis. Growth analysis provides a bridge between quantitative genetics and plant breeding and to fill this gap Nelder

(1963) emphasized the need for a changeover from the existing static models used in quantitative genetics to dynamic analyses involving growth and development. The introduction of the concepts such as NAR and LAR and recent studies by Wallace and Munger (1965, 1966) on genetic differences for both biological and economic yield, harvest index, NAR, LAR etc., are significant contributions. Limited studies on genetic control of differential accumulation of nutrients reflect yet another approach in the understanding of physiology of yield (Vose, 1963).

It has been observed that most Indian pollinator parents did not yield heterotic hybrids with the male sterile *kafir* 60 even though they are genetically quite diverse from this female. On the other hand, some of the exotics like the *feteritas* and *hegaris* yielded highly heterotic hybrids of commercial value, even though they are relatively less diverse in comparison with the pollinator parents of Indian origin (Rao, 1970a). An examination of the dry matter production in these two groups of heterotic and nonheterotic hybrids reveals that while the former exhibited heterosis for total dry matter at all stages of growth, the latter were heterotic only upto the flowering stage. Between flowering and maturity, the total as well as rate of accumulation of dry matter in the stem was maximum for the two non-heterotic hybrids whereas the heterotic hybrids showed greater accumulation in the ear (Table 11). This is in conformity with Yamada's (1959) finding in rice that greater accumulation of carbohydrates and their translocation to the panicle makes the *japonicas* more fertilizer responsive . The observations of Rao and Murty (1963) that the high rate of dry matter production and its accumulation in the ear of the winter variety of soghum M. 35-1 is responsible for its wider adaptability is also in agreement. While in cotton (Galal, Miller and Lee, 1966) the hybrids diverged from their parents with respect to dry matter production six weeks after planting the superiority is maintained throughout the growth cycle in heterotic hybrid sorghums. The early seedling vigour in all sorghum hybrids without exception confers an initial advantage over their parents. Further, in heterotic hybrids, an increase in leaf weight over their superior parents is manifested at all stages of growth while in non-heterotic hybrids, the leaf weights of the male parents were superior to those of their hybrids indicating that there is no heterosis for leaf weight. Thus, the photosynthetic capacity during the growth phase is much higher in the heterotic F_1's. Even the initial advantage in leaf area for such non-heterotic hybrids was lost as growth progressed.

The accumulation of major nutrients such as N, P and K is also in conformity with the findings on dry matter production and distribution. The movement of nutrients from vegetative parts to the grain clearly reveals that there is a great restriction on movement of all these major elements in non-heterotic hybrids (Fig. 5). Such hybrids generally lose the advantage over their superior parents between flowering and maturity. McNeal, Berg and Watson (1966) suggested, if wheat varieties which will translocate as much as 70% or more of leaf and stem nitrogen to the kernels can be found, they will be useful in

TABLE 11

Accumulation of dry matter between flowering and harvest (gm./plant)

Parent/Hybrid	Stem		Ear	
	Total	Rate/day	Total	Rate/day
1. Kafir B	2·0	0·05	47·4	1·21
2. IS 84	1·4	0·03	40·8	1·02
3. IS 3691	14·0	0·35	40·3	1·01
4. Aispuri	9·0	0·18	109·5	2·19
5. B.P. 53	33·3	0·66	121·8	2·43
6. msCK60 × IS 84	1·6	0·33	77·5	1·55
7. ,, × IS 3691	14·4	0·29	117·1	2·34
8. ,, × Aispuri	75·2	1·50	75·3	1·50
9. ,, × B.P. 53	74·8	1·50	73·2	1·46

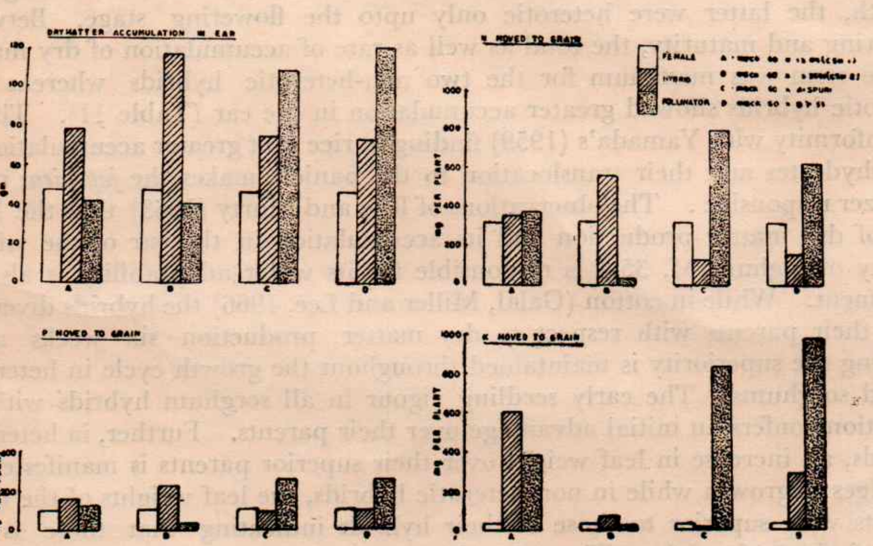

FIG. 5. Accumulation of dry matter in the ear and movement of N, P and K from vegetative parts to the ear.

breeding programmes. While the Indian sorghum varieties by themselves are comparable to the exotics in movement of nitrogen from vegetative parts to grain, the hybrids with Indian varieties exhibited a restricted movement.

These studies also bring forward marked varietal differences in the percentage of N, P and K in the tissues. The common female, *kafir* 60, was generally marked by a relatively high percentage of leaf N. The exotics, in general, exhibited higher percentages of N and P in their tissues than the Indian varieties. Even with regard to K the Indian varieties had relatively higher percentages only during the seedling stage. The percentage of N, P and K in the hybrid tissues generally tended to be intermediate between parents with some exceptions.

The total uptake of the major elements and their transfer to the grain is superior in the hybrids with marked differences even among the hybrids. It is interesting to note that the most heterotic hybrid CSH-2 is characterised by (1) a higher uptake of N over its superior parent at the peak period of absorption indicating that the rate of uptake of N is heterotic, (2) a higher percentage of N in leaf than the superior parents during the first 35 days pointing to heterosis for concentration of N in the leaf tissues during this period and (3) a negative heterosis for the percentage of leaf and stem P. In contrast, the other heterotic hybrid CSH-1 exceeds its superior parent for the rate of P uptake. The findings indicate that CSH-1 can respond better to phosphatic fertilisation while CSH-2 could benefit more from nitrogenous fertilisation. It may also be advantageous to give an additional split dose of N to CSH-2 as it is only this hybrid which exhibited a second peak for the rate of absorption of N.

Against this background of the behaviour of heterotic and non-heterotic hybrids for dry matter production and nutrient uptake, it will be worthwhile examining the genetic architecture of their parents (Rao, 1970b).

The *gca* effects for yield of *Kafir* and *Aispuri* which yielded a non-heterotic hybrid are in opposite directions. The *sca* effects of this cross are also not significant. The genetic behaviour of the other non-heterotic hybrid, msCK60 × B.P. 53, could be expected to be similar. Lack of heterosis in hybrids resulting from such parents was reflected in a restricted movement of N, P and K into the ear and their consequent accumulation in the stem rather than in the ear. Removal of this restriction, possibly by substituting *Kafir* 60 with a suitable female might enable the utilization of Indian varieties in hybrid programmes. Thus, both the genetic architecture of the parents and the degree of heterozygosity appear to be important in the efficient transfer of nutrients within a plant. From a study of components of heterosis in the two heterotic hybrids CSH-1 and CHS-2, Rao and Murty (1970) stated that heterosis for yield in CSH-1 was the result of additive and additive × additive components while in CSH-2 the dominance and dominance × dominance components were effective. This appears to have resulted in different developmental mechanisms namely superior capacity for rate of nitrogen accumulation and transfer of energy in CSH-2 and similar superior capacity for phosphorus in CSH-1.

Summary

The accumulation of dry matter in relation to uptake of N, P and K was examined in two heterotic and two nonheterotic sorghum hybrids and their parents. The nonheterotic hybrids were superior to their parents in dry matter production upto flowering only. Later the accumulation was mostly in the stem resulting in low economic yields. The accumulation of N, P and K also

followed the pattern of the dry matter and there appeared to be considerable restriction on the movement of nutrients from vegetative parts to the grain. On the other hand, in the heterotic hybrids CSH-1 and CSH-2, the transfer was more efficient; an increase in leaf weights over their parents at all stages of growth and heterosis for total uptake of the major nutrients N, P and K and rate of uptake of N or P in some cases was found.

Genetic differences for the percentage of N, P and K in plant tissues of exotic and Indian varieties were observed. The exotics were characterised by higher percentages and the hybrids were generally intermediate with some exceptions. Positive heterosis for percentage of N in early stages of growth in CSH-2 and negative heterosis for percentage of P in the same hybrid were recorded.

The possible relationship between the combining ability effects of the parents and their metabolic behaviour has been examined. The differences in the nature of gene action seem to be reflected in the developmental mechanisms, more particularly, as superior capacity for rate of nitrogen accumulation and transfer in CSH-2 and similar superior capacity for the rate of phosphorus uptake in CSH-1.

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GENETIC ANALYSIS OF SOME EXOTIC×INDIAN CROSSES IN SORGHUM IV. CHI-SQUARE ANALYSIS OF ASSOCIATION BETWEEN YIELD, MATURITY AND PLANT HEIGHT IN F_2 GENERATION

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UTILIZATION of dwarf and early genotypes is becoming increasingly important in most crop breeding programmes including sorghum. The tall and late Indian sorghums could contribute to high yields if suitable segregates are extracted from crosses involving dwarf exotics (Rao, 1970). However, response to selection from such crosses of sorghum is frequently limited due to character association, the association between grain yield, plant height and maturity being of particular significance. While the genetics of plant height (Quinby and Martin, 1954 and Quinby, 1967) and maturity have been extensively analysed in sorghum, available information on their inter-relationships is inadequate. The nature of association between the three characters is examined in segregating populations of crosses among three diverse sorghum varieties.

MATERIALS AND METHODS

IS. 3691 (a derived yellow endosperm *hegari*) and *Kafir B* (fertile counterpart of male-sterile combine kafir 60) were used as dwarf and early parents in cross combinations with B.P. 53, a tall and late Indian variety. The parents, the three possible F_1's and F_2's furnished the material for the present study. The experiment was grown in a randomised block design with three replications. Observations were recorded on nine parental and nine F_1 plants in addition to 45 F_2 plants per replication. The differences between replications were not significant and hence the plants from all replications were considered as a random sample; making a total of 135 F_2 plants per cross and 27 plants for each parent and F_1. Data were collected on three characters, maturity measured as days to 50% bloom, plant height (cm.) and grain yield per plant (gm.).

The association between pairs of characters was examined in two-way tables by total χ^2, the class intervals for days to bloom (A), plant height (B) and yield per plant (C) being 5 days, 10 cm. and 10 gm. respectively. The total $\chi^2$was partitioned into χ^2's due to intergroup, intragroup and regression which are respectively related to linkage, pleiotropy and physiological association (Jeswani and Murty, 1963).

The intergroup χ^2 was obtained by forming three sub-groups under each character (A_1, A_2, A_3; B_1, B_2, B_3; C_1, C_2, C_3 as the character may be) based on the ranges of the two parents and the F_1 for each cross. For example, with respect to the two-way table, days to 50% bloom×plant height, there will be nine sub-groups, namely, A_1B_1, A_1B_2, A_1B_3, A_2B_1, A_2B_2, A_2B_3, A_3B_1, A_3B_2 and A_3B_3 denoted by the subscripts 1–1, 1–2 etc. as in Table 2. The chi-square based on these group totals is the intergroup χ^2.

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The intragroup χ^2 was calculated on the basis of the cell frequencies within each group. Where overlapping occurred, new groups were formed. R, R_i and R_2 in Table 2 refer to such overlapping classes between P_1 and P_2, P_1 and F_1, and P_2 and F_1, respectively. R, R_1 and R_2 occur as subscripts to A, B or C as the character may be.

Regression χ^2 was calculated by the procedure described by Cochran (1954). For this purpose, two yield and two maturity classes were formed considering less than 80 as low and more than 80 as high in the respective cases. The limits of 80 gm. and 80 days were taken as points of demarcation since these correspond to the mid-parent yield per plant and days to bloom.

Results

The probability of no association based on all classes in the frequency table indicated limited overall association and this was particularly true of crosses involving B.P. 53 (Table 1). This appears to be mainly due to the lack of strong linkage as revealed by an examination of the relationships between pairs of characters (Tables 2 and 3).

The main conclusions are summarized in the following table:

	Days to 50% bloom × Plant height	Days to 50% bloom × Yield	Plant height × Yield
Linkage	Weak	Negligible	Weak
Pleiotropy	Strong	Strong	Considerable
Physiological association	Considerable	Negligible	Considerable

The chi-square partitioning has thus brought out the importance of pleiotropy, and physiological association to a limited extent, in the inter-relationships between days to 50% bloom and plant height with yield. This is particularly true of the associations between maturity measured as days to 50% bloom with plant height and days to 50% bloom with grain yield.

Discussion

Earlier studies on combining ability from a diallel mating system between exotic and Indian parents indicated that while the nature of gene action for flowering time and plant height was essentially additive, non-allelic interactions appeared to be of considerable magnitude in influencing grain yields (Rao, 1970). Graphic analysis further revealed that the distribution of dominant and recessive alleles governing yield and flowering was assymetric and in opposite directions; the tall Indian varieties possess the dominant alleles for yield and plant height while the dwarf exotics have the dominant alleles for flowering, that is, earliness. Efforts to bring the recessive alleles for height together with the dominant alleles for flowering (earliness) and yield in homozygous condition have frequently met with difficulties and the recovery of desired recombinants is not to the extent anticipated on account of discontinuous distribution of yield classes. That there is a positive relationship

TABLE 1

Interaction chi-squares between pairs of characters in sorghum

	Days to 50% bloom with						Plant height with		
	Plant height			Yield			Yield		
	I	II	III	I	II	III	I	II	III
1. *Based on all classes in the frequency distribution:*									
DF	132	175	234	72	90	65	200	375	364
χ^2	146·75	168·75	111·24	67·68	87·21	63·45	236·36	294·44	307·94
P	0·05–0·100	0·25–0·50	>0·995	0·50 –0·75	0·50–0·75	0·50–0·75	0·010–0·025	>0·995	0·75–0·90
2. *Based on group totals:*									
DF	16	9	12	12	9	6	12	9	8
χ^2	14·28	44·82	48·14	21·63	16·67	3·78	25·38	6·94	95·58
P	0·50–0·70	<0·001	<0·001	0·025–0·05	0·05–0·10	0·70–0·75	0·01 –0·02	0·50–0·70	<0·001

I: Kafir B × IS 3691 II: Kafir B × B.P. 53 III: IS 3691 × B.P. 53.

TABLE 2

Intragroup chi-squares between some pairs of characters in sorghum

Sub-group		A × B			A × C			B × C		
		I	II	III	I	II	III	I	II	III
1–2*	DF							2	16	14
	χ^2	—	—	—	—	—	—	17·66	3·93	3·00
	P							<0·001	>0·999	>0·999
1–3	DF	4			2		2	7		
	χ^2	5·25	—	—	3·21	—	1·06	7·02	—	—
	P	0·25–0·30			0·20–0·25		0·50–0·70	0·30–0·50		
2–1	DF							2		
	χ^2	—	—	—	—	—	—	3·54		
		—	—	—	—	—	—	0·10–0·20	—	—
	P									
2–2	DF							2	32	28
	χ^2	—	—	—	—	—	—	1·55	24·29	17·39
	P							0·30–0·50	0·75–0·90	0·90–0·95
2–3	DF	2			2		8	7	20	
	χ^2	0·17	—	—	0·73	—	3·13	5·00	12·92	—
	P	0·90–0·95			0·50–0·70		0·90–0·95	0·50–0·70	0·80–0·90	
3–2	DF		8					4	40	
	χ^2	—	31·30	—	—	—	—	1·50	44·90	—
	P		<0·001					0·80–0·90	0·25–0·50	
3–3	DF	14	5	7	4		4	14	25	42
	χ^2	12·20	13·24	3·80	4·67	—	3·60	11·42	8·25	14·87
	P	0·50–0·70	0·02–0·025	0·80–0·90	0·30–0·50		0·30–0·50	0·50–0·70	>0·999	>0·995

TABLE 2 (Contd.)

		A×B			A×C			B×C		
		I	II	III	I	II	III	I	II	III
$1\text{-}R_1$	DF						2		14	24
	χ^2	—	—	—	—	—	6·42	—	4·00	35·99
	P						0·025–0·05		>0·995	0·05–0·10
$1\text{-}R_2$	DF				1					
	χ^2	—	—	—	1·33	—	—	—	—	—
	P				0·20–0·25					
$2\text{-}R_1$	DF					8	6		28	48
	χ^2	—	—	—	—	8·99	9·02		22·00	47·21
	P					0·30–0·50	0·10–0·20		0·75–0·80	0·50–0·75
$2\text{-}R_2$	DF	1				4				4
	χ^2	0·01	—	—	—	2·73	—	—	—	2·00
	P	>0·999				0·50–0·70				0·70–0·75
$3\text{-}R_1$	DF		7	12		10	8		35	72
	χ^2	—	2·00	12·26	—	0·97	11·13	—	2·00	11·08
	P		0·95–0·975	0·30–0·50		>0·999	0·10–0·20		>0·995	>0·995
$3\text{-}R_2$	DF	7				2	5			
	χ^2	7·0	—	—	—	1·33	2·23	—	—	—
	P	0·30–0·50				0·50–0·70	0·80–0·90			
R–1	DF	6						4		
	χ^2	3·75	—	—	—	—	—	1·50	—	—
	P	0·70–0·75						0·80–0·90		

TABLE 2 (Contd.)

		A×B			A×C			B×C		
		I	II	III	I	II	III	I	II	III
R–2	DF		16	35				4		
	χ^2	—	68·85	11·21	—	—	—	1·96	—	—
	P		<0·001	>0·995				0·70–0·75		
R–3	DF		10					14		
	χ^2	—	3·06	—	—	—	—	9·30	—	—
	P		0·97–0·98					0·80–0·90		
R_1–3	DF					4				
	χ^2	—	—	—	—	4·10	—	—	—	—
	P					0·30–0·50				
R–R_1	DF		14	12						
	χ^2	—	1·20	12·26	—	—	—	—	—	—
	P		<0·999	0·30–0·50						
R–R_2	DF	6				2		14		
	χ^2	3·00	—	—	—	0·83	—	4·87	—	—
	P	0·80–0·90				0·50–0·70		0·98–0·99		

A: Days to 50% bloom; B: Plant height (cm.); C: Grain yield (gm./plant); I: Kafir B × IS 3691; II: Kafir B × B.P. 53; III: IS 3691 × B.P. 53.

*Refers to subscripts of A, B or C

TABLE 3

Regression chi-square between pairs of characters in sorghum

	DF	Kafir B × IS 3691		Kafir B × B.P. 53		IS 3691 × B.P. 53	
		χ^2	Probability	χ^2	Probability	χ^2	Probability
1. *Plant height* × *yield:*							
Regression	1	4·80	0·025–0·05	1·30	0·25–0·30	11·52	<0·001
Residual	1	0·60	0·30 –0·50	0·05	0·80–0·90	2·52	0·10 –0·20
Total	2	5·40	0·05 –0·10	1·35	0·50–0·70	14·04	<0·001
2. *Days to* 50% *bloom* × *yield:*							
Regression	1	0·780	0·30 –0·50	14·77	<0·001	0·110	0·70 –0·75
Residual	1	1·110	0·25 –0·30	21·95	<0·001	0·025	0·80 –0·90
Total	2	1·890	0·30 –0·50	36·72	<0·001	0·135	0·90 –0·95
3. *Plant height* × *days to* 50% *bloom:*							
Regression	1	14·695	<0·001	1·30	0·25–0·30	7·37	0·005–0·10
Residual	1	0·830	0·30 –0·50	0·05	0·80–0·90	3·43	0·05 –0·10
Total	2	15·525	<0·001	1·35	0·50–0·70	10·80	0·001–0·005

between maturity and yield in sorghum is also known (Dalton, 1967). This necessitated an analysis of the factors limiting response to selection among which linkage, pleiotropy and physiological association are important (Falconer, 1967).

The association observed between the pairs of characters is expected since the maturity locus (**Ma**$_1$) in the heterozygous condition increased yield and it is also linked to the second height locus, **Dw**$_2$ (Quinby and Karper, 1945; 1946) which in turn influences yield and days to flower (Graham and Lessman, 1966). In addition, it is also known that the **Dw**$_3$ locus alters the yield potential substantially (Casady, 1965; 1967; Hadley *et al.*, 1965). The present findings based on the χ^2 partitioning thus lend support to the earlier ones that the three loci, **Ma**$_1$, **Dw**$_2$ and **Dw**$_3$ are pleiotropic in their effects.

Experience has shown that highly productive lines could be obtained from crosses of dwarf exotics with tall Indians at intermediate maturity and height ranges rather than at the extremes. The recovery of useful recombinants in the intermediate ranges was also confined to very few crosses even though over a hundred such crosses were handled. In view of these findings, it appears that a two gene dwarf (**Dw**$_2$ and **Dw**$_3$ remaining in homozygous dominant condition) and flowering in 75–80 days (in July plantings in India) may provide an ideal genotype for sorghum for realising maximum yield potential. The heterozygous condition of **Ma**$_1$ is an advantage which could be exploited in hybrid programmes or through apomictic fixation in line development (Rao and Narayana, 1968).

With the assembling of the World Sorghum Collection, there is increased interest in the use of the tall Indian and African germ plasm in sorghum improvement in recent years. Limited recovery of desired recombinants is prone to influence the breeders to resort to intermating procedures to force recombination. It therefore appears desirable to handle a large number of crosses to identify the fruitful combinations instead of intensive manipulation of few crosses based on information from conventional combining ability analyses.

Summary

In conventional hybridisation between dwarf early and tall late types, response to selection is frequently limited due to association of characters, particularly plant height, maturity and grain yield. Using a chi-square method of partitioning, an attempt is made to distinguish between linkage, pleiotropy and physiologial association. Strong pleiotropic effects of the flowering and height genes are indicated. Handling a large number of crosses in preference to intensive handling of a few crosses is fruitful while bringing in recombination from crosses involving divergent parents for height and maturity.

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GENETIC ANALYSIS OF SOME EXOTIC×INDIAN CROSSES IN SORGHUM V. CHARACTER ASSOCIATION AND RESPONSE TO SELECTION IN ADVANCED GENERATION PROGENIES*

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FROM a chi-square analysis, Harinarayana, Rao and Venkatraman (1971) felt that in addition to linkage, strong pleiotropic effects of flowering and height genes also played an important role in the association of dwarf stature and earliness. A positive regression between maturity and yield is also generally indicated (Dalton, 1967). Under the circumstances recovery of dwarf, early and high yielding recombinants poses several problems to the practical plant breeder and progress from selection is frequently limited. In the present study an attempt is made to analyse the nature of character association and progress from selection in a sample of F_4 and F_5 segregates derived from some exotic ×Indian sorghum cross combinations.

MATERIALS AND METHODS

The experimental material used in the present study consisted of advanced generation progeny of seven crosses, their parents and F_1 hybrids, as furnished below :

The parents IS 2954, IS 84, IS 2031, IS 3687, IS 3922 and R. 78 represent dwarf, early parents whereas B.P. 53, *Karad local*, M. 35–1 and *Aispuri* represent tall Indian parents. A detailed description of the parents was reported earlier (Rao, 1970). The advanced generation families chosen for the study represented a range of heights and maturities and not necessarily the most superior ones for grain yield.

Family No.	Sib No.	Pedigree
1.	F_5—13, 14, 15, 16, 17 and F_1	IS 2954 × B.P. 53
2.	F_5—66, 67, 68, 69, 71	„
3.	F_5—127, 128, 129, 130, 131 and F_1	IS 84 × B.P. 53
4.	F_5—203, 204, 205, 206, 207 and F_1	R. 78 × B.P. 53
5.	F_5—319, 320, 321, 322, 323 and F_1	IS 2031 × Karad Local
6.	F_5—528, 529, 530, 531, 532	IS 2031 × Karad Local
7.	F_5—825, 826, 827, 828, 829, and F_1	R. 78 × M. 35–1
8.	F_5—945, 946, 947, 948, 949 and F_1	IS 3687 × Aispuri
9.	F_4—1223, 1224, 1225, 1226, 1227 and F_1	IS 3922 × Karad Local
10.	Exotic parents: IS 2954 (*Shallu*), IS 84 (Yellow endosperm *feterita*), IS 2031 (Sel. 133), IS 3922 (Sel. 393), IS 3687 and R. 78 (*Kafir* types).	
11.	Indian parents: B. P. 53, *Karad Local, Aispuri* and M. 35–1.	

*Part of the M.Sc. thesis submitted by B. V. S. Reddy to the P. G. School of the Indian Agricultural Research Institute, New Delhi-12.

The material was grown in a compact family block design with three replications. Each replication was divided into 11 blocks to each of which the 11 families were randomly assigned. Within each block, the entries were allocated randomly. Each plot was a row of 2·4 m. length with 75 cm. between rows and 15 cm. between plants. Two to three seeds were dibbled per hill and later thinned to one plant per hill. Within each replication, the families were separated by a row of male sterile *Kafir* 60.

Five plants in each row were selected at random for recording observations on (1) yield in gm. per plant, (2) height in cm., (3) days to 50% bloom, (4) 100 grain weight in gm., (5) panicle length in cm. and (6) number of secondary branches per panicle.

The data were subjected to compact family block design analysis as outlined by Panse and Sukhatme (1967). The phenotypic, genotypic and environmental correlation coefficients were calculated using standard procedures. The direct and indirect contributions of some yield components like plant height, days to 50% bloom, 100 grain weight, panicle length and number of secondary branches to yield were estimated as suggested by Dewey and Lu (1959). Selection indices and expected genetic advance were computed as suggested by Robinson, Comstock and Harvey (1951). The correlated responses were estimated by the formula suggested by Johnson, Robinson and Comstock (1955). The predicted genetic effects of selection were calculated on the assumption of additive genetic variance. Genetic advance in an unselected character $(g_{1 \cdot 2}/\sigma^2_{p \cdot 1}) \times K$ where $g_{1 \cdot 2}$=genetic covariance between the selected (1) and unselected (2) characters, $\sigma^2_{p \cdot 1}$=phenotypic variance of the selected character (1) and K=selection differential at a particular selection intensity (K at 5% selection=2·06).

Results

Analysis of means

An examination of the family means indicated significant differences between families for almost all the characters under study. The exotic parents were generally dwarf, early and low yielding. The Indian parents, on the other hand, were tall, late and high yielding. The F_1's were most vigorous and most of them are markedly superior to the commercial hybrid CSH-1 in respect of grain yield. The advanced generation hybrid derivatives represent a range of variability between the parental types. The most superior families tended to be tall and late. The family means of some of the derivatives were equal to the commercial hybrid, but none of them approached the corresponding F_1 values with the exception of secondary branches in one family, where it exceeded the F_1 value. In general, most values tended to be intermediate between parents, exhibiting marked superiority for yield over exotic parents only.

While within the family differences for grain yield are significant only for two families, the differences with regard to the components of yield including maturity and plant height are significant in several families. This is indicative of the fact that for these characters sufficient uniformity is not attained by the F_5 generation and further selection is necessary to reach acceptable levels of homogeneity for commercial purposes.

Phenotypic, genotypic and environmental correlation coefficients

The phenotypic, genotypic and environmental correlation coefficients were estimated in all the parents as one group, in F_5* lines as another group and parents and F_5 combined as the third group. The data are presented in Table 1.

*Includes one F_4 family.

TABLE 1

Phenotypic (P), genotypic (G) and environmental (E) correlations

Characters		Plant height (cm.)	Days to 50% bloom	100-grain weight (gm.)	Panicle length (cm.)	No. of secondary branches
		(a) *Based on parents*				
Yield/panicle (gm)	P	·60	·66*	·81**	−·36	·53
	G	·60	·67*	·83**	−·38	·54
	E	·15	·17	·09	·43	·63
Plant height (cm)	P		·92**	·09	−·69*	·23
	G		·92**	·10	−·70*	·24
	E		−·17	−·40	·32	·42
Days to 50% bloom	P			·21	−·56	·49
	G			·21	−·57	·51
	E			·15	−·07	·05
100-grain weight (gm)	P				−·17	·50
	G				−·16	·55
	E				−·49	·41
Panicle length (cm)	P					−·30
	G					−·34
	E					·58
		(b) *Based on F_5 lines*				
Yield/panicle (gm)	P	·57**	·66**	−·19	·37*	·54**
	G	·64**	·71**	−·22	·37*	·58**
	E	−·10	·01	·05	·35*	·24
Plant height (cm)	P		·13	·32*	·17	−·12
	G		·13	·34*	·18	−·12
	E		−·05	·02	−·05	−·06
Days to 50% bloom	P			−·36*	·02	·75**
	G			−·38*	·03	·78**
	E			·09	−·09	−·13
100-grain weight (gm)	P				−·48**	−·51**
	G				−·52**	−·55**
	E				·01	−·02
Panicle length (cm)	P					·31*
	G					·31*
	E					·32*

TABLE 1—(*Contd.*)

Characters		Plant height (cm.)	Days to 50% bloom	100-grain weight (gm.)	Panicle length (cm.)	No. of secondary branches
		(c) *Based on combined data of parents and F_5 lines*				
Yield/panicle (gm)	P	·63**	·68**	·46**	–·16	·54**
	G	1·01**	·89**	·70**	–4·68**	1·82**
	E	·43**	·57**	·06	·38**	·46**
Plant height (cm)	P		·61**	·40**	–·36**	·08
	G		1·02**	·49**	–3·57**	1·46**
	E		·37**	·10	–·01	–·08
Days to 50% bloom	P			·23	–·51**	·62**
	G			·97**	–5·79**	1·40**
	E			–·34*	·15	·61**
100-grain weight (gm)	P				–·29**	·13
	G				1·42**	4·51**
	E				–·38**	–·44**
Panicle length (cm)	P					–·17
	G					+
	E					·50

+ = Spurious value.

The data based on parents and F_5 lines separately, indicate that the phenotypic correlations reflect the genotypic correlations. However, when the data for parents and F_5 are combined, some of the genotypic correlation coefficients assumed spuriously high values.

The correlation coefficients based on parents reveal significant positive association between grain yield and days to 50% bloom, plant height and flowering, yield and seed weight and a significant negative correlation between plant height and panicle length.

The correlations based on F_5 data indicate significant positive associations between yield and height, yield and flowering, yield and panicle length, yield and secondary branches and panicle length and secondary branches. There is negative correlation between flowering and seed weight, seed weight and panicle length and seed weight and secondary branches.

When the data are combined, most associations tend to assume significance, with larger genotypic correlation coefficients.

TABLE 2

Genetic gain from selection based on selection indices

Sl. No.	Selection index	Genetic gain	Relative efficiency
1.	·560550 x1	19·84	100·00
2.	·305356 x2	19·82	99·89
3.	·962016 x3	22·58	113·81
4.	–6·333503 x4	6·59	33·20
5.	1·070691 x5	11·57	58·32
6.	·482597 x6	17·85	89·98
7.	·932470 x1 + –·345198 x2	26·63	134·22
8.	·052381 x1 + 1·129419 x3	27·72	139·74
9.	·475373 x1 +–15·034387 x4	24·62	124·10
10.	·515352 x1 + ·393453 x5	19·64	99·01
11.	·264995 x2 + ·867784 x3	28·29	142·62
12.	·374769 x2 + –13·716532 x4	23·10	120·97
13.	·283154 x2 + ·780092 x5	21·49	108·31
14.	·341795 x2 + ·552039 x6	28·35	142·93
15.	·989227 x3 + 1·705005 x4	22·64	114·11
16.	·950633 x3 + 1·020688 x5	25·13	126·66
17.	·889779 x3 + ·061439 x6	22·63	114·06
18.	–1·284089 x4 + 1·011303 x5	11·63	58·62
19.	3·178169 x4 + ·527875 x6	18·08	91·12
20.	·622617 x5 + ·426803 x6	18·96	95·60
21.	·429581 x1 + –·233151 x2 + ·849379 x3	29·98	151·11
22.	·805320 x1 + –·267796 x2 + –7·723269 x4	27·46	138·43
23.	·894343 x1 +–·342410 x2 + ·305748 x5	26·80	135·11
24.	·078506 x1 + ·948242 x3 + –9·777222 x4	29·29	147·66
25.	–·162507 x1 + 1·323818 x3 + 1·109223 x5	29·69	149·64
26.	·508568 x1 + –16·676906 x4 + –·369980 x5	24·84	125·22
27.	·301039 x2 + ·757475 x3 + –6·108760 x4	28·82	145·25
28.	·242955 x2 + ·866970 x3 + ·775746 x5	29·48	148·58
29.	·303761 x2 + ·482603 x3 + ·315881 x6	29·24	147·38
30.	·370048 x2 + –13·228587 x4 + ·079100 x5	24·01	121·02
31.	·361060 x2 + –4·613057 x4 + ·490232 x6	28·63	144·31
32.	·336126 x2 + ·162690 x5 + ·536308 x6	28·40	143·17
33.	1·105445 x3 + 10·018502 x4 + 1·475893 x5	26·49	133·52
34.	·884966 x3 + 2·698657 x4 + ·102164 x6	22·76	114·71
35.	1·140901 x3 + 1·182181 x5 + –·163359 x6	25·39	127·97
36.	7·126877 x4 + ·868796 x5 + ·506277 x6	19·85	100·07
37.	·363366 x1 + –·183029 x2 + ·806430 x3 + –5·566552 x4	30·36	153·03
38.	·19661 ×1 ±·198257 + 1·050931 x3 + ·910896 x5	31·17	157·13
39.	·806460 x1 + –·265929 x2 + –7·944467 x4 + –·03834 x5	27·47	138·45
40.	–·090687 x1 + 1·179654 x3 + –4·914754 x4 x4 + ·80629 x5	29·92	150·84

TABLE 2—(*Contd.*)

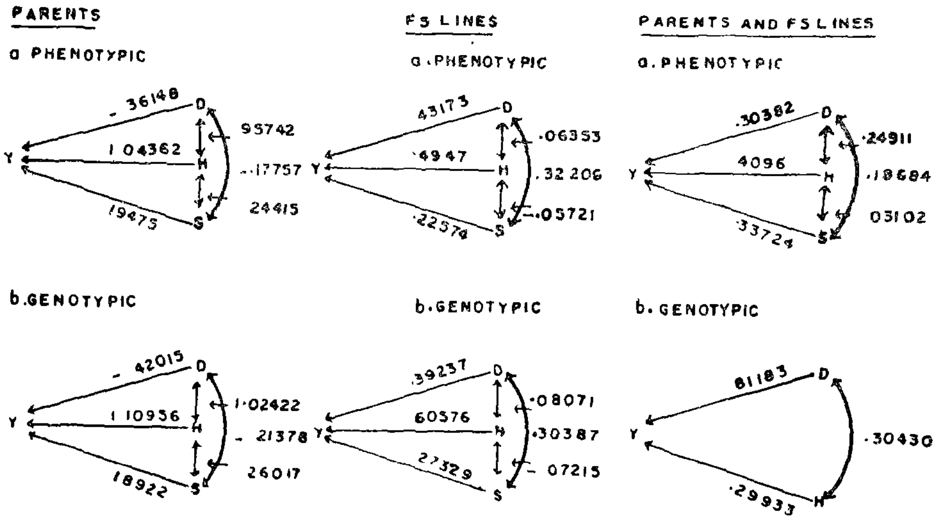
Sl. No.	Selection index	Genetie gain	Reletive efficiency
41.	·195523 x1 + –·202002 x2 + 1·061680 x3 + 5420202 x4 + ·940570 x5	31·18	157·15
42.	·246315 x2 + ·858798 x3 + –·453954 x4 + ·751731 x5	29·48	148·59
43.	·321901 x2 + ·465458 x3 + –4·020269 x4 + ·270408 x6	29·44	148·39
44.	·270910 x2 + ·647626 x3 + ·569560 x5 + ·180058 x6	29·69	149·67
45.	·363595 x2 + –4·862561 x4 + –·042858 x5 + ·491034 x6	28·63	144·32
46.	1·199978 x3 + 9·528680 x4 + 1·540299 x5 + –·087662 x6	26·56	133·87
47.	·276457 x2 + ·633048 x3 + –·722154 x4 + ·529875 x5 + ·181354 x6	29·70	149·69

x1 =yield per panicle (gm.) x4=100-grain weight (gm.)
x2 =plant height (cm.) x5 =panicle length (cm.)
x3 =days to 50% bloom x6 =number of secondary branches.

PATH ANALYSIS

The correlation coefficients were further partitioned through path analysis for parental, F_5 and combined groups, at phenotypic and genotypic levels. The results are presented in Fig. 1.

FIG. 1 PATH COEFFICIENTS



Y=Yield/Panicle (gm.); D= days to 50% bloom; H=Plant height (cm.) S=No. of secondary branches.

As in the case of correlation coefficients, there was general agreement between the path coefficients at genotypic and phenotypic levels. The analysis based on the parental group further reveals that the direct effect of plant height on yield is considerable but the indirect effect *via* flowering is in the negative direction. Similarly, the direct effect of flowering is in the negative direction, but the indirect effect *via* plant height is positive and of considerable magnitude. The direct effect of grain weight is also positive and of considerable magnitude. While the direct effect of panicle length is positive, plant height influences this to a considerable extent in an opposite direction. Grain weight and plant height seem to influence indirectly the number of secondary branches.

The situation with regard to the path coefficient estimates from F_5 lines is somewhat different. While the direct effects of plant height and flowering on yield are positive, the indirect effects are not pronounced. On the other hand the direct effect of 100 grain weight is itself negligible and the indirect effects of other components assume importance. In case of secondary branches the indirect effect of flowering is of greater magnitude.

Path coefficients based on combined data reveal the importance of direct as well as indirect effects of plant height and flowering on yield.

SELECTION INDEX

The predicted gain from selection based on several indices involving the six characters under study is presented in Table 2. The indices were calculated based on the F_5 data.

TABLE 3

Correlated response in terms of genetic advance

Characters selected for	Response in				
	Plant height (cm)	Days to 50% bloom	100-grain weight (gm)	Panicle length (cm)	No. of secondary branches
Yield/panicle (gm)	33·40	13·77	–·18	3·25	17·14
Plant height (cm)		2·90	·31	1·79	–3·97
Days to 50% bloom			–·38	·28	27·53
100-grain weight (gm)				–4·77	–17·15
Panicle length (cm)					10·23

An examination of the relative efficiencies indicate that selection for plant height alone is as effective as selecting for yield. Selection for flowering alone is superior to selecting for yield by 14%. If the selection is based on yield and plant height or yield and flowering or flowering and plant height, the efficiency increases by 34%, 40% and 42% respectively. Of these three combinations, gain is more in two combinations in which flowering is included, rather than plant height.

Selection for grain weight, panicle length and number of secondaries by themselves reduces the efficiency considerably. A combination of any of these three components is also not as effective as selection for yield itself.

Selection index, based on any five of the six characters is only 6% more effective than selection based on three characters namely, yield, plant height and flowering.

CORRELATED RESPONSE

The influence of selecting for one character on other characters is presented in Table 3. It will be seen that the influence of selection for yield is primarily on plant height and flowering time. Similarly, the influence of selection for plant height is on flowering. Selection for plant height influences negatively secondary branches of the panicle. The influence of flowering is again on secondary branches, yield and plant height.

Selection for grain size has generally a negative influence on all characters. Panicle length primarily influences secondary branches and yield. Selection for secondary branches has maximum effect on flowering, yield and panicle length.

Discussion

An examination of the phenotypic and genotypic correlations based on the parents alone, the F_5 segregates and a combination of the parents as well as advanced generation progeny clearly indicates the importance of associations particularly between yield and flowering, yield and plant height, plant height and flowering and yield and secondary branches of the panicle. The correlation coefficients based on F_5 generation are particularly significant and meaningful since the associations were maintained after five generations of visual selection. The studies on correlated response also reflect the same situation, bringing out the importance of flowering and height genes in influencing yield.

Partitioning of the correlation coefficients into direct and indirect effects through path analysis throws further light on character associations. The direct and indirect effects based on parents show that primarily the influence of flowering on yield is *via* plant height, and that of plant height *via* flowering. On the other hand, the direct and indirect effects based on F_5 progeny do not show pronounced indirect effects of flowering and height genes. The direct effects of plant height and flowering are pronounced, while the indirect effects are not. The indirect effects of other componets assume greater importance in F_5 generation. This is significant and is obviously the result of selection which dissipated initial indirect effects.

Thus it appears, that in base populations, flowering and plant height are the major components of fitness and are clearly associated in influencing yield both directly and indirectly. Selection towards earliness and dwarfness dissipated the indirect effects, but the direct effects still remain prominent. In this process, the indirect effect of other components of yield assumed greater importance.

An examination of several selection indices based on the components of yield under study also brings forth that flowering and plant height are the most important components of fitness. If the selection is based on yield and plant height or yield and flowering or flowering and height, the efficiency increases by 34, 40 and 42% respectively. Emphasis on these three characters is almost as effective as selection based on any five of the six characters.

The lack of marked response from crosses of related sorghum varieties and the consequent emphasis on the exploitation of exotic variability is well recognized. The high yielding families tended towards lateness and tallness. There is transgression of parental limits, but there is no transgression of F_1 with the exception of panicle length in most cases and the number of secondary branches in one family where the offspring exceeded the corresponding F_1 hybrid. It is also interesting to note that high yielding hybrids yielded superior progeny and hence a high mean value for F_1 together with other criteria like the nature of combining ability becomes a desideratum if high yielding derivatives are to be isolated (Rao, 1970). Further the differences within a family were also significant in most cases indicating that homozygosity and homogeneity are not yet attained and further response to selection is feasible.

As has been discussed, combining high yield levels with dwarf stature and earliness has become almost inescapable in several crop breeding programmes. While the brachytic dwarfs revolutionized sorghum production in U.S.A., a dwarf and early genotype of non-tillering grain sorghum does not appear to provide immediately a favourable genetic background on which further higher yields could be built up for future.

The work of Saunders (1969) on cotton reveals a reduction in recombination values for linkage groups brought about by the transfer of linkage groups from one species to another resulting in low variability and hence low response to selection. On the other hand the Dee-geo-woo-gen dwarf mutant in rice and the Norin dwarfing genes in wheat provided a favourable genetic background to increase tiller number and yield levels. Efforts to identify suitable recombinants could result in a relatively dwarf and early genetic base around which the superstructure of high yields could be built up by various breeding manipulations.

In an inbreeding population increasing level of inbreeding has much the same effect on the genetic unbalance as tightening linkage (Jain and Allard, 1965 and 1966). Where linkage counters response to selection, recombination through intermating is the only means of releasing variability. Mutation may also provide the necessary variability, sometimes so startingly, that the gap between wild and cultivated forms is bridged as in the case of the nonshattering mutants of cereals or the spiral twist of seed hair that enabled cotton to be spun (Walker, 1969).

Summary

Yield performance and nature of character association in a sample of F_4 and F_5 segregates derived from some exotic ×Indian cross combinations of sorghum were studied in relation to the parents involved and the corresponding F_1 hybrids. The F_1 hybrids represented some of the high yielding exotic× Indian combinations. The segregating families were not the most superior lines available, but represented a range of variation for height, maturity and yield between the parental extremes.

1. The family means are generally superior to the dwarf, exotic parents and sometimes to the mid parental values as well as high parents, but they were not generally superior to the corresponding F_1 hybrids. There was transgression of parental limits but not transgression of the F_1 with the exception of panicle length in most families and secondary branches in a few crosses. The differences within a family were also significant indicating that sufficient homozygosity and homogeneity were not attained and that further response to selection is feasible. The superior progenies generally tended towards lateness and tallness.

2. Phenotypic and genotypic correlations based on parents, F_5 segregates and a combination of parents and F_6 offspring clearly established the positive relationships between flowering and yield, plant height and yield, flowering and plant height, and yield and secondary branches of the panicle. The correlation coefficients based on F_5 generation are particularly significant since the association was maintained after five generations of selection.

3. Partitioning of the correlation coefficients through path analysis indicated that in the parental group both direct and indirect effects of plant height and flowering were pronounced. On the other hand in the F_5 progenies, while the direct effects are pronounced, the indirect effects of flowering and height were dissipated. The indirect effect of other components like grain weight assumed greater importance.

4. Studies on correlated response further revealed the interrelationships of flowering, plant height, yield and secondary branches which appear to be the most important components of fitness.

5. Evaluation of various selection schemes revealed that selection for flowering and height were more effective than selecting for yield itself. Selection based on yield, flowering and plant height was as effective as selection based on all the six components under study.

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SELF-INCOMPATIBILITY IN GRAIN SORGHUMS

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WHILE reporting the occurrence of somatic apospory in grain sorghums, Rao and Narayana (1968) observed that in the apomictic lines, although the pollen is fertile on alien stigmas, it was nonfunctional on the stigmas of the same plant. They suggested that this situation which amounts to self-incompatibility may be an intermediate step in the evolution of apomixis, a form of asexual reproduction, from sexuality. The present report deals with an observation of self-incompatibility in grain sorghum, which occurred in a series of backcrosses involving the transference of cytoplasmic male-sterility from an indigenous cytoplasmic male-sterile to IS. 84, the male parent of the released hybrid, CSH-1. The occurrence of self-incompatibility does not appear to have been reported in grain sorghums so far.

IS. 84 was crossed with an indigenous (*maldandi*) male sterile line and the F_1 was repeatedly backcrossed for five generations to IS. 84. It may be mentioned here that IS. 84 is a fertility restorer on milo cytoplasm but behaves as a nonrestorer in the indigenous sterility system. Apparently sterile segregates were used in the backcross programme. During *kharif* 1968, it was found that some backcross progenies (BC 21, BC 23, BC 47 and BC 57) were shedding pollen. However, under selfing there was no seed set giving rise to the suspicion of self-incompatibility.

BC 47 and BC 57 material was sown at Coimbatore in summer 1969 and these lines were crossed with *Swarna*, *Kafir B*, M 35-1 and some other lines. There was seed set and genuine hybrids were obtained. The F_1's were raised in the following *kharif* at Delhi and were observed to be almost completely self-incompatible (Table 1).

Some remnant F_1 seeds were sown in *rabi* 1969 at Hyderabad and none of them set seed on selfing. Cytological observations were made on the following characteristics of the pollen of these self-incompatible lines : 1. Fertility, 2. Germination on self stigmas, 3. Germination on alien stigmas and 4. Germination in sucrose solution. Pollen fertility was quite normal ranging from 90–100% in the various lines. Both self- and cross-pollinated styles were examined in squash preparations cleared in lactophenol and stained in cotton blue, somewhat similar to the technique outlined by Datta and Nang (1967). There was practically no germination of the pollen on self stigmas (Fig. 1). But

TABLE 1

Seed set on selfing the F_1 hybrids

Combination	Number of seeds set in a panicle on selfing											
	1*	2	3	4	5	6	7	8	9	10	11	12
BC 47 × Swarna	13	1	0	0	1	0	0	12	1	0	2	0
BC 57 × *Kafir* B	0	0	0	0	0	2	0	0	0	—	—	—
BC 47 × M 35–1	0	0	0	0	2	1	1	6	0	0	0	—
BC 57 × Swarna	Mostly				Sterile							
BC 57 × *Kafir* B	4	10	0	1	4	—	—	—	—	—	—	—
BC 57 × M 35–1	0	0	0	0	2	0	0	3	0	6	0	—

*Serial number of the F_1 plants.

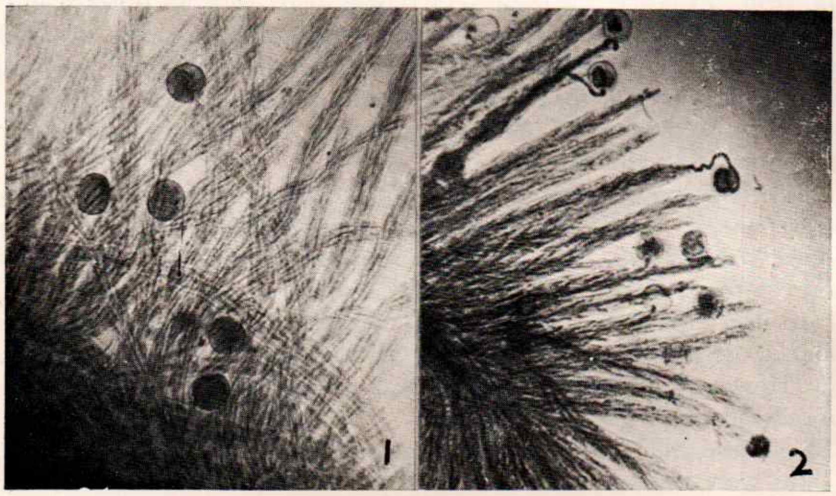

FIG. 1. Part of a self pollinated style of (BC 47 × M 35-1).
FIG. 2. Part of a style of PJ 16 R pollinated with (BC 47 × M 35-1) pollen.

it readily germinated and penetrated the styles of foreign plants (Fig. 2). Pollen germination *in vitro* was quite normal.

The fertility of the pollen, its ability to effect fertilization in other lines and its normal germination *in vitro* and *in vivo* rule out the possibility of sterility and strongly confirm the suspicion of self-incompatibility. Preliminary observations on various crosses also indicated the probable involvement of the cytoplasm in the incompatibility mechanism. Studies on the nature of this incompatibility system, its inheritance and probable origin are under investigation.

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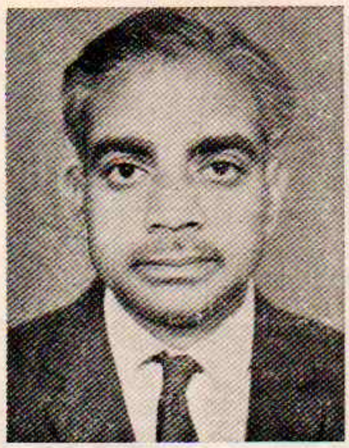
Fertilizer for new varieties of sorghum



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Of the several requirements for successful crop production, the development of an efficient genotype capable of utilising available resources, which include mineral nutrients, moisture regimes and solar energy, and a judicious supply of plant nutrients, may be considered the two major factors subject to scientific manipulation to attain higher agricultural yields. The recently developed hybrids and varieties of grain sorghum satisfy these two needs to a large extent. Based on data from co-ordinated agronomic experiments, the fertilizer needs of these new sorghum varieties are examined.

Fertilizer requirement [redacted]

Sorghum is a heavy feeder of major fertilizer elements. A good crop of grain sorghum capable of yielding about 6,000 kg of grain and 10,000 kg of vegetative matter including roots will remove approximately 150 kg N, 60 kg P_2O_5 and 50kg K_2O from every intensively cultivated hectare. While the practice of ploughing in of fodder after the harvest of earheads, as prevalent in the United States, returns a portion of these major elements to the soil, the habit of cutting the forage and sometimes digging the roots for fuel, as prevalent in India, results in virtually no return of these elements to the soil by way of crop residues. Lack of nitrogen during grain formation would reduce the endosperm protein considerably, resulting in low nutritional quality. Besides the major elements, specific situations may demand a supply of other elements such as calcium, magnesium, iron, zinc etc.

As against such a heavy demand of major fertilizer elements to raise a good crop of sorghum, the actual supply of nutrients by farmers in India is almost nil and sometimes meagre. Apart from the vagaries of the Indian monsoon, it is essentially this lack of application of even the major fertilizer elements like N and P which is responsible for the low national average yields of only 500 kg/hectare against the potential of 5000-6000 kg/hectare.

A good field of C.S.H-1

No doubt, some high yielding hybrids and varieties like CSH-1, CSH-2, CSH-3 and *Swarna* have recently become available to farmers. Unless and until the practice of adequately fertilizing the commercial crops is resorted to, there is little scope of improving upon the present national averages.

Response to nitrogen

Fairly extensive studies were carried out in different parts of the country to study the comparative response of high yielding hybrids, varieties and locals to different rates of nitrogen. These studies have revealed that the response of CSH-1, CSH-2, CSH-3 and *Swarna* was much superior to the local varieties, establishing their genotypic superiority over locals. Even though all the entries were not common at various locations, an examination of the pooled responses during the past 3 year period establishes this fact.

1967 (average of five trials—local not included in the trials)

CSH-1	$Y = 2220 + 23.8N - 0.060N^2$
Swarna	$Y = 2050 + 24.2N - 0.064N^2$

1968 (average of 10 locations—local included only at 4 locations)

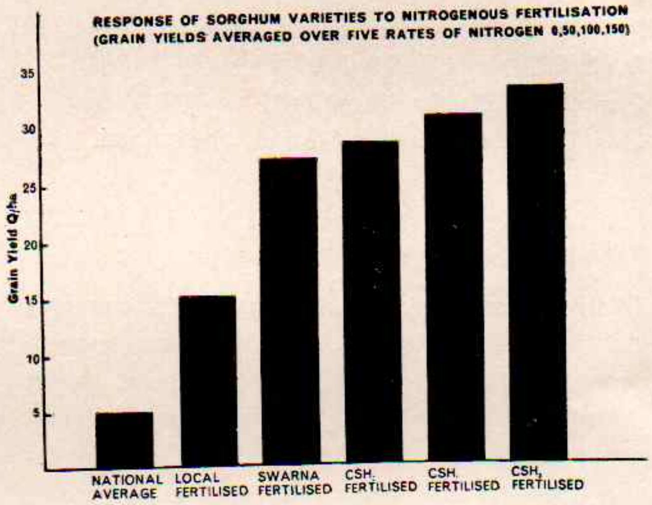
CSH-1	$Y = 2111 + 22.2N - 0.073N^2$
CSH-2	$Y = 2019 + 17.4N - 0.049N^2$
Swarna	$Y = 1793 + 16.1N - 0.054N^2$

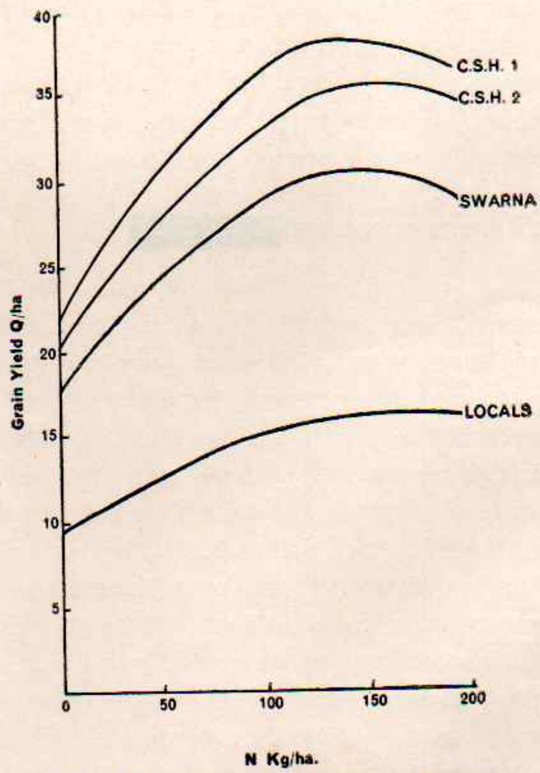
1969 (average of 5 locations—local included in 3 locations)

CSH-1	$Y = 1881 + 26.3N - 0.082N^2$
CSH-2	$Y = 1945 + 15.8N - 0.033N^2$
CSH-3	$Y = 2131 + 21.8N - 0.064N^2$
Swarna	$Y = 1486 + 22.2N - 0.062N^2$
Local	$Y = 1536 + 11.9N - 0.023N^2$

Note : The locations did not necessarily represent areas of adaptation for the respective hybrid/variety. Local was not included in all trials since the superiority of CSH-1 was established. The trials were rainfed.

The economic optimum level of nitrogen for the high yielding varieties varied between 130-200 kgs. N/hectare. The mean grain yields averaged over the different N levels in rates of nitrogen experiments conducted in different states is presented in Table 1 and diagrammatically in Fig. 2.





RESPONSE OF SORGHUM ENTRIES TO N LEVELS (1968-K).

TABLE 1

Response of Sorghum varieties to application of nitrogen-grain yield in quintals/hectare averaged over 5 levels of nitrogen 0,50,100,150, 200 kgs/hectare from rates of N trial conducted over several locations

State/location	Year	Local improved	Yield in Quintals/hectare			
			CSH-1	CSH-2	Swarna	CSH-3
Andhra Pradesh						
Dhone	1965	10.8	27.2	—	—	—
Guntur	1966	5.4	22.6	—	—	—
Vizianagaram	1967	—	47.6	—	39.3	—
Nandyal	1967	—	19.8	—	23.4	—
Nandyal	1968	18.7	22.0	21.5	17.5	—
Hyderabad	1967	—	38.2	—	42.0	—
Hyderabad	1968	—	23.5	—	16.7	—
Mysore						
Dharwar	1965	13.6	51.1	—	—	—
Dharwar	1967	—	59.2	—	59.1	—
Maharashtra						
Nagpur	1968	18.5	37.1	39.4	28.7	—
Dhulia	1969	35.8	41.9	40.2	40.3	43.7
Parbhani	1968	—	37.8	34.9	30.5	—
Parbhani	1969	—	33.8	17.5	25.4	20.3
Madhya Pradesh						
Indore	1968	15.8	18.6	26.4	20.8	—
Rewa	1969	13.4	24.5	23.3	26.4	25.0
Gujarat						
Tancha	1967	—	22.0	—	20.0	—
Surat	1967	—	17.6	—	17.0	—
Surat	1968	14.3	21.2	15.9	19.2	—
Rajasthan						
Bassi (Jayapore)	1965	11.9	13.9	—	—	—
Tonk	1968	15.2	23.5	11.9	15.7	—
Uttar Pradesh						
Pantnagar	1968	—	44.1	39.8	36.9	—
Tamil Nadu						
Coimbatore	1968	—	39.9	27.0	38.5	—
Coimbatore	1969	14.3	29.6	32.2	14.7	38.8
Delhi						
I.A.R.I	1968	—	32.5	31.8	18.9	—
	1969	—	34.4	38.3	31.9	39.5
Average		15.6	31.3	28.6	27.8	33.5
No. of test locations		(12)	(25)	(14)	(21)	(5)

Response to phosphorus & potash

Information from NPK trials conducted during 1965-69 including some on cultivators' fields, reveal a significant response to N at all locations; to P at several locations and response to K was almost negligible at most locations. The NP and PK interactions were also significant at some locations. Experiments on cultivators, fields at Dharwar and Indore brought out the response of P as revealed by the following response equations:

Dharwar : $Y=2113+72.41P-0.628P^2$
Indore : $Y=952+29.27P-0.279P^2$

Fertilizer recommendations

While it is always better to have fertilizer recommendations based on soil analysis, the following general recommendations could be made for fertilizing grain sorghums.

A. Nitrogen fertilizers

(i) Apply 100-120 kg N/hectare in areas of assured high rainfall (400-500 mm per season or more). This should be applied one half at sowing time and one half at about the knee-high stage (about 30 days after sowing).

(ii) Apply 80 kg N/hectare in low rainfall areas. 40 kg. N/hectare should be applied at planting. The remaining 40 kg N/hectare should be side-dressed at about the knee-high stage, if there is sufficient rainfall. *If the rainfall is insufficient, no additional application of N should be made.*

B. Phosphorus fertilizers

Soil test information be used wherever possible. If no soil test information is available, apply 60 kg P_2O_5/hectare in high rainfall areas, and 40 kg P_2O_5/hectare in low rainfall areas.

C. Potassium fertilizers

Research information indicates that response to potassium is very infrequent. Therefore, no potassium should be applied except in those soil areas known to be deficient in potassium. A soil test is a good indicator of the potassium status of soils.

Method of placement

When fertilizers are applied in direct contact with sorghum seeds, injury to germination frequently occurs. The best placement of fertilizers for sorghum is in a band along the row, two inches to the side and at least two inches deep. This is best done with a seed-cum-fertilizer drill.

Conclusion

While critical and sophisticated studies could yield valuable experimental data, the fertilization of sorghum with adequate nitrogenous fertilizers alone could increase the yields of high yielding varieties six times more than the national average. At corresponding levels of nitrogen application, the response of the new varieties is more than double in comparison with locals. Inspite of the fluctuating monsoons, the use of high yielding varieties together with the application of 80-100 kg. N per hectare and suitable plant protection measures, could result in the stabilisation of grain sorghum yields at least at 2,500 kg/hectare as against the all India average of 500 kg/hectare.

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Sorghum Breeding in India: Recent Developments

N. Ganga Prasada Rao

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7. SORGHUM BREEDING IN INDIA : RECENT DEVELOPMENTS

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I. Introduction

World sorghum acreages and production during the past decade have been continuously increasing. While these increases are spectacular in areas where sorghums are of relatively recent introduction for feed and forage, the areas as well as production levels remained stagnant in countries like India and parts of Africa where sorghum culture has been ancient and sorghums constitute a major food crop. This is a disturbing situation which needs critical analysis and ameliorative measures. Recent researches in India offer potentialities for rapid transformation ; the present paper is an attempt at projecting the results of sorghum breeding during the past eight years.

II. Varietal Improvement

Sorghum occupies more area than any other crop except rice in India

Contribution from the All India Coordinated Sorghum Improvement Project.

and is the most important among the food crops grown under rainfed conditions. From an annual area of over 18 million hectares, the harvest of grain is only about 9 million metric tons reflecting the low level of national average yields, less than half a tonne per hectare. Maharashtra, Mysore, Andhra Pradesh, Madhya Pradesh, Gujarat, Rajasthan, Uttar Pradesh and Tamilnadu, are the States where grain sorghum is chiefly grown.

Most grain sorghums of India belong to *Sorghum durra*, *S. cernuum* and *S. subglabrascens* of Snowden (1936). Cultured under different seasonal, soil and climatic conditions, Indian sorghums exhibit a wide range of variability with respect to duration, panicle morphology and grain quality.

A. Early Work

Natural selection and domestication over thousands of years has resulted in the development of numerous varieties highly local in their adaptation. Most of the present day improved varieties are the result of pure line selection practised in principal local varieties. Limited intervarietal hybridisation followed by selection has primarily contributed towards combining the then existing levels of grain yield with juicy stems to improve forage quality; noticeable changes in yield levels were not marked. Prominent among those who contributed to the genetics and breeding of sorghum in the early years were G. N. Rangaswamy Ayyangar and his colleagues from the then Madras State and Rao Saheb Kottur and his colleagues from the then Bombay State. A review of the earlier varietal improvemental work by Chavan and Shendge (1957) reveals that in spite of the availability of over a hundred improved strains, the yield levels remained low representing marginal increase (10-15%) over the base populations. Notable among the varieties developed during this early period and are still under cultivation are the *Co* series in Tamilnadu; the Nandyal, Guntur and Anakapalle series of Andhra Pradesh; the *PJ kharif* and *rabi* selections, *Saonar*, *Ramkel*, *Aispuri*, the *Maldandi* and *Dagadi* (compact headed) selections of Maharashtra; the *Bilichigan*, *Fulgar white*, *Fulgar yellow*, *Kanvi*, *Nandyal*, *Hagari*, *Yanigar* varieties of the Mysore State; the *Budh Perio*, *Sundhia and Chasatio* of Gujarat; the selections of Gwalior and Indore from Madhya Pradesh; the *RS* selections of Rajasthan and a few others. In addition, there are also special varieties for popping, parching and to suit special requirements. The age old association and the consequent local preferences for the taste of the respective local varieties are the dominant reasons for their continued cultivation in spite of their erratic behaviour and low yields.

An examination of the trends in sorghum production in India does not reveal any marked increases in yields, the per hectare averages ranging from 400-480 kgs. The cultivation of tall, long duration varieties over a vast proportion of the area the yields of which are most affected in years of drought, almost the total absence of the practice of fertilization and the tradition of growing sorghums only under low populations have been the major limiting factors in realising higher yields.

B. Performance of Recent Hybrids and Varieties

As a result of the efforts under the accelerated hybrid sorghum project initiated by the Indian Council of Agricultural Research during the year 1962, which became a comprehensive Coordinated Sorghum Improvement Project from the beginning of the Fourth Five Year Plan Period (1969-70), four commercial hybrids, CSH-1 (1964), CSH-2 (1965), CSH-3 (1970), CSH-4 (1970) and an improved variety *Swarna* (1968) were released for general cultivation. The development and release of these new hybrids and varieties marked a genetic breakthrough in the otherwise stagnant yield levels. The hybrids yielded 60-100% more grain than the presently available improved varieties. Comparative yields of the new hybrids and local improved strains from rainfed yield trials and the performance of CSH-1 in national demonstrations all over India (Kanwar, 1971) are depicted in Figs. 7-1 and 7-2 respectively. The superior response of hybrids and locals to fertility and population levels will be presented at this symposium by Mr. Mahendra Singh and his colleagues. In spite of the severe drought conditions which existed during the years 1965 and 1966, the average grain yields of CSH-1 in no year were less than 2500 kg/ha. The linear response of the new hybrids and varieties to nitrogen application was three times that of the local improved varieties. The response of the erect leaved *Swarna* to increased populations was well demonstrated.

The recent breeding work resulting in the development of high yielding hybrids and varieties was presented by House and Rao (1966), Rao and House (1966), Rao *et al.* (1966), Rao (1969), Rao *et al.* (1969) and Swaminathan *et al.* (1971).

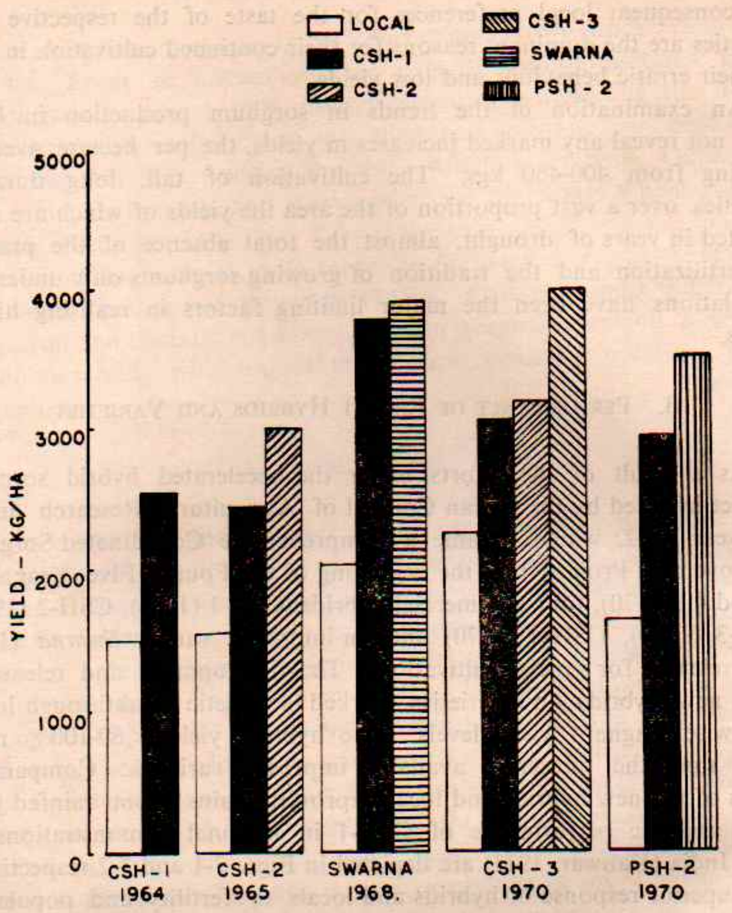

FIG. 7-1. Comparative performance of released hybrids and varieties (based on release data).

C. STABILITY OF PERFORMANCE

An ideal variety is one that combines high yield and stability of performance. Stability assumes increased importance in breeding dry land crops, the yields of which are subject to climatic fluctuations.

The indigenous varieties are known to be highly local in their adaptation. Even within a given region, the late varieties frequently failed under moisture stress caused by erratic monsoons. Studies on

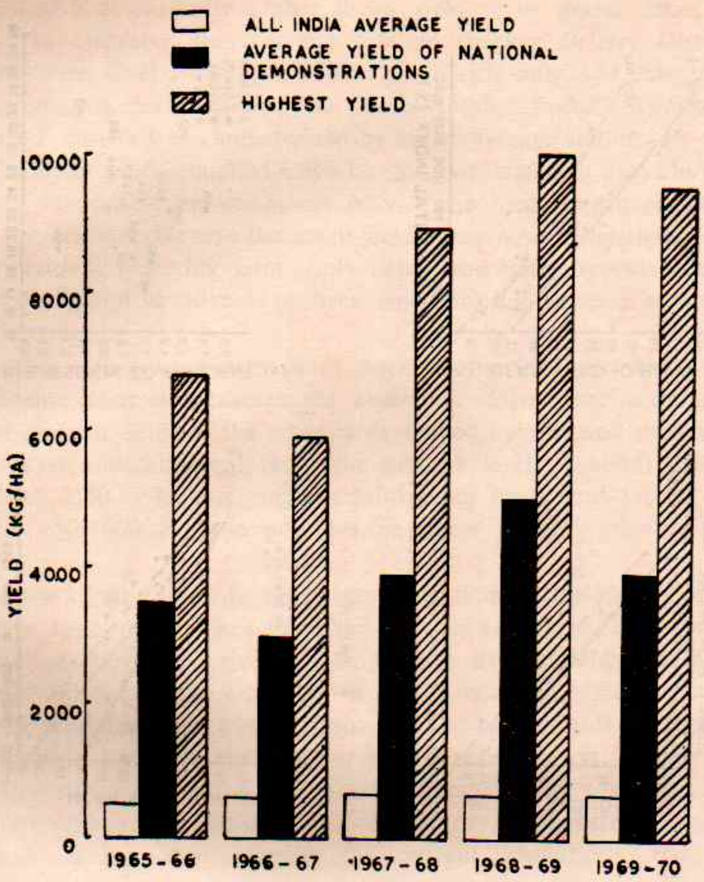

FIG. 7-2. Performance of CSH-1 in national demonstrations (Kanwar, 1971).

$g \times l \times y$ interactions by Rao (1970a) indicated that hybrids were consistently superior over varying environments. The superiority of the hybrids was more pronounced when the yields of the locals tended to be low obviously on account of moisture stress and other unfavourable growing conditions.

Studies of Rao and Harinarayana (1969) on the phenotypic stability of hybrids and varieties (Fig. 7-3) brought out the consistency of yield performance of hybrids, particularly, under stress. CSH-1 was the best genotype that was consistently high in performance over several environments. It had an average stability index, *i. e.*, *b* value close to 1.00

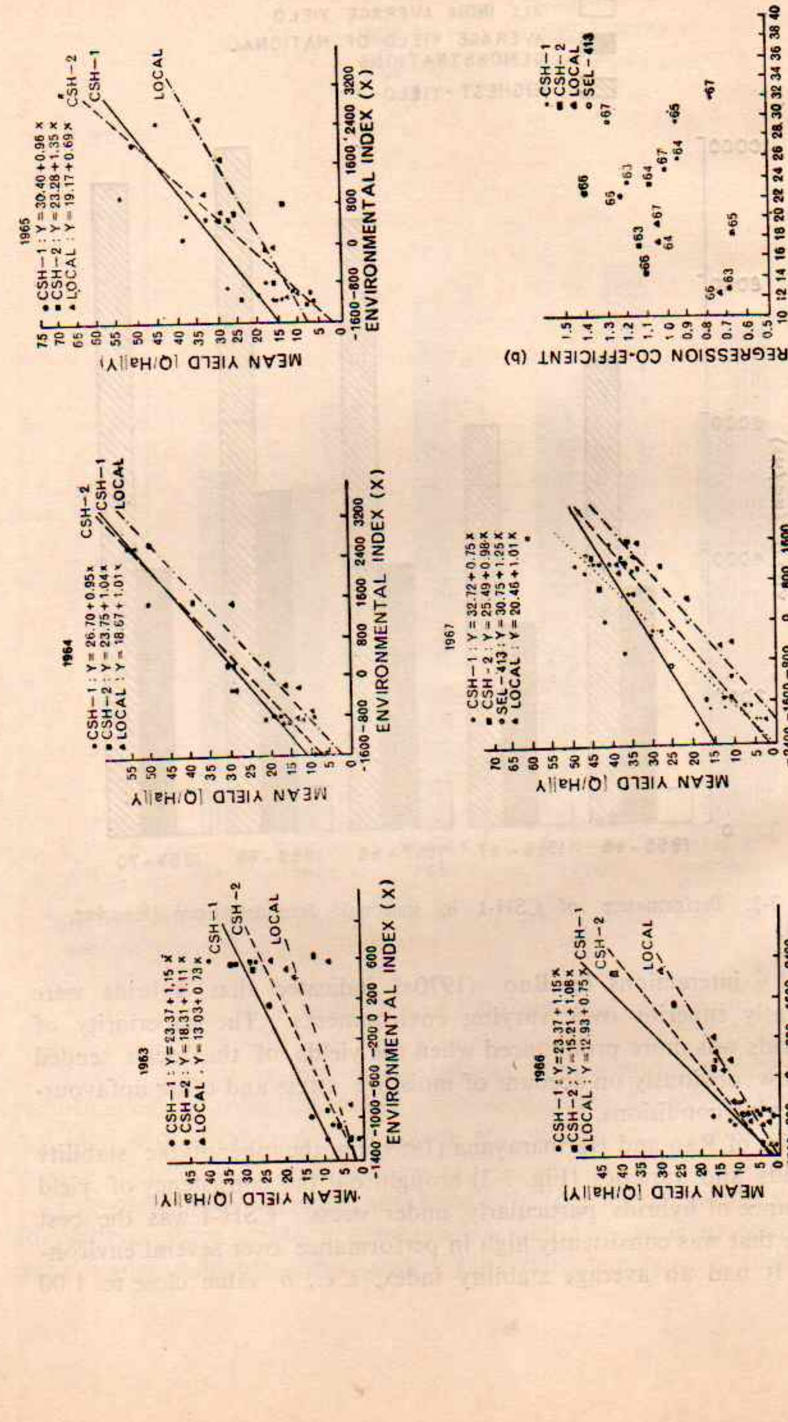

FIG. 7-3. Stability of performance of hybrids and varieties.

coupled with consistently higher mean yields over grand mean in all years. In extensive areas of the drought stricken Bellary District of Mysore State, CSH-1 averaged 2500 kg/ha with only 184 mm rainfall during growth period when the locals totally failed. *Swarna*, the improved variety was characterized by above average stability (b >1.00) and the mean yields equalled CSH-1. *Swarna* tended to outyield CSH-1 in more favourable environments only. The local improved varieties were the least stable and the mean yield levels were lower than the rest. The individual buffering commonly associated with hybrids seems to confer an adaptive advantage over true breeding varieties particularly under stress.

Further, data on optimum plant populations, fertilizer doses, insect and disease control measures are available. Given the recommended inputs, average yields of the recently developed hybrids and varieties can be elevated and stabilised from the present level of about 500 kg/ha to at least 2500 kg/ha even under conditions of stress and yields of the order of 5000-6000 kg/ha are feasible under normal growing conditions.

In spite of all this data and significant demonstration on farmers' fields, in spite of the benefits which accrued to hybrid seed producers, in spite of fairly extensive and impressive hybrid fields on farmers' holdings and despite the suitability of early hybrids to the practice of multiple cropping, the overall impact of the new hybrids and varieties on the national average yields of sorghum is yet to be felt. Apart from extension efforts, it will be necessary to further tailor sorghums to suit the preferences and requirements of the dry land farmer and the consumer taking into account the current limitations and future needs.

D. General and Specific Adaptation

One of the remarkable achievements in plant breeding in recent years has been the development of high yielding cereal varieties, particularly, rice and wheat, with wide ecological adaptability. While the advances in yield improvement in sorghum are comparable to those of rice and wheat and in spite of the established fact that the sorghum hybrids are more versatile than the varieties, barriers to spread of sorghum still exist. The reasons for this appear to be more due to lack of efforts rather than any real barrier to adaptability.

Studies of Rao (1970a) in India revealed that sorghums could be bred for few large maturity zones in the country at least within a season rather than several small regions limited by state and geographic barriers. That genotype × season interaction could be a major factor in limiting the heterotic expression of economic characters was established by Rao (1970b). The number of panicle branches was the component most affected during the winter season and selection of parents stable for this character together with photoinsensitivity was visualised to enable breeding of hybrids or varieties which could be grown across seasons as well.

Cultivation of winter sorghum is perhaps unique in India, but in the wider context, the Indian *Kharif* (monsoon) season compares to sorghum growing conditions in Africa and many other countries. Information on the genotype × location × year interactions during this season is, therefore, more amenable for wider application. From Indian studies, two sets of data are available on this aspect (Rao, 1970a; and unpublished data). In both the studies the g × y interaction was not significant indicating that marked superiority over a large number of locations even during a single year could enable release of new hybrids or varieties resulting in saving of time and effort. The mean squares due to locations were of considerable magnitude in both the studies, but the relative magnitudes of mean squares for g×1, 1×y and g × 1 × y varied in the two studies. As would be presented by Rana and his colleagues at this symposium, geographic barriers may not present any limitations to wider adaptability provided the performance levels are high and coupled with photoinsensitivity. Regarding genotypic responses to varying environments, the advantages and disadvantages of varieties and hybrids in relation to environmental stress have been discussed at some length earlier and this does not at any rate appear to provide anv barrier to adaptability over wide regions.

The question of general *vs.* specific adaptation has been raised many times but a mechanism of testing the available promising varieties or hybrids over wider geographic regions could not only provide answers to questions on adaptability, but would also enable profitable utilisation of breeding material developed any where. This aspect of organised testing needs some consideration and direction.

III. Selection in Exotic × Indian Crosses

The development and release of high yielding hybrids and *Swarna* primarily based on exotic breeding materials and the accelerated change in the varietal composition have brought to the fore problems of consumer preference, price differentials and increased incidence of insect pests. An extensive program of hybridization between early, dwarf, exotic sorghums and late, tall Indian sorghums was therefore initiated during 1965-66 and this has now yielded valuable breeding material of economic worth as well as basic genetic information.

A. Heterosis

With Kafir 60 as the common female parent, traditional improved Indian varieties of sorghum used as pollinator parents did not result in hybrids of commercial value. This was attributable to lack of heterosis during the *kharif* (July-October) season, an undesirable plant type and difficulties in threshability, besides practical problems involved in establishing crossing blocks between parents widely different in height and maturity. During the *rabi* (October-January) season, limited heterosis, relatively inferior grain quality compared to local *rabi* varieties and greater susceptibility to shoot fly did not permit development of commercial hybrids between Kafir 60 and Indian *rabi* varieties. The first hybrids were, therefore, exotic × exotic combinations and were recommended primarily for the *kharif* and summer seasons.

Analysing the reasons for the lack of heterosis in some Kafir 60 × Indian crosses, Rao (1970b) felt that the emphasis in evolution of the compact headed Indian varieties was on the girth of the panicle while in most of the dwarf exotics panicle length was more pronounced. Heterosis for panicle components seems to be maximum for characters evolved in the same direction. Even recovery of promising segregates may be more frequent if the diverse parents involved have similar panicle morphology.

Further studies involving crosses between diverse exotic dwarf early parents and tall late Indian varieties (Rao, 1970c) revealed that such crosses could be as heterotic as exotic × exotic combinations with the exception of CSH-2 which was the most heterotic exotic × exotic combination studied (Table 7-1).

What is of greater importance than the magnitude of heterosis itself is the range of yield levels in these three groups of crosses *viz.*, exotic × exotic, exotic × Indian and Indian × Indian. The highest yielding crosses are some of the exotic × Indian combinations (Rao, 1970c). These results were further confirmed by studies of Kang (1969) and Nanda (1971). It was, therefore, felt that the answer to a major genetic

TABLE 7-1. *Range of Yield Levels and Heterotic Responses from Diallel Crosses (Rao, 1970)*

Character		Exotic × Exotic	Exotic × Indian	Indian × Indian
1. Grain yield (gms/plant)	Mean	58 to 113	81 to 149	91 to 125
	Heterosis	3 to 68	−9 to 45	−9 to 21
2. Days to flower	Mean	62 to 88	82 to 93	97 to 109
	Heterosis	0 to 50	−1 to 37	−4 to −1
3. Plant height (cms)	Mean	116 to 181	180 to 293	253 to 305
	Heterosis	10 to 57	32 to 85	6 to 22

Heterosis = $(\overline{F}_1 - \overline{SP})/\overline{F}_1 \times 100$

improvement in yield performance of future hybrids lies in developing known combinations into males and females and correcting the drawback of excessive height and late maturity of Indian parents.

B. COMBINING ABILITY

Studies on combining ability and components of genetic variation involving exotic × Indian crosses revealed that while the gene action for days to flower and plant height was essentially additive, the general and specific combining ability variances were of equal magnitude for yield (Rao, 1970c). The importance of specific combining ability, particularly, in crosses involving diverse germ plasm was also brought out by the studies of Niehaus and Pickett (1966), Malm (1968) and Liang *et al.* (1968, 1969).

The *gca* effects revealed distinct differences between the dwarf and tall parents. The *gca* effects of tall parents particularly for yield are in a desirable direction and are of considerable magnitude, whereas the *gca* effects for dwarf parents are in the negative direction (Table 7-2). Such diverse exotic × Indian crosses also permit identification of cross combinations with high general and low specific effects for purposes of selection and those with high specific and low general effects for exploiting in programs of hybrid development.

TABLE 7-2. *Estimates of General Combining Ability (Kang, 1969)*

Parents	Grain Yield	Days to 50% Bloom	Plant Height	Nitrogen Uptake	Protein Content
1. Dwarf Exotic					
Kafir B	−33.18**	−7.63**	−51.14**	−0.47**	+0.19**
IS 3691	− 1.77	−5.53**	−55.42**	−0.18	+0.35**
Swarna	− 4.16*	−2.83**	−17.02**	−0.24	+1.27**
2. Tall Indian					
R. 173	+12.46**	+5.78**	+46.03**	+0.30	+0.02
R. 170	+ 9.46**	+5.84**	+41.22**	+0.43*	−1.08**
R. 160	+ 2.52	+3.50**	+29.90**	+0.14	−0.67**
R. 168	+14.57**	+2.77**	+47.36**	+0.36	−0.08**
S. E. $(\hat{g}_i)$	±2.27	±0.25	±0.85	±0.23	±0.02

*Significant at 5% **Significant at 1%

Graphic analysis of diallel data of exotic × Indian crosses by Rao (1970c), Kang (1969) and Nanda (1971) reveal that the distribution of dominant and recessive alleles for grain yield, plant height, flowering and total protein and lysine is asymmetric and in opposite directions (Fig. 7-4). The tall Indian varieties possess the dominant alleles for yield and plant height whereas the dwarf exotics have alleles for earliness. While the dwarf exotics are rich in protein, the desirable alleles for lysine are more prominent in the tall Indian varieties. Efforts to bring together the recessive alleles for height with dominant alleles for flowering (earliness) and yield in homozygous condition through recombination present difficulties and appear to be the chief cause of limited success in variety hybridization programs.

C. CHARACTER ASSOCIATION

The role of height and maturity genes in growth control has been analysed in detail by Quinby (1967). Tropical varieties have been reported to be dominant at the first maturity locus whereas the temperate varieties are generally recessive at this locus. The maturity locus Ma_1

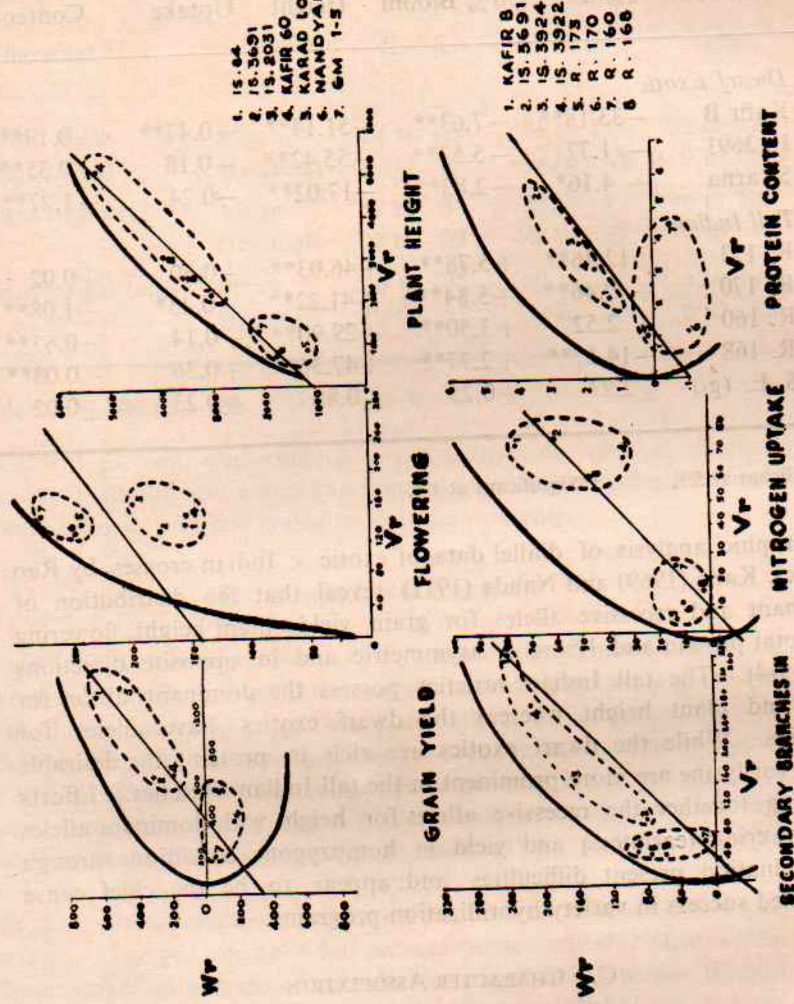

Fig. 7-4. Graphic analysis of diallel data from exotic × indian crosses (E : Exotic group; I : Indigenous group).

in the heterozygous condition increases yield and is also linked to the second height locus Dw_2 which in turn influences yield and days to flower (Graham and Lessman, 1966). It is also known that the Dw_3 locus alters the yield potential substantially (Casady, 1965). Thus the three loci Ma_1, Dw_2 and Dw_3 are pleiotropic. From a chi-square analysis of association in F_2 generation between yield, maturity and plant height, Harinarayana, Rao and Venkataraman (1971) obtained evidence of pleiotropic effects of flowering and height genes and they suggested handling of large number of crosses in preference to intensive handling of few crosses while attempting recombination from crosses involving divergent parents for height and maturity.

Further studies on association between maturity, plant height and yield in advanced generation progeny by Subba Reddy and Rao (1971) also established the positive relationships between flowering and yield, plant height and yield, flowering and plant height and panicle branches and yield. These associations have been maintained through five generations of selection. Partitioning of the correlation coefficients through path analysis indicated while in the parental group both direct and indirect effects of flowering and plant height were pronounced, in the F_5 progenies, the indirect effects of flowering and height were dissipated (Fig. 7-5). The indirect effects of other components like grain weight assumed greater importance in later generations of selection. Studies on correlated reponse and selection indices also revealed these inter-relationships among flowering, plant height, yield and panicle branches which appear to be the most important components of fitness.

Further studies on character association based on the different groups *viz.*, (i) the tall and late parents, (ii) the dwarf and relatively early parents and, (iii) high yielding advanced generation segregates, intermediate in height and maturity between the parental groups yielded interesting results (Rao *et al.*, under publication).

This group analysis (Table 7-3) reveals that prolonged natural selection among grain sorghums resulted in the establishment of tall and late forms, the individuals of which were superior relative to their performance in a population; hybridization and selection among such forms did not markedly alter this situation. On the other hand perpetuation of dwarf and early forms under human selection resulted in the isolation of populations which may be considered superior, particularly under intensive cultivation, but the individuals contributing to the population were themselves inferior; commercial hybrids constituted from such dwarf populations contributed to considerable increase in

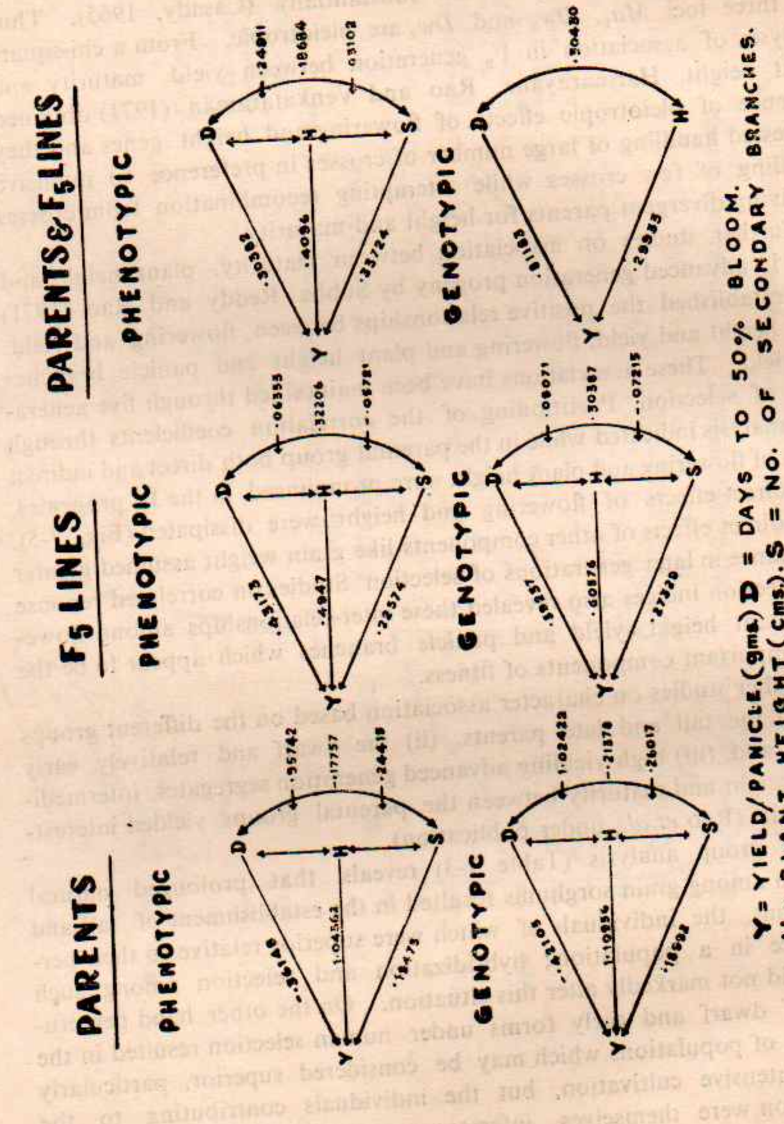

Fig. 7-5. Path analysis of parents and advanced generation progeny (Subba Reddy and Rao, 1971).

yield levels. Thus, association of characters conferring fitness in the two groups of populations is different and is frequently the limiting factor in recombining the desirable attributes of both groups under conventional hybridization followed by selection. Surprisingly, these associations in the productive intermediate group are almost absent or insignificant.

TABLE 7-3. *Group Means and Correlations Between Yield, Days to Half-Bloom and Plant Height (Rao et al., Unpublished)*

		DE	DE×DE	DE×TL	TL×TL	TL	IS
A. Means							
Yield (gms/plant)	(Y)	45.7	86.8	112.7	103.5	86.0	101.8
Days to half-bloom	(X)	70-9	73.7	87.1	104.3	107.3	83.7
Plant height (cms)	(Z)	111.3	148.5	241.8	287.3	258.2	164.1
B. Phenotypic Correlation Coefficients							
γ_{xy}		0.91*	0.82**	0.23	−0.53	−0.41	0.18
γ_{zy}		0.89*	0.70*	−0.17	0.22	0.28	0.26
γ_{xz}		0.76	0.81**	−0.42	−0.64	−0.89	0.36**

DE = Dwarf, Early (Exotic) parents ;
TL = Tall, Late (Indian) parents ;
IS = Intermediate Selections from Exotic × Indian Crosses.
*Significant at 5%; **Significant at 1%.

The dynamics of association between grain yield, maturity and plant height under natural and directional selection have brought out the feasibility of establishing productive intermediate populations with little association between the three characters. Such populations are not only of direct utility but might also furnish the bridge populations from which gene transfer could be accomplished with relative ease. The chances of establishment of such intermediate populations in nature are remote and could be achieved only under conscious selection and through perpetuation of selected forms.

D. Selection Limits

The limit to progress from selection is a function of initial genetic variability, new genetic variabilities introduced and the selection scheme employed. From a practical breeding point of view, the visible limit is the identified highest yielding F_1 hybrid. From the studies so far made some of the exotic × Indian crosses yielded the highest yielding F_1's. The resulting hybrids are tall and tend towards lateness. Tallness is not an advantage to capitalise on population performance and the development of a commercial hybrid in one step from such combinations also gets ruled out. The alternative is to explore the possibilities of isolating suitable (dwarf and relatively early) segregates that are true breeding and tend to equal the corresponding F_1 in yield levels. Transgression of parental limits is known to occur but could a highest yielding F_1 be transgressed through selection? The problem is not certainly a simple one and needs an understanding of the various factors that influence response to selection.

Directional selection for one character in a population will bring about changes in other characters. Upon relaxation of selection, random mating populations tend to revert back to the original state, but this is not so under inbreeding. Every component of the population depends on every other component and hence the population is an integrated and cohesive system (Allard, 1966). The interrelationships among the integrated genotypes constituting the population demonstrate the complexity of co-adaptation and the obstacles involved in changing an integrated genotype.

The first and foremost principle is that the kinds and amounts of variation and response to selection are interrelated. When the amount of additive variance for a trait is known, the degree of change in the trait by various selection methods could be predicted. Identification of high yielding cross combinations with high general and low specific effects is a useful step. The choice of parents based on the performance of line *per se* together with the nature of combining ability has been suggested (Rao, 1968).

This information facilitates a decision on the type of selection to be practised. When selection is practised simultaneously for several traits character association and correlated responses restrict gain from selection. The influence of height and maturity genes on grain yields was adequately discussed. These associations may be due to divergent causes such as linkage, pleiotropy and physiological associations and each situation calls for ameliorative measures. The role of intermating in segregating generations is being increasingly emphasised (Doggett, 1970; Koenig and Gardner, 1971). Experience from exotic × Indian crosses suggests handling of large number of crosses in preference to intensive handling of a few crosses while attempting recombination involving divergent parents for height and maturity.

Studies of Comstock (C. F. Kojima, 1969), on long term selection in mice where continued response without loss in additive genetic variance from a mass selected population of narrow genetic base involving a cross of only two inbreds is a significant pointer to plant breeders involved in the improvement of self-pollinated crops. The availability of continued variability was attributed to polygenic mutations which need to be capitalised in breeding self-pollinated crops like sorghum.

Similarly, the work of Bell (1969) and his colleagues on major and minor genes in relation to genetic background is also of considerable importance. Unlike rice and wheat the genes for dwarfing and earliness which appear to be interrelated in sorghum have adverse effects on grain yield. The effects of the major genes for height and flowering in sorghum in diverse genetic backgrounds needs further study. The thinking of Thoday (1967) that continuous variation can be effectively exploited by non-biometrical techniques also deserves attention.

Conventional hybridization followed by selection in exotic × Indian crosses, though frustrating to start with, some crosses yielded promising progenies. With a reduction in height and maturity, the yield levels have transgressed the superior parent but not the corresponding F_1 hybrid. The breeding material, presently in advanced stages of selection and testing, appears superior to the available commercial hybrids. The coming one or two years will write the final words on their commercial utility, but such breeding material represents an 'intermediate optima' and may be of immediate direct utility to Indian and African needs besides its value as potential breeding material.

IV. Developing New Hybrids

As has been stated earlier, the first commercial sorghum hybrids CSH-1 and CSH-2 released for general cultivation in India are based on the introduced male sterile combine Kafir 60. The acceptance of this male sterile as the common female parent limited the choice to the pollinator parents only (Rao, 1970b). Since most male steriles have been essentially kafirs or kafir-milo derivatives, the genetic diversity for combining ability among A-lines has been observed to be generally less than among the restorer lines (King *et al.*, 1961). Extensive use of the limited diversity in the kafir, hegari, feterita, shallu and milo groups of U. S. A. as pollinator parents, has turned the attention of their breeders to the tropical germ plasm and its conversion to day length insensitive 4-dwarf forms. Thus the search for superior females and males has become imperative if the yield pleteaus attained by the present day hybrids are to be broken.

A. New Male Steriles

Since the chalky white grains of kafir place a limitation on grain quality immediate efforts in India were directed towards developing new steriles with corneous endosperm through substitution backcrosses in milo cytoplasm. At Coimbatore, Vidyabhushanam (1970) developed several such steriles, *viz.*, 2219A (kafir-shallu), 2077A, 3675A, 3677A (kafir types) etc., which are presently available to various breeders. CSH-3, a new hybrid released during 1970 is based on such a new sterile, 2219A.

The Maharashtra workers at Nagpur and later at Parbhani took to an indirect method of developing new steriles. They first crossed the tall Indian varieties (which are normally fertility restorers on milo-kafir sterility system) to Kafir B, identified sterility maintainers in the F_2 by test cross and carried them through several generations of backcrossing till a stable sterile was developed. The steriles resulting from such a program were ultimately derivatives of Kafir × Indian crosses and were close to Kafir in several respects with some refinements in grain quality. The male sterile 1036A, based on PJ 7R, has furnished the female parent for a new hybrid CSH-4 (1036A × *Swarna*). Several new steriles based on PJ 16K, PJ 1R, PJ 15R, *Shenoli*, etc., are presently available. The steriles so developed are all based on milo cytoplasm.

Rao (1962) reported the occurrence of cytoplasmic genetic male sterility in Indian sorghums and using this new cytoplasmic source, Rao and his associates converted M35-1 (an Indian winter sorghum) and IS 3691, a yellow *hegari*, into steriles. Both M35-1 and IS 3691 are restorers on milo-kafir sterility system. However, fertility restoration became difficult on these steriles and efforts are being made to take advantage of non-restoration to develop a random mating population (Rao, 1968) using this new source of cytoplasmic genetic sterility. Fertility restorers have also been identified recently and studies are in progress to use them in the development of commercial hybrids.

Additional sources of cytoplasmic sterility have been reported in *durra* (G2, VZM 1 and VZM 2) by Hussaini and Rao (1964). At Parbhani, steriles based on *feterita* cytoplasm are in final stages of development. At Raichur, another indigenous sterile M31-A is said to owe its origin to induced mutation. Sterile cytoplasms were also found in the grass sorghums, *S. arundinaceum*, *S. verticilliflorum*, *S. niloticum* and *S. sudanense* (Rose, 1965; Appadurai and Ponnaiya, 1967; and Allam and Sandal, 1967).

Thus it will be seen that besides the milo-kafir cytoplasmic-genetic male sterility mechanism, which has been extensively exploited so far, the new sources of sterile cytoplasm which need to be characterized may provide immense opportunities for future hybrids and need world wide exploitation.

B. Superior Restorers

First studies of converted restorer lines as pollinator parents with established steriles in the U. S. A. have not been very encouraging but further studies are said to be in progress (Koenig and Gardner, 1971). Similarly use of derived lines from exotic × Indian crosses on available steriles in India also did not indicate any major breakthrough in the yield levels of resulting hybrids although some hybrids do appear promising.

Induced dwarf mutants of an Indian variety, *Gidda maldandi*, have been extensively used as pollinator parents by the workers at Dharwar (Goud, 1970). While some of these hybrids also appear promising a major breakthrough is not yet visible.

C. Changes in the Magnitude of Heterosis and Combining Ability

Thus the effort and time spent in the development of the new steriles and restorer lines have not been really rewarding from the point of view of improvements in yield *per se* over the available commercial hybrids. This needs further analysis.

Evaluation of numerous male steriles introduced from U. S. A. by Reddy (1963) and Singhania (1968) using Indian as well as established restorer lines as common tester parents did not result in superiority over the released CSH-1 or CSH-2. Estimates of variances for *gca* were relatively larger. Rao, Rana and Tripathi (1968) evaluated new steriles developed by Vidyabhushanam (1970) in India but the results were no different.

In the Indian program, the **B** lines of the new steriles under development are being evaluated in multilocation tests and the results so far indicate that while the new restorers are definitely at higher yield levels, the B lines did not reflect such improvement for yield *per se* over Kafir 60. It, therefore, appears that improvement of the males alone may not result in significant hybrid superiority. The female parents also should be at a high yield level. Rao, Rana and Tripathi (1968) therefore, recommended conversion of known high yielding derived lines from the exotic × Indian program as females. Since most such lines are restorers on milo-kafir sterility, other sources of sterile cytoplasm may be of value in conversion of such superior lines into steriles and such a program is presently in progress.

Further, in view of the interrelationships between plant height and maturity, the inheritance of which is relatively simple and which are closely related to yield, it should be possible to identify a few major genes which contribute to substantial heterosis without simultaneous effects of increasing height or maturity. I visualise that the establishment of such marker lines with known genes for heterosis might provide an invaluable aid to the hybrid breeding projects.

V. Varieties, Hybrids and Populations

High genetic variability is a necessity in the breeding process itself, but homogeneity is a desideratum in the final product, the agricultural variety. It is well established that adaptation which is fitness to a given environment and adaptability or capacity for change in fitness are antagonistic. During the past century advances in agriculture were made through increased adaptation at the expense of serious losses in adaptability (Simmonds, 1962).

In countries where the seed industry is not advanced, high yielding varieties if available, have obvious advantages from the point of view of seed multiplication and rapid spread. Commercial experience with sorgum hybrids, however, suggests that the hybrids are generally advantageous, particularly, under stress obviously on account of superior homeostatic properties.

Soon after the advent of commercial sorghum hybrids which significantly altered the yield levels, there was also a tendency for the yield levels to plateau at least in a given maturity group (Maunder, 1969).

This is generally true of U. S. A., India and other countries. In the U. S. A. where the emphasis has been on hybrid programs the lack of variability in further stepping up of yield levels was felt and to get over this limitation a conversion program has been in progress to transfer the desirable genes from the tropical germ plasm of the world sorghum collection to dwarf U. S. types. While the contribution of the converted lines as varieties *per se* or to commercial hybrids is yet to be fully assessed, as has already been stated, indications are available that they do not have enough yield potential and their contribution to enhanced heterosis also does not appear to be significant (Koenig and Gardner, 1971).

Studies of Griffing and Langridge (1963) and Pederson (1968) on *Arabidopsis thaliana* suggest that in self-fertilized species, homozygotes and heterozygotes differ little in fitness under optimum conditions, but under unfavourable conditions the advantage of the heterozygotes has been striking. Sorghums in India and Africa are predominantly cultivated as rainfed crops and are frequently subject to environmental stress. As pointed out by Rao and Harinarayana (1969, the advantage of CSH-1, the commercial hybrid, was more striking under stress whereas the high yielding variety *Swarna* tended to outyield CSH-1 under more favourable conditions.

The behaviour of selected hybrids, and their male parents which were superior lines derived from exotic × Indian crosses were evaluated in three diverse environments by Singhania (1972). The results indicate that the hybrids were superior when the general yield levels were low, obviously due to unfavourable conditions, but some of the male parents tended to outyield the corresponding hybrids as the yields went up under more favourable conditions. Instances where the hybrids were superior to the males in both favourable and unfavourable conditions and where the hybrids were intermediate between the two parents were also recorded (Fig. 7-6 A & B). In general, the superior males tended to outyield the hybrids in favourable environments. Whatever may be the causes for the differential behaviour of hybrids and parents in relation to environmental stress, the general superiority of the hybrids under conditions of stress has been generally well established in the earlier studies of Rao and Harinarayana (1969) and also by Singhania (1971) and are in general agreement with the basic studies in *Arabidopsis*. Spread of hybrids under rainfed conditions, therefore, needs particular consideration.

Progress from directional selection in varietal crosses to select high yielding lines in Africa has not been generally rewarding and Doggett (1970) suggested practising of mass and recurrent selection procedures employing

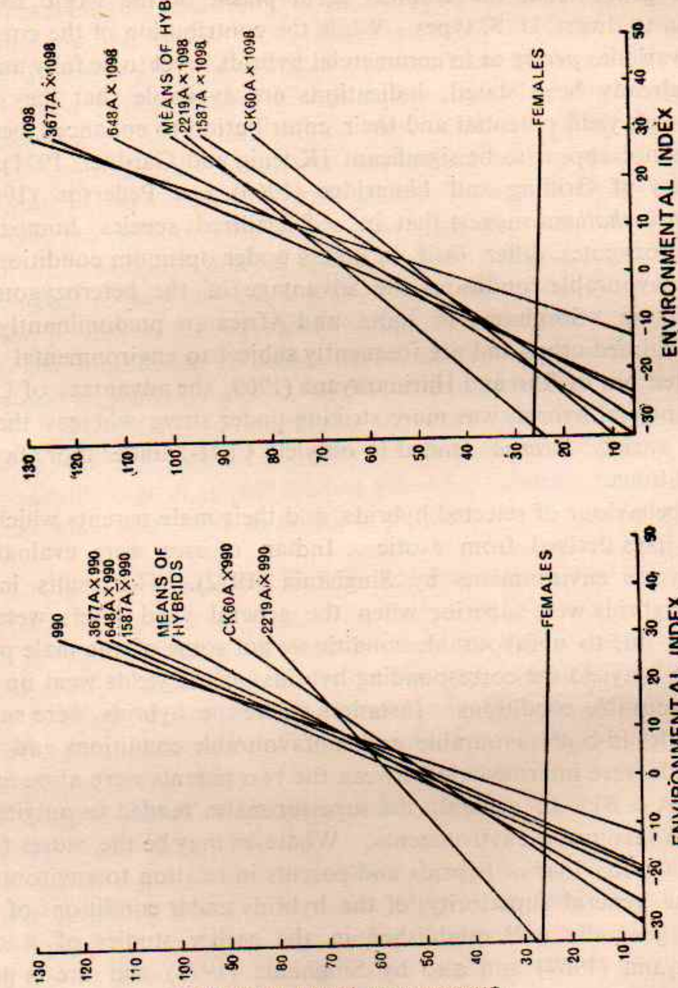

FIG. 7-6A. Stability analysis of parents and hybrids. Note superiority of males under favourable conditions (Singhania, 1972).

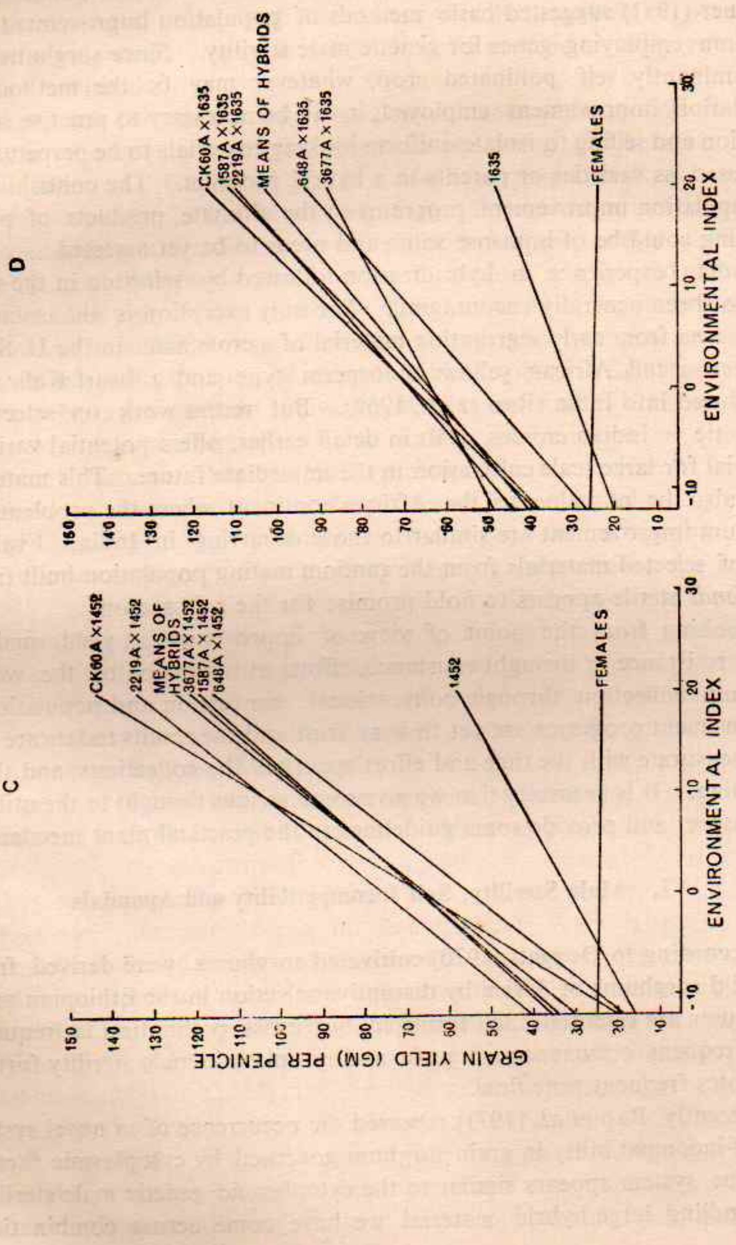

Fig. 7-6B. Stability analysis of parents and hybrids. Note hybrid superiority (Singhania, 1972).

genetic male sterility to aid recombination. Prompted by developments in corn breeding methodology, Doggett and Eberhart (1968) and Ross and Gardner (1971) suggested basic methods of population improvement for sorghum employing genes for genetic male sterility. Since sorghum is a predominantly self pollinated crop, whatever may be the method of population improvement employed, it will be necessary to practise some selection and selfing to isolate uniform looking materials to be perpetuated and used as varieties or parents in a hybrid program. The contribution of population improvement programs to the ultimate products of plant breeding could be of immense value and needs to be yet assessed.

Indian experience in hybridization followed by selection in the past has not been generally encouraging. The only exception is the isolation of *Swarna* from early segregating material of a cross made in the U. S. A. between a tall African yellow endosperm type and a dwarf Kafir and introduced into India (Rao *et al.*, 1969). But recent work on selection in exotic × Indian crosses, dealt in detail earlier, offers potential varietal material for large scale cultivation in the immediate future. This material may also be of value to the African continent where the problems of sorghum improvement are similar to those occurring in India. Evaluation of selected materials from the random mating population built from *Maldandi* sterile appears to hold promise for the *rabi* season.

Looking from the point of view of improvement in yield, quality, insect resistance or drought resistance, efforts at utilisation of the world sorghum collection through conventional, conversion and populational improvement programs are yet to bear fruit and the results todate are not commensurate with the time and effort spent on the collections and their screening. It is necessary that we give some serious thought to the utilisation aspect and provide some guidelines to the practical plant breeders.

VI. Male Sterility, Self Incompatibility and Apomixis

According to Doggett (1970) cultivated sorghums were derived from the wild sorghums of Africa by disruptive selection in the Ethiopian area. Sorghums are essentially self fertilized but cross pollination is frequent. The frequent occurrence of genic and cytoplasmic male sterility further promotes frequent gene flow.

Recently Rao *et al.* (1971) reported the occurrence of a novel system of self-incompatibility in grain sorghum governed by cytoplasmic factors and the system appears similar to the cytoplasmic genetic male sterility. In handling large hybrid material we have come across combinations which do not show reciprocal differences for seed set in F_1 but some F_2 segregates do not set seed on selfing. Such segregates persisted through 5-6 generations of selfing and selection. Whether the lack of seed set is due to male sterility or incompatibility and its genetic basis needs to be yet established.

The genes for male sterility and self incompatibility which might have been masked under natural selection are being perpetuated under human selection. Genes for genetic as well as cytoplasmic male sterility are being exploited in hybrid and population improvement programs.

Extensive hybridization in some exotic × Indian crosses resulted in some incompatible forms which under continued selfing and selection seem to have taken to an obviously alternate mode of apomictic reproduction. The establishment of obligate apomixis consequent on continued selfing and selection of incompatible forms was first reported by Rao and Narayana (1968). Subsequently, Hanna *et al.* (1971) reported a case of facultative apospory in a male sterile polygyneceous line of sorghum. Rao and Murty (1972) presented direct evidence for the autonomous development of endosperm and demonstrated the presence of unreduced egg and polar nuclei in the aposporus embryo sac. We have also come across a family segregating for male sterility, self incompatibility and apomixis. There are indications that apomixis based on male sterility, without the stimulus of pollen which was essential in the case of self incompatibility based apomixis, could be established in the near future. Thus, observations to date indicate a close but as yet not understood association between self incompatibility, male sterility and apomixis (Rao and Murty, 1971).

The role of apomixis in maintaining and perpetuating heterozygosity particularly in grain cereals has no doubt been emphasised. Its importance in the improvement of sorghum where commercial hybrids based on cytoplasmic-genetic male steriles have today contributed to substantial yield increases needs no re-emphasis. What is required is a concerted effort and pooling of resources to understand the genetic basis of obligate apomixis itself and its interrelationships with male sterility, and self-incompatibility. Gene cytoplasm interactions have been reported by Rao (1962), Rao *et al.* (1972), Appadurai and Ponnaiya (1968), Hussaini and Rao (1964) and various other workers, but efforts to characterise the diverse sterile cytoplasms and understand their utility have been less frequent. Two such efforts, one by a graduate student Mr. T. Nagur at Coimbatore and a second at our center are presently in progress.

A critical understanding of these related phenomena may, therefore, lead to greater advances in sorghum improvement in the coming years leading to the development of superior populations, which in turn could provide useful breeding materials for conventional and hybrid programs and eventually lead to the development of perpetual hybrids which could capitalise on the antagonistic demands of uniformity for immediate fitness and diversity for long term survival.

VII. Insect and Disease Resistance

Apart from yield, the major problem confronting sorghum improvement in India has been resistance to insect pests (shoot fly, stem borer, midge and earhead bug) and grain deterioration. The problem of breeding for insect resistance has not been very rewarding and this will be dealt by other workers at this symposium and only a brief mention will be made here.

Exotic breeding materials as well as the hybrids and varieties based on them were particularly susceptible to sorghum shoot fly (*Atherigona soccata* Rond.). Screening of the world collection over several years under field as well as artificially infected conditions by Drs. M. G. Jotwani, W. R. Young and their colleagues, established tolerant varieties which were mostly from the Indian *rabi* types. The following I. S. Nos. represent the most tolerant ones identified todate: 1034, 1054, 1061, 1082, 2122, 2123, 2146, 2265, 2269, 3902, 4522, 4545, 4553, 4567, 4607, 4646, 4664, 4776, 5072, 5251, 5285, 5383, 5469, 5470, 5480, 5483, 5490, 5566, 5604, 5613, 5615, 5622, 5633, 5636, 5658, 5801 and 8315. All these varieties are tall, late in maturity, photosensitive and generally low yielding. It is now almost quite definitely established that the resistance (tolerance) of these varieties is primarily due to non-preference for oviposition. Studies are in progress to develop dwarf to semi-dwarf and high yielding forms tolerant to shoot fly from the exotic × Indian crossing program.

Screening for stem borer (*Chilo zonellus*) based on stem tunnelling and leaf injury under field as well as artificially infected conditions was also attempted by Drs. Jotwani, Young and their colleagues. Amongst several tolerant types reported, mention may be made of I. S. Nos. 1020, 1041, 4008, 4142, 4182, 4218, 4225, 4244, 4247, 4299, 4404, 4443, 4471, 4505, 4512, 4827, 4872, 4886, 4987, 5024, 5026, 5031, 5076, 5119, 5727, 6086, 6098, 6102 and 6111. Most of the derived lines from exotic × Indian crosses presently under yield testing have tolerance to stem borer.

Diseases of sorghum have not been as serious as insect pests in India.

Screening work for disease resistance will be presented by Dr. N. V. Sundaram at this symposium. Head molds of hybrids have become serious in some areas. The early hybrids and varieties, though consistently high yielding, were frequently caught in September-October rains and there was fast grain deterioration, and the market value of grain goes down. Present results on breeding for resistance to 'head molds' and grain deterioration appear promising.

The Indian sorghums by and large are characterised by the presence of flavonoid pigments in the stem, leaf, glumes and seed coats which do not confer any mold resistance. The U. S. sorghums with brown seed colour are high in tannin which is known to affect their palatability. Brown sorghums at any rate are not acceptable in India. Some of the derivatives involving yellow endosperm parentage possess tannins in leaves as well as glumes and perhaps seed coats. Such types when caught in rains show less of grain deterioration. A redistribution of the plant pigments, particularly tannins, in such a way that they are high in glumes but low in seed coats might help development of types which do not deteriorate even if caught in rains or under humid conditions of coastal areas.

VIII. Nutritional Quality and Yield

Sorghums provide the staple diet for the low income groups of India and Africa where protein supplementation through pulses or other sources is negligible. Besides, sorghums are important as feed crops all over the world. While the exploitation of dwarfing genes together with heterosis resulted in spectacular improvements in grain yield enabling it to compete with maize, the nutritional status of sorghum is no where near that of maize where the recent discovery of opaque-2 genes has brought a revolutionary outlook on the possibilities of upgrading nutritional quality.

In addition to being generally low in essential amino acids, lysine, threonine, methionine and cystine, sorghums have generally high amounts of leucine which has been shown to be pellagragenic (Gopalan and Srikantia, 1960).

Since the alcohol soluble prolamine fraction, which is low in essential amino acids, contributes the dominant fraction of sorghum proteins and in view of the generally observed negative relationship between total protein and lysine, enhancement of nutritional quality in sorghum involves increasing the concentration of essential amino acids, particularly, lysine, threonine, methionine and cystine, at a reasonable protein level with reduction in the pellagragenic leucine content. The yellow endosperm sorghums originally discovered in Nigeria with appreciable quantities of carotene provide a further opportunity of enriching grain sorghums for vitamin-A activity (Singhania, Rao and House, 1971). Based on the findings by one of the graduate students (Nanda, 1971), a brief genetic analysis of nutritional quality and yield in grain sorghums is attempted.

A. Variability for Yield and Quality Attributes

Virtually all genetic variation resulting in observable differences in biological structure and function are probably controlled by variability in proteins and enzymes. Even though Virupaksha and Sastry (1968) identified a sorghum variety *cernuum* 160 with higher proportion of glutelin to prolamine and 3.14% lysine, no subsequent reports have appeared confirming these findings. Analytical work on world sorghum collection at the National Institute of Nutrition did not yield varieties with more than 2.67% lysine (Deosthale, Mohan and Visweswara Rao, 1970).

The variability in a set of parents and all possible hybrids among them with respect to yield, components of yield, total protein, essential amino acids and carotene is presented in Table 7-4 (Nanda, 1971).

A comparison of the means and ranges for parents and hybrids reveals that for yield and yield attributes the hybrids have higher values. On the other hand the means of the hybrids are slightly lower than the parental mean for lysine, threonine, methionine, cystine and carotene. The hybrid means slightly exceed parental values for total protein, isoleucine, leucine, phenylalanine, tyrosine and valine. The range in hybrids generally exceeds the parental range for yield as well as quality attributes. The mean of total essential amino acids is almost the same for parents and hybrids while the range of hybrids is much greater than the parental range.

Thus, from an examination of means and ranges it appears that with the exception of lysine, there is adequate amount of variability for yield as well as quality attributes and that it should be possible to synthesise a variety or hybrid which would satisfy the F. A. O. protein pattern in addition to incorporation of some beta-carotene.

B. Gene Action for Quality Attributes

An examination of the general and specific combining ability

TABLE 7-4. *Genetic Variability for Yield and Factors Contributing to Nutritional Quality (Nanda, 1971)*

S. No.	Attribute	Mean		Range		FAO Provisional Protein Pattern
		Parents	Hybrids	Parents	Hybrids	
1.	Yield (gm/plant)	37.81	58.29	6.91—88.41	1.27—120.44	—
2.	Seed size (gm)	2.78	3.17	1.08— 3.49	1.79— 4.15	—
3.	Grain hardness (kg)	8.01	8.95	3.70—10.29	4.75— 11.21	—
4.	Protein percent	14.12	14.51	12.16—18.31	11.63— 19.25	—
5.*	Lysine	1.86	1.67	1.51— 2.13	1.35— 2.29	4.3
6.	Threonine	3.01	2.96	2.74— 3.26	2.38— 4.27	3.3
7.	Methionine	1.09	1.05	0.62— 1.47	0.33— 1.63	1.7
8.	Cystine	1.02	0.97	0.90— 1.34	0.61— 3.28	1.7 (half cystine)
9.	Isoleucine	3.85	3.95	3.55— 4.08	3.52— 5.72	4.3
10.	Leucine	14.05	15.08	13.30—14.90	13.82— 22.98	4.9
11.	Phenylalanine	5.19	5.36	4.80— 5.79	4.90— 7.85	2.9
12.	Tyrosine	4.39	4.43	4.23— 4.60	3.93— 6.73	2.5
13.	Valine	5.05	5.09	4.12— 5.58	4.13— 6.71	2.8
14.	Tryptophan	—	—			1.1
15.	Total essential amino acids	39.50	40.55			
16.	Leucine/Lysine	7.57	9.05			
17.	Carotene	36.81	30.84	12.83—60.60	8.46— 63.97	

* 5 through 14 expressed as percent protein.

variances for nutritional attributes and the degree of dominance reveal (Nanda, 1971) that for lysine, the first limiting amino acid, gene action was predominantly additive and the degree of dominance was also not as high as that of other amino acids. On the other hand the proportion of $\hat{\sigma}^2$ *gca* to $\hat{\sigma}^2$ *sca* is about the same or $\hat{\sigma}^2$ *sca* predominated for several of the essential amino acids. The mean degree of dominance was also larger than the values of lysine, yield and yield attributes. Since the variance due to *gca* predominated for yield, seed size, grain hardness, protein, lysine, threonine, isoleucine, phenylananine and carotene, it may be assumed that they are highly heritable and are consequently transmissible provided there are no undesirable associations.

C. Association between Yield and Nutritional Attributes

The generally reported negative and undesirable associations between yield and protein, protein and lysine, carotene and protein were also observed in the study of Nanda (1971). Notable among the desirable associations are those of yield with grain size, grain hardness, lysine and methionine; lysine with methionine, threonine and leucine; carotene with lysine and methionine; and grain hardness with lysine. Thus the nature of associations offer scope for strengthening of lysine, methonine and carotene and reduction of leucine along with efforts to step up yield levels. However, this appears feasible at normal protein level only.

Thus an examination of the range of variability, nature of gene action and character associations between yield and quality attributes revealed that the amount of variability available to step up lysine levels to the F. A. O. provisional pattern is not adequate. As far as other essential amino acids are concerned, recombination breeding could result in the realisation of the F. A. O. standards besides the addition of some beta carotene. The fact that the nature of gene action for yield attributes, carotene and lysine is essentially additive and the predominance of non-allelic interactions for most essential amino acids indicates the utility of conventional as well as hybrid development programs in combining yield with nutritional quality. Grain hardness appears to provide a useful index since it is positively associated with lysine. But it is very necessary that the variability for lysine has to be enhanced either by induced mutagenesis or through more intensive screening of germ plasm; investigations in breeding nurseries might yield transgressive segregates. This breakthrough for variability in lysine is a desideratum if programs of nutritional improvement of sorghum are to match those of maize. Some of the best combinations, where the yields are high, the amino acid balance favourable and the gene action mostly additive, are exotic × Indian combinations.

IX. Physiological Approaches

High yielding varieties have been bred without fully understanding as to why they are superior in performance. In breeding for biological efficiency, increased knowledge of the form and function components of productivity would enable modifications in breeding methodology to achieve efficiency in production (Sprague, 1969; Jensen, 1969).

Total plant yield is the direct outcome of the extent and duration of photosynthesis, subject to addition of minerals and losses due to respiration (Donald, 1962). In recent years, there has been increasing emphasis on understanding varietal, and therefore genetic differences in dry matter production and photosynthetic efficiency. That plant genotypes differ in their ability to absorb, translocate and utilize specific nutrient elements provide yet another physiological basis for developing desired genotypes through plant breeding (Gerloff, 1963; Vose, 1967, and Picciurro *et al.*, 1967).

A. Differential Dry Matter Production and Distribution

The tall and late sorghums of India and Africa have higher biological yields, and low economic yields as against the dwarf and early United States varieties and hybrids which have a high harvest index.

There was greater accumulation of dry matter in the stem after flowering in most tall varieties as against greater accumulation in the ear in dwarf hybrids (Goldsworthy, 1970; Rao and Venkateswarlu, 1971). The greater adaptability of the *rabi jowar* variety, M35-1 was attributed by Rao and Murty (1963) to its high rate of dry matter production and its accumulation in the ear.

The growth rates were heterotic for CSH-1 and CSH-2 whereas they were intermediate for the two non-heterotic hybrids (Figure 7-7). An examination of the accumulation of dry matter in two heterotic and non-heterotic hybrids and their parents by Rao and Venkateswarlu (1971) revealed that non-heterotic hybrids were superior to their parents in dry matter production upto flowering only. Later the accumlation was mostly in the stem resulting in low economic yields. The accumulation of N, P and K, also followed the pattern of dry matter and there

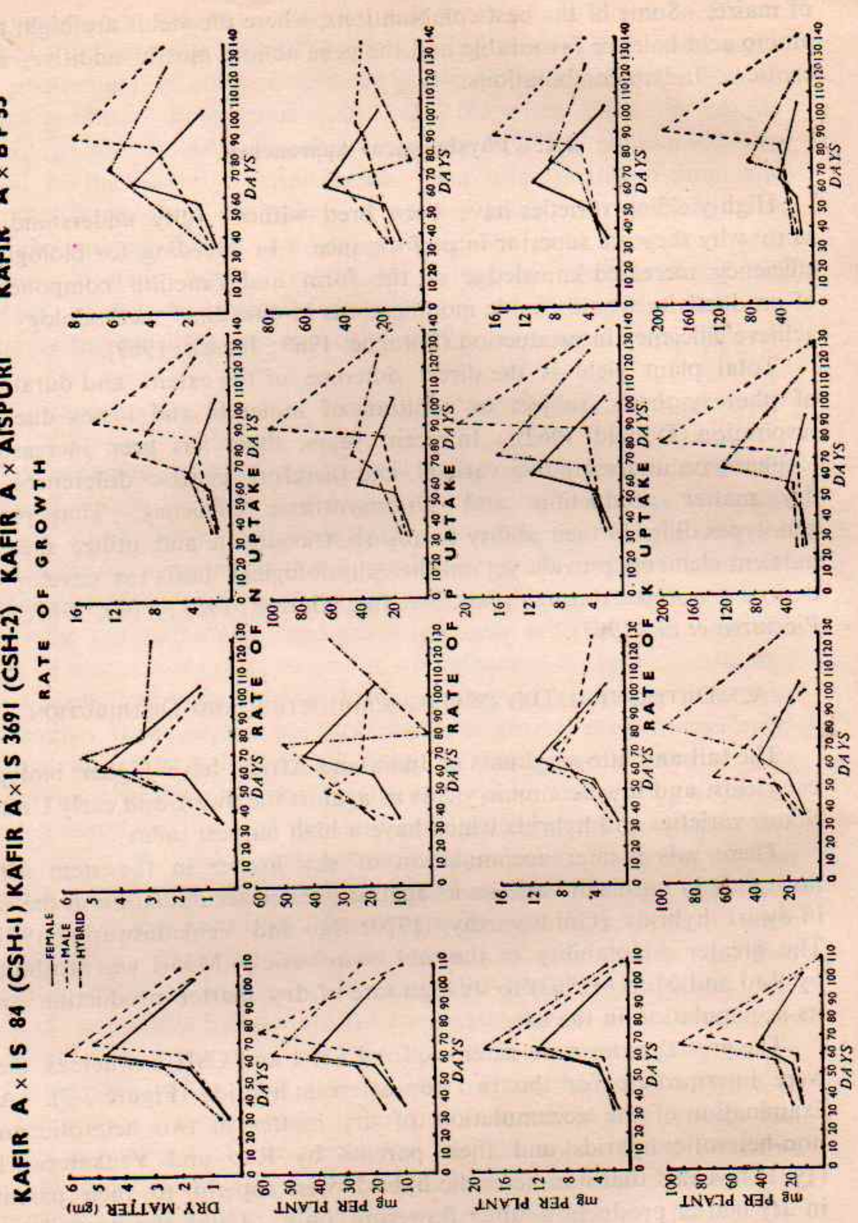

Fig. 7-7. Rates of growth and uptake of N, P and K in heterotic and non-heterotic hybrids and parents.

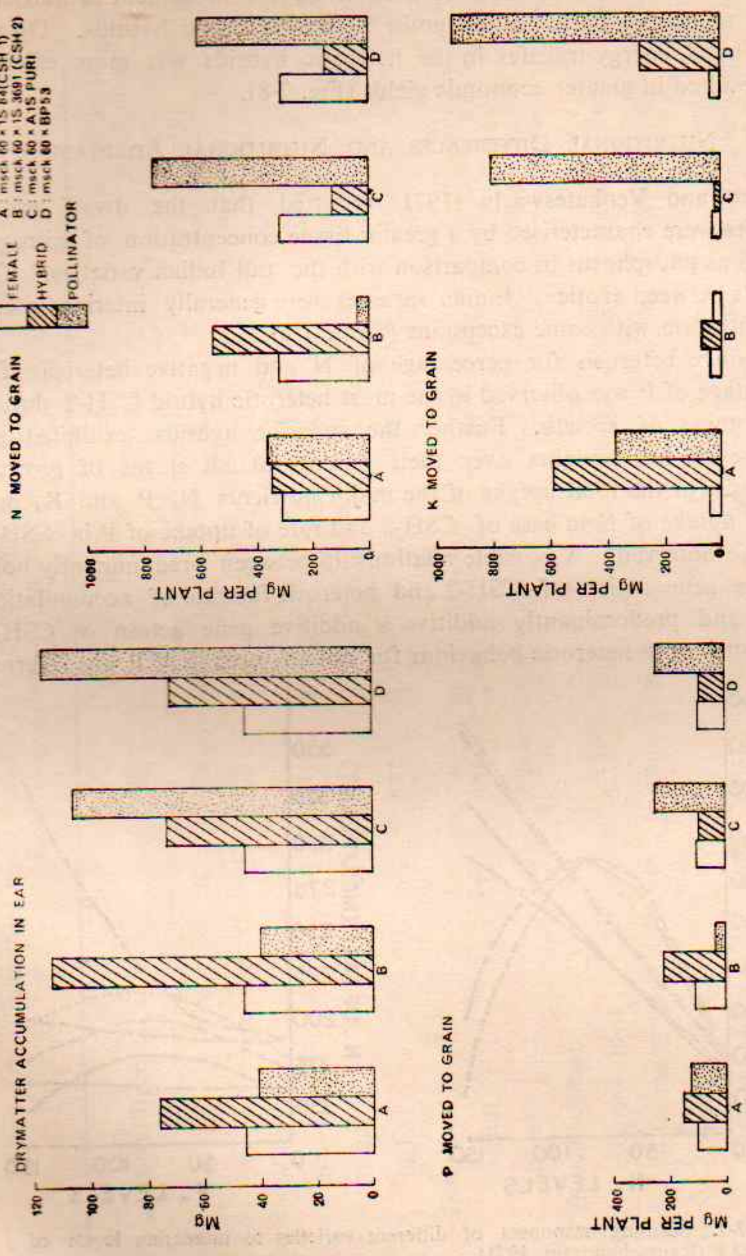

FIG. 7-8. Accumulation of dry matter in the panicle and the movement of N, P and K from vegetative parts to panicle (Rao and Venkateswarlu, 1971).

appeared to be considerable restriction on the movement of nutrients from vegetative parts to the grain in non-heterotic hybrids. On the other hand, energy transfer in the heterotic hybrids was more efficient and resulted in greater economic yields (Fig. 7-8).

B. Nutritional Differences and Nutritional Adaptation

Rao and Venkateswarlu (1971) reported that the dwarf exotic varieties were characterised by a greater tissue concentration of nitrogen as well as phosphorus in comparison with the tall Indian varieties. The hybrids between exotic × Indian varieties were generally intermediate in concentration with some exceptions (Table 7-5).

Positive heterosis for percentage of N and negative heterosis for percentage of P was observed in the most heterotic hybrid CSH-2 during early stages of growth. Further the superior hybrids exhibited an increase in leaf weights over their parents at all stages of growth. Heterosis for the total uptake of the major nutrients N, P and K, and rate of uptake of N in case of CSH-2 and rate of uptake of P in CSH-1 was also observed. A possible relationship between predominantly non-additive gene action of CSH-2 and heterosis for rate of accumulation of N and predominantly additive × additive gene action of CSH-1 associated with heterotic behaviour for rate of uptake of P was inferred

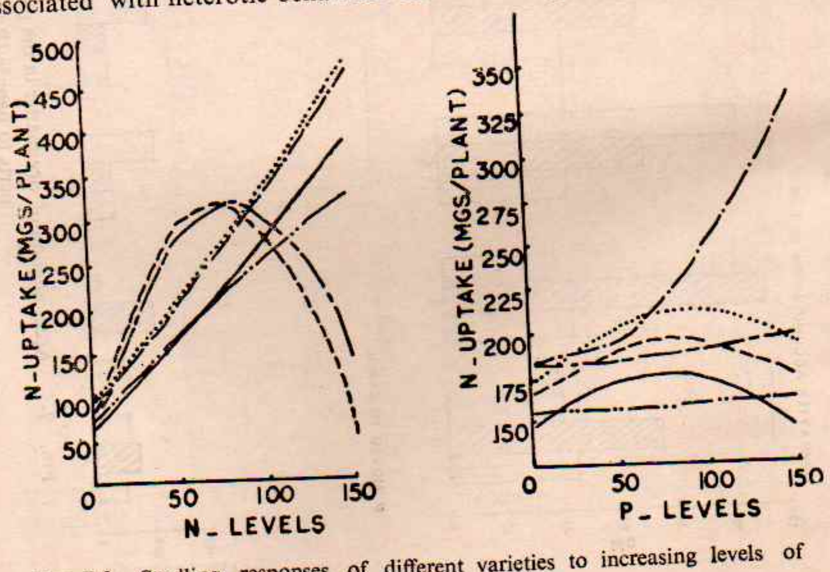

Fig. 7-9. Seedling responses of different varieties to increasing levels of N and P (Ramachandram, 1971).

TABLE 7-5. *Percentage of N, P and K in Leaf and Stem in 35 Days Old Seedling and Ear at Flag Leaf Stage (Rao and Venkateswarlu, 1971)*

Parent/Hybrid	Leaf			Stem			Ear At Flag Leaf Stage		
	N	P	K	N	P	K	N	P	K
Dwarf Exotic									
Kafir B	3.10	0.33	1.53	2.34	0.32	4.00	3.74	0.65	2.06
IS 84	3.03	0.39	1.47	2.36	0.29	3.70	3.23	0.65	2.28
IS 3691	2.96	0.31	1.73	2.57	0.31	3.94	3.11	0.49	1.80
Tall Indian									
Aispuri	2.72	0.31	2.00	2.09	0.30	4.22	2.59	0.44	1.64
BP 53	2.70	0.28	1.84	2.12	0.32	4.30	2.08	0.40	1.22
Heterotic Hybrids									
ms CK60×IS 84	3.06	0.35	2.16	2.59	0.31	4.34	3.02	0.55	2.13
ms CK60×IS 3691	3.15	0.31	1.55	2.40	0.27	3.89	2.69	0.42	1.41
Non-heterotic Hybrids									
ms CK60×Aispuri	2.79	0.31	2.02	2.10	0.31	4.44	2.77	0.51	1.75
ms CK60×BP 53	2.75	0.32	2.05	2.13	0.30	4.67	3.04	0.47	1.53

by Rao and Murty (1970). While the increased rate of uptake of nitrogen was attributable to non-additive gene action, the total uptake of nitrogen appears to be additive in inheritance (Kang, 1969).

Ramachandram (1971) also observed distinct varietal differences for tissue concentration, uptake and response patterns to application of major nutrient elements. In spite of comparative growth rates seedling responses of different varieties to increasing levels of nitrogen and phosphorus were strikingly different (Fig. 7-9). With increasing nitrogen levels, uptake of P reached maximum at 75-100 kg N/ha for most varieties whereas for CSH-1 uptake of P increased even beyond 150 kg N/ha. Similarly with increasing levels of P seedling dry weights increased linearly for M35-1, CSH-1 and R78 whereas there was a declining trend for the varieties R21 and R32 beyond 75-100 kg P_2O_5/ha.

Further studies on the association of seedling characters with adult response revealed several significant positive and negative associations (Fig. 7-10). While the percentage of N is positively correlated with final yields, the percentage of tissue P is negatively correlated. Tissue concentration of K has no marked influence on grain yield.

C. Selection for Nutritional Response

A vigorous seedling resulting from inherent capacity as well as high concentration and uptake of N and with a low tissue concentration of P and K but a higher uptake consequent on large seedling size appears to result in higher economic yields.

These studies of Ramachandram (1971) on dry matter production, mineral composition and nutrient uptake and the interesting relationships between seedling behaviour and adult response furnish physiological criteria for selection and provide guidelines for characterisation and breeding of nutritionally efficient genotypes. Such physiological criteria together with the nature of gene action would enable synthesis of desirable derivatives with *erectophile* habit to capitalise on solar energy and excellent response to the application of nitrogenous and phosphatic fertilizers. The tall Indian x dwarf exotic crosses seem to offer immense potentialities in this direction also.

X. Summary and Outlook

1. Contemporary researches in sorghum are comparable to those of wheat and rice. Yet, the impact of high yielding hybrids and

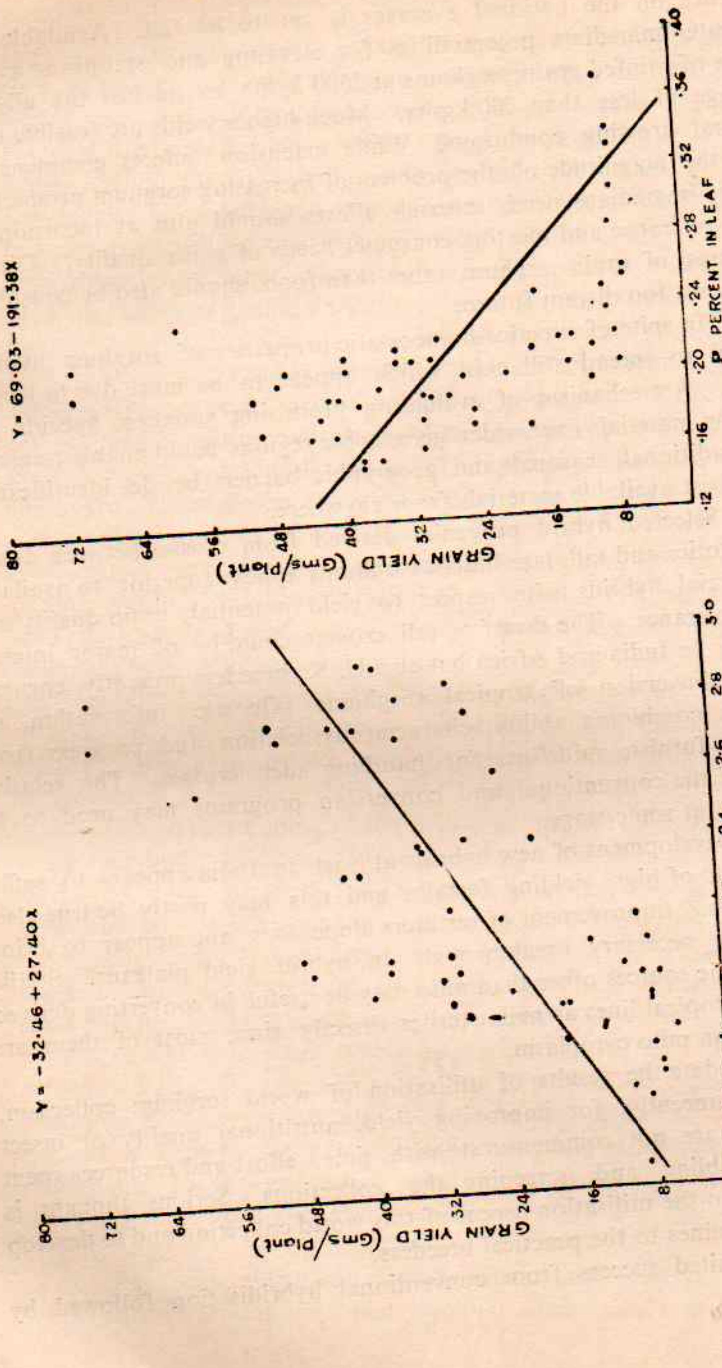

Fig. 7-10. Regression of grain yield on seedling concentration of N and P (Ramachandram, 1971).

varieties on the national averages is yet to be felt. Available data indicate immediate potentialities for elevating and stabilising average yields of rainfed grain sorghums at 2500 kg/ha as against the all-India average of less than 500 kg/ha. Much higher yields are feasible under optimal growing conditions. While extension efforts commensurate with the magnitude of the problem of increasing sorghum productivity are the immediate need, research efforts should aim at incorporating insect tolerance and meeting consumer needs of grain quality. Diversified uses of grain sorghum, other than food, should also be considered in the not too distant future.

2. In spite of superior homeostatic properties of sorghum hybrids, barriers to spread still exist which appear to be more due to lack of efforts. A mechanism of evaluating promising varieties, hybrids and breeding materials over wider geographic regions could enable transcending traditional, seasonal and geographic barriers besides identification of the best available materials from anywhere.

3. Selected hybrid progenies derived from crosses between dwarf, early exotics and tall, late Indian sorghums appear superior to available commercial hybrids with respect to yield potential, grain quality and insect tolerance. The dwarf $\times$ tall crosses could be of major interest not only to India and Africa but also U. S. breeders presently engaged in the conversion of tropical sorghums. Genetic information on heterosis, combining ability, character association and progress from selection furnish guidelines for handling such crosses. The relative merits of the conventional and conversion programs may need to be evaluated at some stage.

4. Development of new hybrids at least in India appears to suffer from lack of high yielding females and this may partly be true elsewhere also. Improvement of restorers alone does not appear to bring about the necessary breakthrough in hybrid yield plateaus. Sterile cytoplasmic sources other than milo may be useful in converting derived superior tropical lines as male steriles directly since most of them are restorers on milo cytoplasm.

5. Todate the results of utilisation of world sorghum collection, assembled recently, for improving yield, nutritional quality or insect resistance are not commensurate with time, effort and resources spent on assembling and screening the collections. Serious thought is necessary to the utilisation aspect of this world collection and to develop some guidelines to the practical breeders.

6. Limited success from conventional hybridisation followed by

selection or through various backcross procedures including the conversion program, the yield plateaus attained by commercial sorghum hybrids and the maize experience are turning sorghum geneticists and breeders to population improvement programs employing male sterility genes. While this is valuable and should be pursued with vigour, it should also be remembered that some superior selections from dwarf × tall crosses outyielded their corresponding hybrids under more favourable growing conditions. There is convincing evidence that suitable true breeding varieties could outyield hybrids in the absence of environmental limitations. Conversely, hybrids could still play a significant role in stabilising yield levels under climatic fluctuations. It, therefore, appears that varieties could outyield hybrids under more favourable U. S. conditions and hybrids could be more desirable under fluctuating conditions of India and Africa. The present situation is just the opposite. The question of varieties, hybrids and populations, therefore, needs critical analysis for varying situations.

7. It is now evident that gene-cytoplasm interactions could result in male sterility or self-incompatibility and each of these may in turn lead to apomictic seed development. Both male sterility and self-incompatibility could be exploited to promote gene flow in populations and apomictic fixation could enable capitalise on the demands for diversity as well as uniformity. A critical understanding of these related phenomena could lead to greater advances in sorghum improvement.

8. Our understanding of the nature of insect resistance in sorghum is meagre and breeding for insect resistance still does not have established procedures. Present information on screening also is still incomplete and absolute resistance to shoot fly, stem borer and midge is yet to be identified. It has been our experience that while the Indian sorghums are more tolerant to insects, the dwarf exotics (particularly some of the U. S. dwarfs and the derived yellow endosperm kafir, feterita, shallu and other types) appear more tolerant to diseases in general. Some plant pigments, tannins in particular, appear to confer resistance to head molds and also some leaf diseases. High tannin content is known to affect palatability and digestibility. Attempts to redistribute such pigments in plant parts might enable developing types resistant to head molds without influencing palatability and digestibility.

9. Regarding nutritional quality, with the exception of lysine there is adequate variability for other essential amino acids to match FAO

protein standards. Identification or induction of high lysine character is a desideratum to nutritional upgrading of sorghum grain. Once this is achieved, manipulation for high lysine character appears easy since lysine content is additive in inheritance.

10. Studies on varietal differences for dry matter production and distribution, mineral composition and nutrient uptake and the interesting relationships between seedling characters and adult response might furnish guidelines for characterisation and breeding physiologically efficient sorghum genotypes.

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36. ADAPTABILITY OF GRAIN SORGHUM HYBRIDS AND VARIETIES IN INDIA

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Introduction

That traditional Indian sorghums are highly local in their adaptation has been well recognized (Chavan and Shendge, 1957). During the period 1965-1970, four high yielding hybrids and an improved dwarf variety, *Swarna* were developed and released for general cultivation. While the superiority of these recent hybrids has been well established, the question of their adaptability to specific regions of the country has been frequently raised. The present paper is an attempt to study the adaptability of the recently developed sorghum strains.

Materials and Methods

The experimental material comprised of eight hybrids and two varieties. Four of the hybrids, CSH-1, CSH-2, CSH-3 and PSH-2 and the variety *Swarna* were released for general cultivation and the rest comprised of experimental hybrids and the respective local check, which was the best available improved variety, at each of the test locations. The

Contribution from the All India Co-ordinated Sorghum Improvement Project.

total number of test locations during the three year period was 82. Although most of the entries and locations were common during this period, there were some variations. Eight to ten entries were common at 54-82 locations.

These hybrids and varieties (genotypes) were grown in a randomized complete block design over the 82 diverse locations for three years, 1968-1970, in the monsoon season (July-October). A net plot size of 1.8 × 7.5 meters was uniformly maintained.

Stability analysis was carried out over unequal number of entries and locations following the methodology of Eberhart and Russell (1966). The phenotypic index, P_i was calculated as the deviation of the i^{th} variety mean from the general mean,

$$\left(P_i = \sum_{j=1}^{n} Y_{ij}/n - \sum_{i=1}^{v} \sum_{j=1}^{n} Y_{ij}/vn\right), \quad \sum_{i=1}^{v} P_i = 0$$

where Y_{ij} is the i^{th} variety mean at the j^{th} environment; n is the number of environments and v is the number of entries tested.

TABLE 36-1. *ANOVA for Grain Yield of Some Sorghum Hybrids/Varieties Over 82 Environments*

Source	D.F.	M. S.
Environments	81	25.76**
Genotypes	9	26.78**
Genotypes × Environments	584	1.32*
Environments (Linear)	1	2086.78**
Genotypes × Environments (Linear)	9	2.88**
Pooled deviations	655	1.44**
Average error	1186	0.71

* Significant at 75% **Significant at 1%

Results

The differences between the genotypes and their interactions with the environments, both linear and non-linear were significant (Table 36-1).

The stability parameters are presented in Table 36-2. Hybrid yields are generally superior to varietal yields. The yields of the released hybrids CSH-1, CSH-3, PSH-2 and two experimental hybrids 2219A × CS 3541 and 2947A × CS 6398 were higher than the mean. The respective locals were generally the lowest in yielding ability.

TABLE 36-2. *Stability Parameters for Some Hybrids/Varieties of Sorghum*

S. No.	Hybrid/Variety	Mean Yield (kg/ha)	$\hat{P}_i$	$\hat{b}$	$\hat{\delta}_{ij}$
1.	3675A × CS 2644	2991	0.00	1.07	1.21**
2.	2219A × CS 3541	3493	0.70	0.91	1.73**
3.	2947A × CS 6398	3443	0.63	0.99	0.66
4.	CK60A × D-1	2740	0.35	1.07	0.58
5.	CSH-1 (CK60A × IS 84)	3163	0.24	1.02	0.91
6.	CSH-2 (CK60A × IS 3691)	2826	0.23	1.07	0.78
7.	CSH-3 (2219A × IS 3691)	3508	0.72	1.06	0.77
8.	PSH-2 (1036A × *Swarna*)	3249	0.36	1.02	0.78
9.	*Swarna*	2489	0.70	0.92	0.84
10.	Local	2181	1.13	0.71	2.51**

** Significant at 1%.

The regression coefficients of hybrids were near 1.0. The deviations from regression were also not significant except in the case of two of the eight hybrids tested. As against this the local had the b value of 0.70

and the deviations from regression were also significant. This is indicative that the hybrids are generally more adaptable. The locals besides low yielding exhibit only limited response to changing environments.

The percent distribution of the locations in different quadrants of Fig. 36-1 with environmental index on X-axis and mean yield on Y-axis is given in Table 36-3. The percent distribution of test locations in Q_1 was higher for all hybrids as compared to locals indicating that the performance of locals was not above average even in favourable environments. The comparison of test locations in $(Q_1 + Q_2)$ or $(Q_3 + Q_4)$ reveals that the hybrids with above average yield did well both under rich and poor environments as compared to locals.

The relative distribution on test locations in the different yield ranges for each of the entries is presented in Table 36-4. The upper as well as lower limits for grain yield were much higher in hybrids as well as *Swarna* as compared to the improved local varieties used as checks. Particularly, the hybrids CSH-1 and 2219A × CS 3541 did not yield less than 860 kg/ha at any of the locations. The higher yield levels of released hybrids and high percentage of test locations in the range of 3000 to 4500 kg/ha and above further establish their superiority.

Discussion

Earlier studies on the stability of performance across diverse locations within the *kharif* (monsoon) season revealed that the hybrids were generally more stable; that the high yielding variety *Swarna* tended to outyield the hybrids in superior environments and that the performance of locals was generally inferior (Rao and Harinarayana, 1969). However, these studies based on limited entries did not indicate the regions of adaptability of the released hybrids or varieties. The resent studies based on ten entries tested over 82 locations during a three year period further confirm the general superiority of the hybrids and their stability of performance.

Based on the *inter se* superiority among the hybrids, an effort has been made to examine if the released hybrids and varieties or the experimental hybrids could be assigned to any definite zones or regions in the country. When the superiority of each of the entry was marked against the respective local in the test locations, it was observed that the superiority was general rather than confined to any specific zone or region in India. The analysis further confirms the earlier assumption (Rao, 1970) that geographic barriers, at least within a season, may not be of much

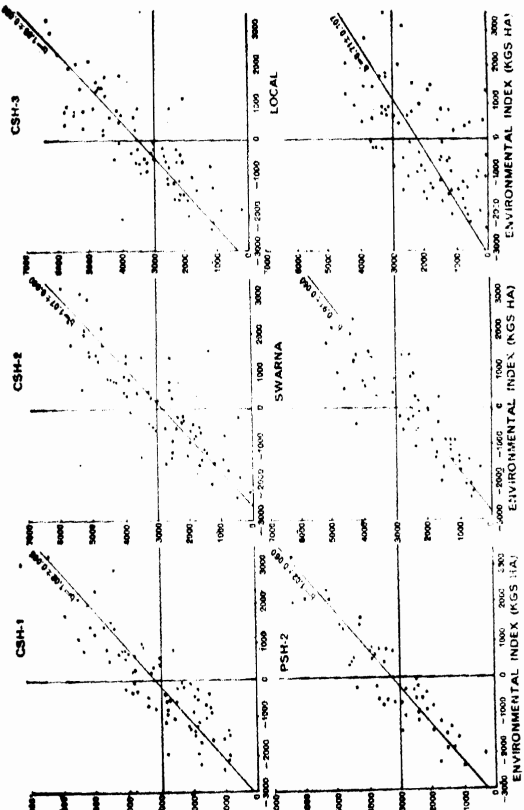

FIG. 36-1. Grain Yield of Sorghum Hybrids and Varieties in Relation to Environmental Index.

TABLE 36-3. *Percent Distribution of Test Locations of Sorghum Hybrids/Varieties in Different Quadrants*

S. No.	Hybrid/Variety	Q_1 Above average yield, rich environment	Q_2 Above average yield, poor environment	Q_3 Below average yield, poor environment	Q_4 Below average yield, rich environment
1.	3675A × CS 2644	36.6	7.3	50.0	6.1
2.	2219A × CS 3541	42.2	2.5	39.5	15.8
3.	2947A × CS 6398	48.5	17.1	34.4	0.0
4.	CK601 × D-1	33.3	2.1	58.3	6.3
5.	CSH-1	40.5	11.4	46.8	1.3
6.	CSH-2	34.6	7.7	50.0	7.7
7.	CSH-3	40.5	20.3	36.7	2.5
8.	PSH-2	37.3	13.2	47.6	1.9
9.	*Swarna*	29.6	1.9	57.4	11.1
10.	Local	19.4	5.6	54.2	20.8

TABLE 36-4. *Percent Distribution of Test Locations in Different Yield Ranges of Sorghum Hybrids/Varieties*

S. No.	Hybrid/Variety	Range of Yield (kg/ha)	Below 860 kg/ha	860-1500 kg/ha	1500-3000 kg/ha	3000-4500 kg/ha	Above 4500 kg/ha
1.	3675A × CS 2644	57-6742	7.3	12.0	36.6	26.8	17.3
2.	2219A × CS 3541	1169-7625	0.0	10.8	32.4	36.5	20.3
3.	2947A × CS 6398	602-6800	2.9	5.7	28.5	45.7	17.2
4.	CK60A × D-1	437-6089	10.3	12.4	42.0	21.0	14.3
5.	CSH-1	861-7625	0.0	12.5	37.5	31.3	18.7
6.	CSH-2	402-5961	8.6	11.1	37.0	11.1	32.1
7.	CSH-3	244-6907	1.2	6.1	31.7	31.7	29.3
8.	PSH-2	308-7409	1.9	11.1	33.3	35.2	18.5
9.	Swarna	272-5150	11.1	16.7	40.7	24.1	7.4
10.	Local	14-4483	21.9	20.6	34.3	23.2	0.0

consequence in breeding sorghums for the various *kharif* tracts of the country which grow two-thirds of the total 18 million hectares put to sorghum in India. In addition to the general superiority of performance, desired maturity based on soil and rainfall pattern appears to be the primary factor in breeding sorghums for the *kharif* areas.

Summary

Performance and stability of performance of four released hybrids, a released variety *Swarna*, four experimental hybrids and local checks were studied during the *kharif* season at 82 locations over a three year period. The hybrids were generally superior and more stable. Based on *inter se* superiority it was not possible to assign the entries to any contiguous regions or zones in India during this season. General superiority and maturity period appear to be the deciding factors in determining adaptability of sorghums in India during *kharif* season rather than geographic or regional limitations.

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Amylase Complementation as an Index of Heterosis in Sorghum

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37. AMYLASE COMPLEMENTATION AS AN INDEX OF HETEROSIS IN SORGHUM

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Introduction

There have been several attempts to understand the physiological and biochemical basis of heterosis (Hageman *et al.*, 1967; McDaniel and Sarkissian, 1968; Ghose *et al.*, 1971; Sinha and Ghildiyal, 1971). Of special interest are the studies of mitochondrial complementation wherein mitochondria isolated from the parents producing heterotic hybrids, when incubated together showed activity comparable to the mitochondria isolated from heterotic hybrids (McDaniel and Sarkissian, 1966). McDaniel (1970) has suggested the use of this technique for determining specific combining ability. In sorghum, the activity of amylase was found to be higher in hybrids than their parents during germination (Ghose *et al.*, 1971). When the seeds of two parents were germinated together they showed complementation and the amylase activity reached close to that of the hybrid. The present study is the extension of this work to assess if amylase complementation could be used as an index of combining ability.

Materials and Methods

Seeds of different hybrids and their parents were raised at the IARI

Regional Research Station, Hyderabad. Uniform seeds were soaked in 0.02% mercuric chloride for one minute and then washed in distilled water. Fifty washed seeds were placed over filter paper in petridishes containing 2 ml distilled water. After incubation for 48 hours at 30°C seeds were assayed for amylase activity as described by Ghose *et al.* (1971). The response of GA was tested in embryoless grains. The embryos for this study were excised after one hour of soaking and incubated in GA_3 (gibberrellic acid) solution as detailed above.

Results and Discussion

Two heterotic hybrids—msCK 60 × IS 84 (CSH-1) and msCK 60 × IS 3691 (CSH-2)—were analysed for amylase activity 40 hours after incubation. The enzyme activity in the former hybrid was poorer than its parents while the latter hybrid had higher amylase activity than its parents. When the seeds of two parents were germinated together, the amylase activity in a preparation obtained from 1 : 1 mixture of the parentel seeds was higher than the mean value of the two parents. Therefore, it can be concluded that the parental seeds complemented during germination (Table 37-1.)

TABLE 37-1. *Amylase Activity in Inbred Parents and their Hybrids in Full Seeds and Embryoless Grains in the Presence of GA_3 $10^{-5}M$*

Genotype	μg Starch Hydrolysed/Grain/5 min	
	Full Grain	GA_3 10^{-5}M
msCK 60	1400	300
IS 3691	1440	360
msCK 60 × IS 3691 (CSH-2)	1860	500
Average parental activity	1420	330
Complementation	1700	520
msCK 60	1400	1220
IS 84	1080	1200
msCK 60 × IS 84 (CSH-1)	1260	1040
Average parental activity	1240	1210
Complementation	1500	1320

The loss of viability in sorghum genotypes varies and the amylase activity of the endosperm is dependent upon the presence of embryo. Therefore, the differences observed in amylase activity of parents and their hybrid could be due to the differences in the viability of embryo. Apparently it is a GA or GA like substance which is supplied by the embryo to induce amylase synthesis in barley and an external application of GA_3 can replace the need of embryo (Varner and Ram Chandra, 1964). In sorghum also GA_3 was found to replace the embryo activity (Ghose *et al.*, 1971). Therefore, embryoless grains were incubated in 10^{-5}M GA_3 solution. The parental seeds of heterotic hybrid showed complementation, thus confirming that the complementation observed in full grains was not due to the differential viability of embryos. The seeds of two non-heterotic hybrids and their parents (Rao and Venkateswarlu, 1971) were also examined for amylase activity and amylase complementation (Table 37-2). Of the two hybrids, ms 2219 × Karad Local had higher amylase activity. This hybrid exhibits seedling vigour also but is non-heterotic for yield like the other hybrid ms 2219 × BP-53. However, there was no complementation in the parental seeds of both the hybrids. In the embryoless grains no complementation was observed in the presence of GA_3.

TABLE 37-2. *Amylase Activity in Inbred Parents and their Hybrids in Full Grains and Embryoless Grains in the Presence of GA*

Genotype	μg Starch Hydrolysed/Grain/5 min	
	Full Grain	GA_3 10^{-5}M
Karad Local	1560	1080
ms 2219	1480	1000
ms 2219 × Karad Local	1840	1280
Average parental activity	1520	1040
Complementation	1540	820
BP-53	1780	1680
ms 2219	1480	1000
ms 2219 × BP-53	1800	1220
Average parental activity	1630	1340
Complementation	1580	1380

These results indicate that the parents producing heterotic hybrids show complementation in amylase activity when their seeds are germinated together. This is not true of parents producing non-heterotic hybrids. In this respect this test is comparable to that of the mitochondrial complementation. The difference, however, is that the mitochondrial complementation is completely an *in vitro* effect whereas amylase complementation is *in vivo* effect.

The method for amylase analysis is simpler than the determination of mitochondrial activity. Therefore, if extended to a larger number of combinations this test may be used profitably for identifying heterotic hybrids.

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Five Years of Sorghum Breeding*

SORGHUM is considered to be the third important food crop in the world. World sorghum acreages and production are continuously on the increase. While these increases are spectacular in areas where sorghums are of relatively recent origin and are primarily used for forage and cattle feed, the areas as well as production levels remained stagnant in countries like India and Africa where sorghum culture has been ancient and sorghums constitute a major food crop. This is a disturbing situation, but recent researches in India bring to the fore the potentialities for a transformation of the existing situation.

Sorghums in India

Sorghum, frequently referred to as the great millet of India, is the most important among the food crops grown under rainfed conditions. With an annual area of about 18 million hectares, it is only next in importance to rice; the yearly production of only 9 million tonnes of grains, however, is not commensurate with this vast area and reflects the low level of national average yields, less than half a tonne per hectare. Maharashtra, Mysore, Andhra Pradesh, Madhya Pradesh, Gujarat, Rajasthan, Tamil Nadu and Uttar Pradesh are the states where grain sorghum is chiefly grown.

Natural selection and domestication over thousands of years have resulted in the development of numerous varieties, highly local in their adaptation. Cultured under different seasonal, soil and climatic conditions, Indian sorghums exhibit a wide range of variability in respect of duration and grain quality. Most of the present-day improved varieties are the result of pure line selection practised in principal local varieties. Limited intervarietal hybridization followed by selection has primarily contributed towards combining the then existing levels of grain yield with juicy stems to imporve forage quality. Changes in yield levels were not marked even in experimental plots. Prominent among those who contributed to the genetics and breeding of sorghum varieties in the early years were G. N. Rangaswamy Ayyangar and his colleagues from the Madras State and Rao Saheb Kottur and his colleagues from the then Bombay State. A review of the earlier varietal improvement work by Chavan and Shendge[1] reveals that in spite of the availability of over a hundred improved strains, the yield levels remained low and marginal (10-15%) over the base populations. Notable among the varieties developed during this early period and which are still under cultivation are the *Co.* series in Tamil Nadu; the *Nandyal*, *Guntur* and *Ankapalle* series of Andhra Pradesh; the *PJ kharif* and *PJ rabi* selections, *Saoner*, *Ramkel*, *Aispuri*, *Maldandis* (M 35-1 M 47-3 and M 31-2) and *Dagadi* (compact-headed types) selections of Maharashtra; the *Bilichigan*, *Fulgarwhite*, *Fulgaryellow*, *Kanvi*, *Nandyal*, *Hagari* and *Yenigar* varieties of Mysore; the *Budhperio*, *Sundhia* and *Chasatio* of Gujarat; the selections of Gwalior and Indore of Madhya Pradesh; the *RS* selections of Rajasthan and a few others. In addition, there are also special varieties for popping, parching and to suit special requirements. The age-old association and the consequent local preferences are the dominant reasons for their continued cultivation in spite of their erratic behaviour and low yields.

An examination of the trends in sorghum production in India during the previous years does not reveal any marked increases in yields, the per hectare yields varying between 400 and 480 kg. The cultivation of tall, long duration varieties over a vast proportion of the area, the yields of which were most

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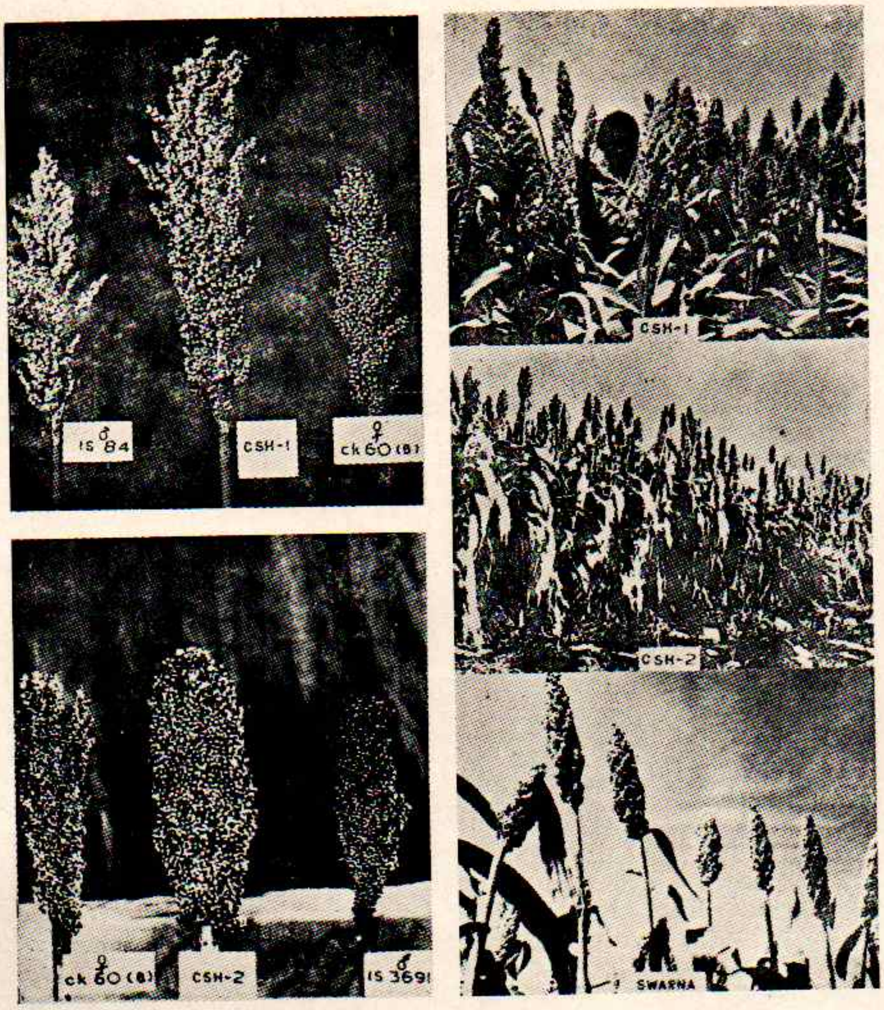


Fig. 1 — High yielding hybrids and varieties of sorghum — CSH-1, CSH-2 and *Swarna*

affected in years of drought, almost the total absence of the practice of fertilization and the tradition of growing sorghums only under low populations have been the major limiting factors in realizing higher yields.

The Accelerated Hybrid Sorghum Project

Since the development of commercial hybrids of sorghum has provided the most important genetic tool in improving yields, an ad hoc committee constituted by the Indian Council of Agricultural Research (ICAR) recommended that as an immediate measure, male sterile combine *Kafir* 60 (ms CK 60) be used as the common female parent and the wide range of sorghum germ plasm available be tried as male parents so as to identify suitable hybrids for the different sorghum-growing regions of India. Towards this end, efforts have been in progress under an accelerated hybrid sorghum project initiated by ICAR during 1962. The Genetics Division of the Indian Agricultural Research Institute served as the major research and coordinating centre with sub-centres at Coimbatore in Tamil Nadu, and Dharwar and Dhadesagur in Mysore State. Testing work was carried out all over the country. The Rockefeller Foundation and the various State Departments of Agriculture actively cooperated. Subsequently, this project be came a comprehensive multidisciplinary All Indi Coordinated Sorghum Improvement Project com mencing with the Fourth Five Year Plan durin 1969-70.

The First Hybrids

Acceptance of the exotic male sterile as th common female parent for the first hybrids presente certain limitations as well as potentialities. Grai sorghums in India are primarily for human co sumption and the grain quality of the exotic femal though white chalky, does not compare well wit the pearly white Indian sorghums. The sorghu germ plasm from which the male parents were be selected consisted of predominantly tall ar coloured types which would not result in hybri of desired grain type and plant height. Thu in spite of the availability of over 7000 genet stocks of sorghum at that time, the choice of pol nator parents had to be restricted to only about 1 yellow endosperm derivatives which yielded hybri with white pearly grain. While the exotic fema imposed a restriction on the choice of the pollinat parents, it was quite stable with respect to sterilit relatively photo-insensitive and could be grown over India.

With the choice of experimental hybrids reduced due to restrictions on grain quality and plant type, intensive selection in yellow endosperm types was practised and the hybrids with selected yellow endosperm types were simultaneously tested all over the country in preference to the earlier practice of testing large number of hybrids at a few locations only. Thus, this early realization of the potentialities and limitations in the choice of parents and simultaneous testing over a wide range of environments resulted in the identification and release of the first commercial sorghum hybrids CSH-1 and CSH-2 in India in a record time[2].

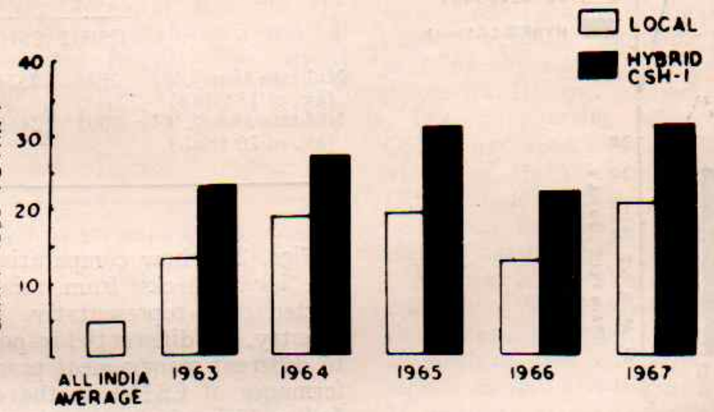
Release of CSH-1 — The first hybrid, coordinated sorghum hybrid (CSH-1), was released for general cultivation in the early and medium duration *kharif* areas and the irrigated summer tracts all over the country towards the end of 1964[3-5]. This high yielding hybrid (Fig. 1) is the product of hybridization between ms CK 60 and a selected yellow endosperm *feterita*, IS 84. Data enabling the release of this hybrid are presented in Appendix I and summarized in Table 1.

SHC-1 is an early hybrid maturing in 90-100 days and gives on an average 60-80% increase in grain yields over the locals. The fodder yields are 60-80% of the local checks. Under optimum fertilization and plant protection, maximum yields of over 6000 kg/ha have been recorded.

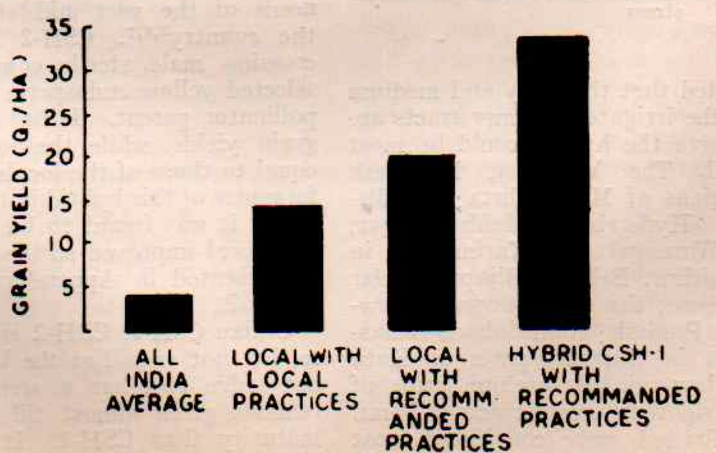
The general area of adaptation for this hybrid is estimated at 5 million hectares. The data from

TABLE 1 — AVERAGE YIELDS OF CSH-1 AND LOCAL

Region	Average grain yield kg/ha		% of local
	CSH-1	Local	
Summer (irrigated), 1963 and 1964	4885	3032	161
Early *kharif* (rainfed), 1963	1296	713	182
Mid-late *kharif* (rainfed), 1963	2578	1519	170
Mid-late *kharif* (rainfed), 1964	2562	1567	164



(AV OF 8-12 REPRESENTATIVE LOCATIONS WHICH WERE COMMON OVER YEARS)



HYBRID SORGHUM DEMONSTRATIONS 1965
AV. OF 46 DEMONSTRATIONS

Fig. 2 — Comparative performance of CSH-1 and local

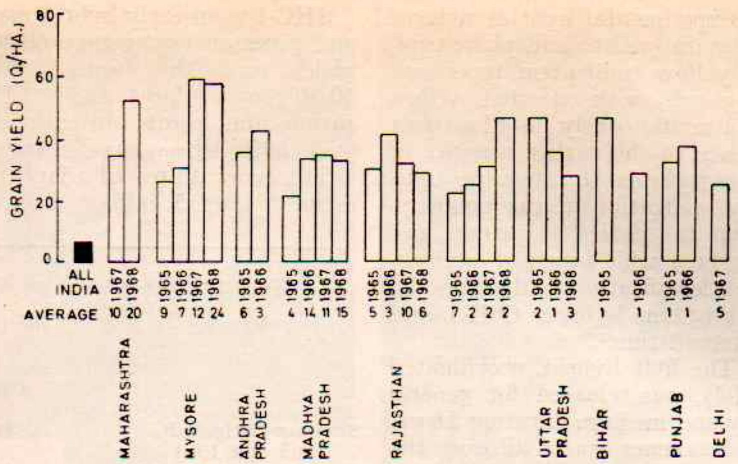


Fig. 3 — Performance of CSH-1 in different states

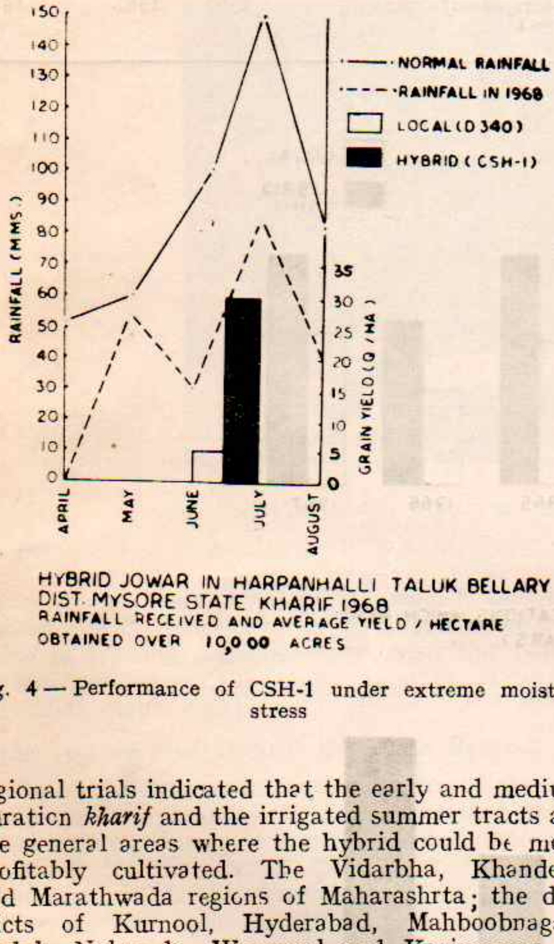


Fig. 4 — Performance of CSH-1 under extreme moisture stress

regional trials indicated that the early and medium duration *kharif* and the irrigated summer tracts are the general areas where the hybrid could be most profitably cultivated. The Vidarbha, Khandesh and Marathwada regions of Maharashrta; the districts of Kurnool, Hyderabad, Mahboobnagar, Medak, Nalgonda, Warangal and Karimnagar in Andhra Pradesh; Raichur, Bellary, Bijapur, Bidar and Gulbarga in Mysore; the early sorghum growing areas of Madhya Pradesh; Ahmedabad, Banaskantha and Mehsana in Gujarat; parts of Kota Division and other low rainfall sorghum areas of Rajasthan; and the irrigated summer tracts of Tamil Nadu and Andhra Pradesh were considered most suitable for this hybrid at the time of its release. It has, however, spread extensively in parts of Maharashtra and Mysore States only. It is estimated that about a million acres were put to CSH-1 during 1970-71.

TABLE 2 — COMPARATIVE PERFORMANCE OF CSH-2, CSH-1 AND LOCAL

Region	Grain yield, kg/ha			% of local	
	CSH-2	CSH-1	Local	CSH-2	CSH-1
Mid-late *kharif*, '63 (av. of 15 trials)	2948	2324	1535	192	151
Mid-late *kharif*, '64 (av. of 20 trials)	3002	2465	1700	177	145

Figs. 2-4 show comparative yields of CSH-1 and the local checks from rainfed yield trials conducted over representative locations all over the country, the differential response of CSH-1 and local to different management practices, the average performance of CSH-1 in the different states of the Indian Union in large-scale national demonstrations and the yields of this hybrid under extreme moisture stress in Bellary District of Mysore State.

Release of CSH-2 — The 'coordinated sorghum hybrid 2' (CSH-2) released in 1965 by the Central Variety Release Committee caters to the needs of the vast mid-late *kharif* tracts all over the country[2,6,7]. CSH-2 has been developed by crossing male sterile combine ***Kafir*** **60** with a selected yellow endosperm *hegari* (IS 3691) as the pollinator parent. It has a 70-90% superiority in grain yields, while the fodder yields are almost equal to those of the locals. The comparative performance of this hybrid in the mid-late *kharif* tracts, where it was found to be superior to both CSH-1 and local improved strains and enabled its release, is presented in Appendix II and summarized in Table 2.

Unlike CSH-1, CSH-2 is medium tall, about 1·8 m, but not as tall as the locals. The variety does not lodge and has a stem which is leafy and remains green almost till harvest. It is later in maturity than CSH-1. It flowers in 70-75 days and matures in 110-120 days. The grains are white pearly, and the protein content and cooking tests are comparable to those of locals. Under optimum moisture, fertility and plant protection, maximum yields up to 7000 kg/ha have been obtained.

Regarding the area of adaptability, particular mention may be made of the Dharwar-Belgaum region of Mysore State, Sangli-Satara region of Maharashtra, the eastern districts of Madhya Pradesh and the Bundelkhand region of Uttar Pradesh. In addition, the following *kharif* tracts should be considered as the general area of adaptation: the monsoon sorghum tract of Tamil Nadu; parts of Adilabad in Andhra Pradesh, the mid-late areas of Maharashtra and the forage sorghum areas in Orissa, Bihar and Uttar Pradesh, including the hilly areas. However, this hybrid also spread to limited areas in Maharashtra and Mysore States only.

Sorghum stalks in our country are more valued for fodder than stalks of other cereals and millets. While a certain amount of dwarfing of the present-day Indian varieties is essential, it may still be possible to combine high yields with non-lodging hybrids of intermediate height. CSH-2 is one such in that its height is less than that of the locals and what is lost by way of plant height is made good by increasing the number of plants per unit area[2].

The agronomic attributes of the two hybrids in comparison with those of the locals are presented in Table 3. These two hybrids are suitable for nearly two-thirds of the sorghum area in the country. Besides, the hybrids performed well in some African countries and Brazil. The advent of the hybrids has given rise to an organized hybrid sorghum seed industry both in the public and private sectors.

TABLE 3 — COMPARISON OF HYBRIDS AND LOCALS

Character	CSH-1	CSH-2	Local improved strains
Days to 50% flowering	58-60	70-75	60-95
Plant height, cm	140-160	150-200	200-300
Lodging percentage	0-1	0-10	0-90
Grain colour	Cream, pearly	Cream, pearly	Yellow, white-chalky, red, white-pearly
Fodder quality	Juicy, high proportion of leaf to stem	Juicy, high proportion of leaf to stem	Juicy to pithy
Threshability	Good	Good	Good
Taste	Satisfactory	Satisfactory	Good
Reaction to shoot fly	Susceptible	Susceptible	Susceptible
Nutritional quality*	—	—	—
Moisture, %	10·9	10·8	9·9
Protein, %	9·7	11·1	8·9
Fat, %	2·8	2·2	2·5
Minerals, %	1·7	1·5	1·8
Carbohydrates, %	74·9	74·4	76·9
Cal./100 g	364·0	362·0	366·0
Calcium, mg/100 g	34·3	23·3	32·0
Phosphorus, mg/100 g	327·3	314·2	311·4
Iron, mg/100 g	6·3	5·7	8·7

*Analysis from the Nutritional Research Laboratory, Hyderabad.

Hybrids were grown at Delhi and the locals compared were from Hyderabad.

TABLE 4 — COMPARATIVE PERFORMANCE OF CSH-1 AND *Swarna*

Variety/ Hybrid	Grain yield, kg/ha		% of CSH-1	
	Summer 1967	*Kharif* 1967	Summer 1967	*Kharif* 1967
Swarna	3850	3745	99·6	101·7
CSH-1	3864	3682	100·0	100·0
Local	2836	2358	73·4	64·0

Summer: Av. of 5 locations. *Kharif*: Av. of 25 locations.

Swarna, the Variety that Equalled Hybrids

In the case of commercial hybrids, the seed needs to be renewed every year. Consequently, the hybrid seed is not readily available to all sections of farmers and the need for a suitable high yielding variety, the seeds of which could be saved by farmers for future use, has been keenly felt.

Intensive selection in yellow endosperm derivatives to select suitable male parents resulted in the isolation of selection 413, which after extensive testing was released by the Central Variety Release Committee under the name *Swarna* (Fig. 1). Data enabling the release of *Swarna*[8,9] are presented in Appendix III and summarized in Table 4.

The comparative performance of *Swarna* and CSH-1 averaged over 30 locations spread in the States of Maharashtra, Mysore, Madhya Pradesh, Uttar Pradesh, Tamil Nadu, Orissa and Bihar reveals that it has the yield potential equalling the commercial hybrid CSH-1.

Swarna is suitable for cultivation during the traditional *kharif* and summer seasons. It has been the general experience that *Swarna* tends to yield as much or even more than CSH-1, if there is adequate rainfall and the growing conditions are good. If moisture stress is experienced, CSH-1 tends to outyield *Swarna*. *Swarna* is 120-150 cm tall, matures in 110 days and is characterized by erect leaves which enable it to respond better to high population levels.

Stability of Performance

The ability of the genotypes to adapt to random and cyclic climatic fluctuations is inherited. An ideal variety is one which combines high levels of yield with stability of performance over several environments. The importance of stability of performance under rainfed farming is particularly important.

When the first hybrids were released for general cultivation in India, they were meant for irrigated conditions only. Contrary to the belief that hybrids are meant only for cultivation under assured moisture regime., it has been demonstrated that suitable hybrids may be particularly useful and may even be advantageous under conditions of moisture stress.

An analysis of the phenotypic stability of hybrids and varieties by Rao and Harinarayana[10] over a five-year period (1963-67) clearly established the pronounced superiority of hybrids, particularly under stress (Fig. 5). CSH-1 was found to be the best genotype that has consistently high performance over several environments. These studies

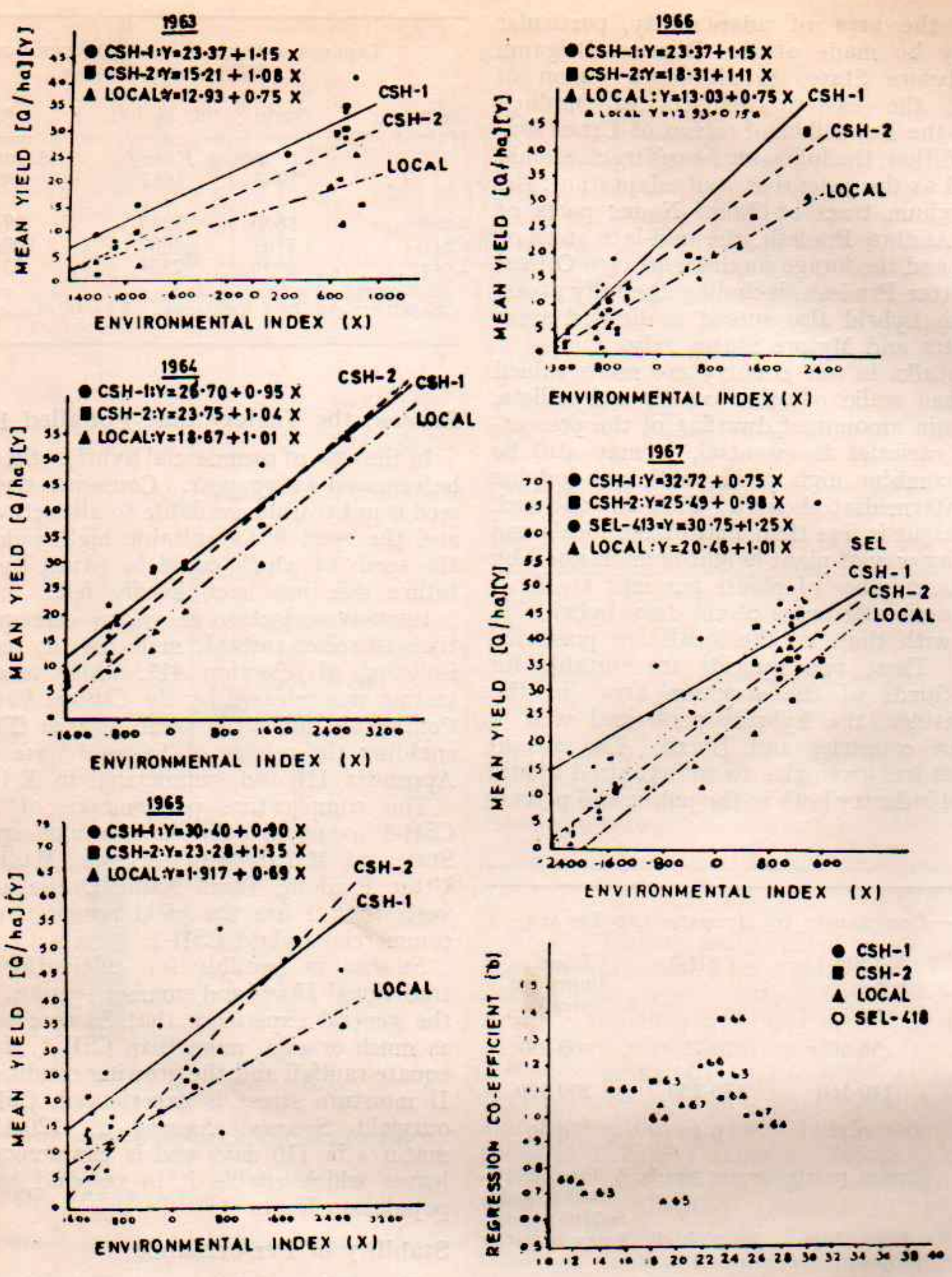


Fig. 5 — Stability of performance of hybrids and varieties of sorghum

TABLE 5 — ESTIMATES OF COMPONENTS OF VARIANCE FOR VARIOUS CHARACTERS FROM THE COMBINED ANALYSIS

Character	σ'^2_g	σ'^2_{gl}	σ'^2_{gy}	σ'^2_{gly}	σ'^2_e
Grain yield, kg/plot	1·08 ±0·68	1·98* ±0·52	0·01 ±0·08	1·71* ±0·36	1·73* ±0·13
Fodder yield, kg/plot	39·16 ±22·00	26·67* ±7·97	1·50 ±0·60	33·73* ±6·33	20·11* ±1·54
Days to 50% bloom	44·83 ±25·98	29·40* ±6·96	2·32 ±2·05	23·03* ±3·86	2·80* ±0·22
Plant height, cm	2077·02 ±1130·82	337·18* ±94·28	8·62 ±19·05	327·87* ±67·79	271·30* ±21·38

*Significant at 1%.

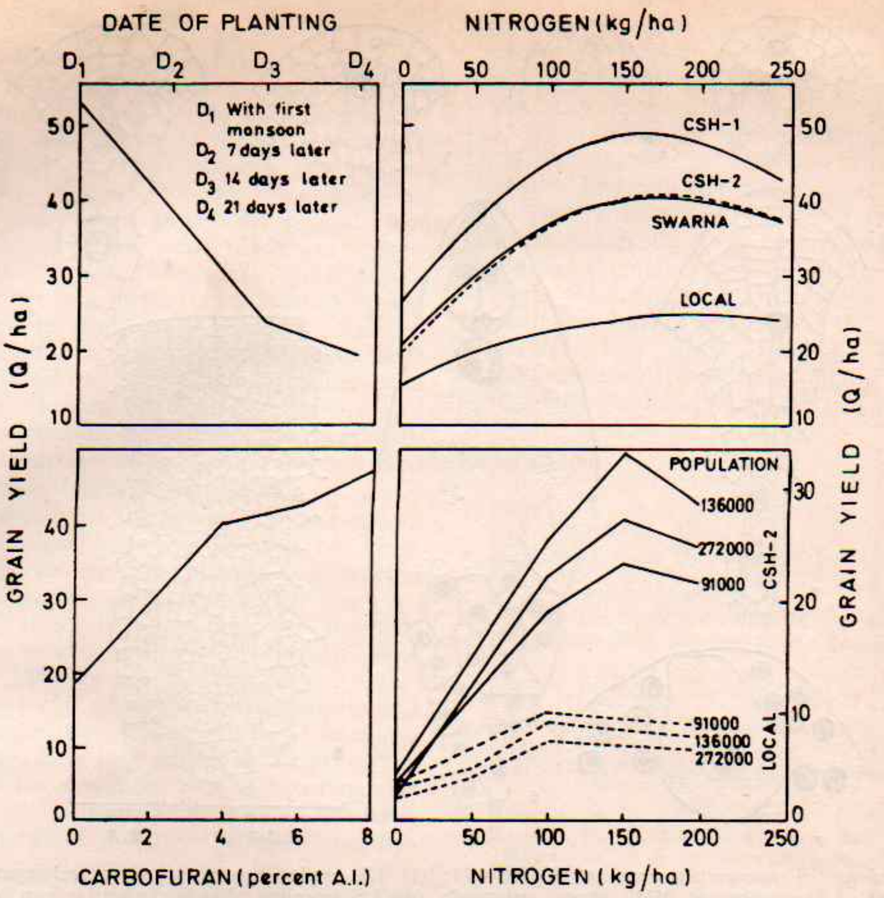


Fig. 6 — Components of production

TABLE 6 — RESPONSE EQUATIONS, ECONOMIC OPTIMUM LEVEL OF NITROGEN AND GRAIN PRODUCTION EFFICIENCY OF HYBRIDS AND VARIETIES OF SORGHUM

(*Kharif*, 1970)

Entry	$Y = a + bx + cx^2$	X-Max N kg/ha	Y-Max grain kg/ha	$\frac{Y\text{-Max}}{X\text{-Max}}$	Economic optimum level of N, kg/ha	Relative efficiency
CSH-1	$Y = 2592 + 27{\cdot}44N - 0{\cdot}0832N^2$	165	4854	29·4	152	235
CSH-2	$Y = 1922 + 24{\cdot}04N - 0{\cdot}0672N^2$	180	4072	22·6	165	181
Swarna	$Y = 2055 + 22{\cdot}60N - 0{\cdot}0640N^2$	177	4050	22·9	160	183
Local	$Y = 1536 + 9{\cdot}55N - 0{\cdot}0240N^2$	199	2486	12·5	154	100

also established that in self-fertilized crops like sorghum, while varieties like *Swarna* which could outyield hybrids under optimal conditions of cultivation could be developed, hybrids did have an advantage under suboptimal conditions, presumably due to the individual buffering commonly associated with commercial hybrids.

Changes in Adaptability Concepts

It has been generally believed that the indigenous varieties which are the outcome of prolonged natural selection do not normally perform well when transported outside their respective areas of adaptability. Consequently, breeding for many small regions was considered necessary and resulted in the development of numerous varieties with local adaptation.

Studies on the genotype × environment interactions based on data obtained during 1963-64 on the performance of released hybrids all over India (Table 5) clearly indicated that sorghums could be bred for large maturity zones rather than small regions limited by state and geographic barriers. These studies also revealed that locations could be substituted for years, thereby enabling rapid identification and spread of new varieties.

Components of Production

The development of high yielding hybrids and varieties will not contribute by itself to the realiza-

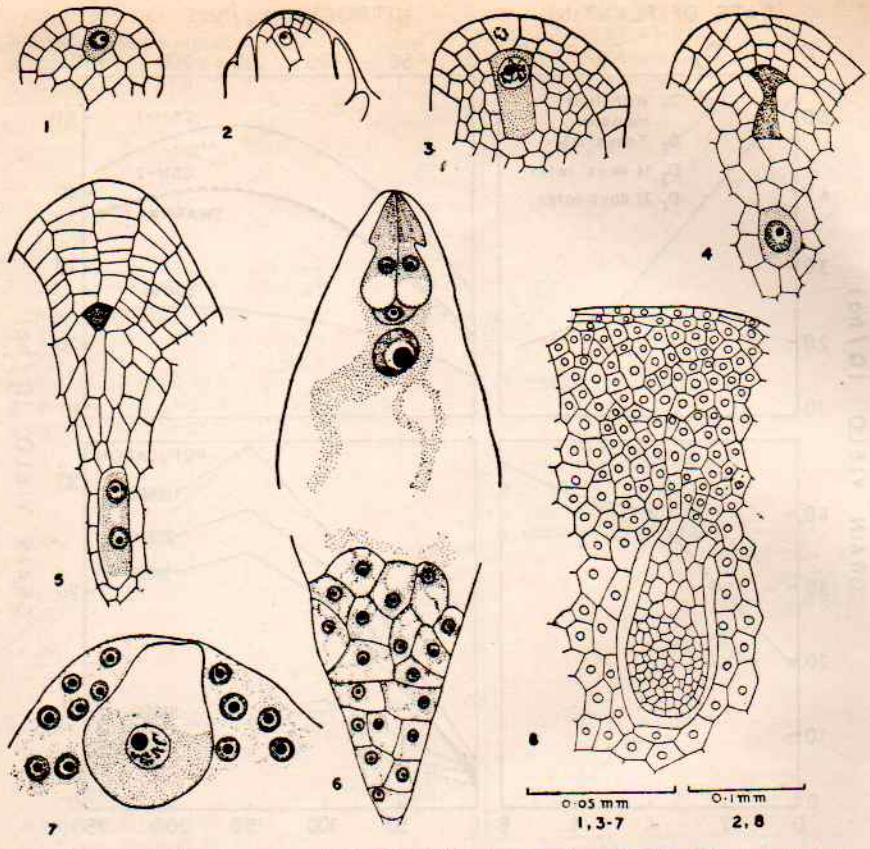


Fig. 7 — Embryology of apomictic progeny of R. 473: (1) LS ovule showing primary archesporium; (2) LS ovule at MMC stage; (3) LS nucellus at MMC stage, enlarged; (4) LS nucellus showing nucellar cap, degenerating MMC and enlarging nucellar cell which functions as the embryo sac mother cell; (5) LS nucellus showing nucellar cap and 2-nucleate stage of embryo sac (Note degenerating MMC below the cells of the nucellar cap); (6) mature embryo sac; (7) upper part of the embryo sac showing free endosperm nuclei and undivided egg cell; and (8) upper part of embryo sac showing embryo surrounded by cellular endosperm

tion of higher yields unless varietal improvement and researches in production technology go hand in hand. It is only then the potential yields could be translated into realized yields. Through co-operative efforts with the related disciplines of agronomy, entomology and plant pathology, vast experimental data with regard to dates of planting, fertilizer schedules, insect and disease control measures leading to the development of the package of practices for the various sorghum-growing regions of the country have been collected. The role of some of the major components of production, dates of planting, response to fertilizer and population levels and insect control are illustrated in Fig. 6. The response of the high yielding hybrids and varieties to application of nitrogenous fertilizers is much superior to those of locals as illustrated in Table 6.

New Sources of Male Sterility

The occurrence of cytoplasmic genetic male sterility in Indian sorghums was observed[11]. This new source of sterile cytoplasm, whose behaviour has been shown to be different from that of the milo cytoplasm, is now being used to convert fertility restorers on milo cytoplasm into male steriles. Efforts are also under way to utilize this source of new cytoplasmic male sterility to develop a random mating sorghum population.

Discovery of Apomixis

Although apomictic form of reproduction is known in the grass family, no such instance was known before in grain sorghums or other cereals where grain is the economic product. Since one of the major advances in the improvement of sorghum has been through commercial exploitation of heterosis, apomictic development of seed would be of considerable use to the plant breeder in maintaining and perpetuating heterozygosity.

The existence of apomixis in grain sorghums has been established and was reported during 1968[12]. Restrictions to pollen germination under selfing, the stimulus provided by its own pollen, the possibly autonomous development of the endosperm and a reduction in the competition of embryo sacs under selfing seem to have been responsible for the evolution of somatic apospory in hybrid material derived from exotic × Indian crosses. Embryological studies (Fig. 7) revealed that the megaspore mother cell degenerates and one of the cells of the nucellus enlarges and acts as the embryo sac mother cell. This nucellar cell divides mitotically, giving rise to the diploid embryo sac. Further studies have been in progress to understand this mechanism more critically and utilize the findings towards preservation and perpetuation of heterozygote advantage in grain sorghum.

Foundations for Future Work

The development of first hybrids and *Swarna* was based on introduced breeding materials. The development and release of these high yielding varieties based on exotic materials and the accelerated change in the varietal composition has in its wake brought to the fore problems of consumer preference, price differentials and incidence of insect pests and diseases, sometimes in epidemic proportions. The problems of dryland agriculture are further complicated by unpredictable random and cyclic climatic changes. The present plant breeding efforts together with developments in related agricultural sciences aim at amelioration of some of these problems and establishing a successful genetic relationship with environmental components to further elevate and stabilize production levels at a new high.

Extensive screening of the world sorghum collection for the prevalent pests and diseases has been carried out under the project and resistant sources have been identified for utilization in breeding programmes. An extensive programme of hybridization between exotic × Indian sorghums was initiated during 1965-66 and this has yielded valuable breeding material as well as basic genetic and physiological information which will be of immense value to the plant breeding efforts in sorghum[13-19]. Work on identifying sorghums rich in carotene and essential amino acids, lysine in particular, has been taken up to contribute towards the nutritional upgrading of this poor man's cereal.

With the beginning of the Fourth Five Year Plan during 1969, a network of stations in the sorghum-growing regions of the country have been established under the All India Coordinated Sorghum Improvement Project to work on this crop on a coordinated and multidisciplinary basis. It is hoped that the project will contribute towards the overall improvement of this millet on a countrywide basis leading to greater efficiency in production.

Acknowledgement

I am fully conscious that the conferring of this signal honour on me is a recognition of the devoted efforts of my colleagues and many scientists in the centre as well as the states, who even in the absence of a formal coordinated project on sorghum, voluntarily cooperated in the implementation of the programme. I am particularly grateful to Dr M. S. Swaminathan, Director, Indian Agricultural Research Institute, for his support, encouragement and participation in the programme. The late Dr S. M. Sikka, Dr A. B. Joshi and Dr B. P. Pal of the Indian Council of Agricultural Research were very helpful. The collaboration of the scientists of the Rockefeller Foundation, Dr L. R. House in particular, has been very valuable. This recognition is a tribute to all those who labour for the betterment of the dryland sorghum farmer.

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APPENDIX I

Mean Performance of CSH-1

Kharif, 1963)

Location	State	Grain yield, kg/ha			Fodder yield, kg/ha		
		CSH-1	Local improved strain	CD %	CSH-1	Local improved strain	CD %
Region 1 — Early Tract, Flowering in 60 Days							
Guntur	AP	2128	1087	262	4600	6918	789
Viramgam	Gujarat	980	445	266	2956	3319	1586
Bassi	Rajasthan	1594	1199	820	7369	9503	5416
Pali	do	481	119	238	2296	2583	1082
Mean		1296	713		4305	5581	
% of local		182	100		77	100	
Region 2 — Medium Duration, Flowering in 70 Days							
Rajendranagar	AP	765	573	368	5023	5927	3100
Dhone	do	1894	1094	610	2110	2332	840
Yemmiganur	do	6081	3667	559	6200	8862	2042
Siruguppa	Mysore	3809	3139	568	10782	10985	3301
Raichur	do	3305	1073	818	6369	12378	2598
Bijapur	do	1513	304	718	1895	2387	647
Dhulia	Maharashtra	1758	1423	506	4354	5215	NS
Deesa	Gujarat	1498	875	462	2996	3857	NS
Mean		2578	1519		4964	6493	
% of local		170	100		77	100	
Region 3 — Late Duration, Flowering over 80 Days							
Bhavanisagar	Tamil Nadu	3875	1868	606	6717	11367	1071
Coimbatore	do	838	703	292	5285	7725	2639
Tindivanam	do	1194	879	413	6379	11668	NS
Mudhol	AP	2644	1575	506	5848	13724	1467
Goregaon	Maharashtra	603	822	398	2512	3498	1094
Annigeri	Mysore	2892	2232	466	4682	6250	1826
Dharwar (black soil)	do	2820	1021	947	3561	7804	1066
Dharwar (red soil)	do	1702	709	472	2278	2558	660
Bailhongal	do	2888	804	588	3175	3714	1166
Gwalior	MP	2512	1650	847	7750	11883	3818
Mauranipur	UP	2773	2254	962	13667	14667	4158
Mean		2249	1320		5623	8623	
% of local		170	100		65	100	
Region 4 — Areas where Grain Sorghum is not Grown but Forage Varieties are Cultivated							
Phulbani	Orissa	2675	507	784	9849	11571	5171
Sambalpur	do	813	1070	NS	4998	2547	2637
Sundargarh	do	3049	2352	800	18442	23321	5045
Dholi	Bihar	1920	—	990	6347	—	3444
Delhi	Delhi	3975	1148	524	4611	5131	1361
Mean		2486	1269		8849	10643	
% of local		196	100		83	100	

APPENDIX I — *Contd*

Location	State	Grain yield, kg/ha			Fodder yield, kg/ha		
		CSH-1	Local improved strain	CD %	CSH-1	Local improved strain	CD %
REGION 5 — IRRIGATED SUMMER TRACT, FLOWERING IN 60 DAYS							
Coimbatore (1963)	Tamil Nadu	2657	1414	490	8948	10816	1876
Bhavnisagar (1963)	do	4440	1884	612	8305	10159	1390
Bhavanisagar (1964)	do	5520	2549	295	10690	12600	533
Coimbatore (1964)	do	5840	4265	665	4975	7790	780
Scattered block trials (1964)	do	5218	3597	532	15280*	17330*	NS
Agronomy trials (1964)		5636	4484	533	12950*	15360*	1429
Mean		4885	3032		10191	12343	
% of local		161	100		83	100	

*Fresh weight.
NS, not significant.

APPENDIX II

Comparative Performance of CSH-2 in Some Mid-late Areas where it is Superior in Grain Yield to CSH-1 and Local Improved Strains

(*Kharif*, 1964)

Location	State	Grain yield, kg/ha				Fodder yield, kg/ha			
		CSH-2	CSH-1	Local improved strain	CD 5%	CSH-2	CSH-1	Local improved strain	CD 5%
Coimbatore (MBS)	Tamil Nadu	1916	1780	893	608	4937	3520	4729	1001
Coimbatore (PIRRCOM)	do	3695	2405	670	665	5740	5025	5290	780
Bhavanisagar	do	2956	3064	1550	879	5597	4506	5281	944
Vizianagaram	AP	3131	2771	1359	416	7133	4097	8209	969
Dharwar (red soil)	Mysore	4542	4270	2727	563	12558	8468	16361	1654
Dharwar (black soil)	do	5375	4901	5332	545	17150	14424	26479	1033
Bailhongal	do	4248	3204	2339	800	10190	4880	17976	2727
Digraj	Maharashtra	1927	2009	761	865	2063	1704	3050	NS
Akola	do	2077	1686	1625	419	7032	4413	6745	1683
Gwalior	MP	2727	2332	1392	685	19375	11912	13993	1848
Nowgong	do	1162	309	732	249	4090	3193	4664	1428
Betul	do	2325	1521	2038	897	3875	2870	4987	1435
Tancha	Gujarat	1881	1938	322	610	10271	6970	10063	2318
Junagadh	do	757	574	578	260	4079	2958	3541	1165
Almora	UP	3090	2053	1455	738	22923	10963	9727	4465
Jeypore	Orissa	2691	2299	2018	1045	3532	3924	3252	1641
Phulbani	do	4375	3192	1957	881	4375	3192	6151	1631
Keonjhar	do	2690	2279	2560	861	8370	8703	7087	2047
Rayagada	do	2888	1363	2512	—	16505	12020	14172	—
Sabour	Bihar	5588	5355	1184	933	25026	17581	26999	3749
Mean		3002	2465	1700		9741	6766	9938	
% over local		177	145	100		98	68	100	

MBS — Millet Breeding Station; PIRRCOM — Project for the Intensification of Regional Research in Cotton, Oilseeds and Millets.

APPENDIX III

Comparative Performance of *Swarna*, CSH-1 and Local at 25 Locations

(*Kharif*, 1967)

State	Location	Grain yield, kg/ha				Fodder yield, kg/ha		
		Swarna	CSH-1	Local	SEM	*Swarna*	CSH-1	Local
Maharashtra	Parbhani	4352	4945	3582	252	13452	8309	23202
do	Nanded	4520	4734	2410	270	9324	7410	16438
do	Somnathpur	4468	5064	3490	159	10285	12737	16026
do	Akola	5140	3935	2582	201	11388	8790	17282
do	Buldhana	2637	3084	1746	240	3229	4783	10046
do	Yeotmal	3983	4150	2201	299	7893	6458	9329
do	Karad	2215	1937	1650	239	4485	5561	10225
do	Kolhapur	3032	4084	1650	320	7843	12027	14704
Mysore	Dharwar	3961	3564	3799	254	5143	6040	13454
do	Siruguppa	3707	4126	3169	206	4784	4784	5262
do	Raichur	3535	3480	2115	344	4521	4521	10261
do	Bailhongal	4092	3107	2780	321	6004	4389	4783
do	Bagalkot	6551	4040	3268	237	6996	6518	11242
Andhra Pradesh	Warangal	2562	2971	1528	170	10094	11290	10859
do	Rudrur	3683	4066	2296	241	9089	9918	15260
do	Amberpet	4285	4463	3570	—	—	—	—
do	Rajendranagar	5045	4282	1099	277	12387	9300	23907
Madhya Pradesh	Khargone	2936	3976	1118	192	4604	6578	11661
Uttar Pradesh	Jhansi	2758	1834	—	—	—	—	—
do	Pantnagar	4072	3738	2121	174	17000	23200	34700
Tamil Nadu	Coimbatore	4403	3885	3885	364	—	—	—
Orissa	Rajgangpur	3450	3392	1859	143	11685	11393	23215
do	Bhawanipatna	3074	3681	1208	387	13735	18594	34892
do	Phulbani	2858	2978	1794	213	5501	7774	15308
Bihar	Kanke	2296	2535	1674	329	9807	15403	36118
	Average	3744	3682	2358		8602	9353	16735
	% of CSH-1	101	100	64		92	100	179
	% of local	158	156	100		51	56	100

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TRANSFORMING SORGHUMS

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RESEARCHES leading to the improvement of sorghum, the premier rainfed food and fodder crop of the country, have made more progress during the past decade than in the preceding period. These investigations embraced the fields of plant breeding and agronomy leading to the development of new hybrids and varieties and their production technology, entomology and pathology resulting in the development of insect and disease control measures besides attempts at nutritional upgrading of this poor man's cereal. Today an integrated approach to sorghum improvement is feasible; some of the more important findings of immediate applicational value are described.

Early Work

Natural selection and domestication over thousands of years has resulted in the development of numerous varieties highly local in their adaptation. Most of the present day improved varieties are the result of pure line selection practised in principal local varieties. Limited intervarietal hybridisation followed by selection has primarily contributed towards combining existing levels of grain yield with juicy stems to improve forage quality; noticeable changes in yield levels were not marked. Prominent among those who contributed to the genetics and breeding of sorghum in the early years were G.N. Rangaswamy Ayyangar and his colleagues from the then Madras State and Rao Saheb Kottur and his colleagues from the then Bombay State. A review of the earlier varietal improvement work by Chavan and Shendge (1957) reveals that in spite of the availability of over a hundred improved strains, the yield levels remained low representing marginal increases (10—15%) over the base populations. Notable among the varieties developed during this early period which are still under cultivation are the *Co* series in Tamilnadu; the Nandyal, Guntur and Anakapalle series of Andhra Pradesh; the PJ *kharif* and *rabi* selections, *Saoner*, *Ramkel*, *Aispuri*, the *Maldandi* and *Dagadi* (compact headed) selections of Maharashtra; the *Bilichigan*, *Fulgar white*, *Fulgar yellow*, *Kanvi*, *Nandyal*, *Hagari*, *Yanigar* varieties of the Mysore State; the *Budh perio*, *Sundhia* and *Chasatio* of Gujarat; the selections of Gwalior and Indore from Madhya Pradesh; the *RS* selections of Rajasthan and a few others. In addition, there are also special varieties for popping, parching and to suit special requirements. The age old association and the consequent local preferences for the taste of the respective local varieties are the dominant reasons for their continued cultivation in spite of their erratic behaviour and low yields.

An examination of the trends in sorghum production in India does not reveal any marked increases in yields, the per hectare averages ranging from 400—480 kg The cultivation of tall, long duration varieties over a vast proportion of the area the yields of which are most affected in years of drought, almost the total absence of the practice of fertilization and the tradition of growing sorghums only under low populations have been the major limiting factors in realising higher yields.

Recent Hybrids and Varieties

As a result of the efforts under accelerated hybrid sorghum project initiated by the Indian Council of Agricultural Research during the year 1962, which became a comprehensive Co-ordinated Sorghum Improvement Project from the beginning of the Fourth Five Year Plan period (1969-70), four commercial hybrids, CSH-1 (1964), CSH-2 (1965), CSH-3 (1970), PSH-2 (1970) and an improved variety *Swarna* (1968) were released for general cultivation. The development and release of these new hybrids and varieties marked a genetic breakthrough in the otherwise stagnant yield levels. The hybrids yielded 60—100% more grain than the presently available improved varieties.

The new hybrids and varieties represent dwarf plant types as against the traditional tall forms which lodge on fertilisation. Their response to fertiliser and population inputs is much superior to the traditional talls. *Swarna* is erect leaved and stands even thicker populations than CSH-1. While the total fodder yield of the new varieties is less than the talls, the fodder being less fibrous, is more digestible.

The new hybrids were not only high yielding, but they were characterised by stability of performance. Severe drought conditions prevailed during the years 1965 and 1966. Yet, in no year the average yield levels of CSH-2 were less than 25 Qtls/ha in yield trials or national demonstrations. Besides being drought tolerant, they also escape midge which has of late become serious with the late varieties of Maharashtra and Mysore. The new varieties have a decided advantage for midge and various diseases but they are relatively more susceptible to shoot fly and stem borer.

Components of Production

The development of high-yielding hybrids and varieties will not by itself contribute to the realisation of higher yields unless varietal improvement and researches in production technology go hand in hand. It is only then the potential yields could be translated into realised yields. Through cooperative efforts with the related disciplines of agronomy, entomology and plant pathology vast experimental data with regard to dates of planting, fertiliser schedules, insect and disease control measures leading to the development of the package of practices for the various sorghum growing regions of the country have been obtained.

Recommended Production Practices

Based on countrywide agronomic experiments, the following recommendations are available.

Time of sowing: (a) Under rainfed conditions during kharif, plant sorghum at the onset of first monsoon showers or slightly ahead; (b) During rabi, advance planting of sorghum by one month over normal dates, mid August or mid September depending on the locality. This assures high yield and minimum incidence of shoot fl

Fertilisation: (a) Under rainfed conditions, the optimum level of N is 80—100 kg. The level of $P_2 O_5$ and $K_2 O$ shall depend upon soil test; (b) The optimum time of application of N under medium to heavy textured soils is full at planting; in case of light textured soils split application half at planting + half at knee-high stage is advantageous.

Plant population: The optimum plant population for dwarf sorghum hybrids is near about 2,00,000 plants/ha in rows 45 cm apart. *Swarna* can tolerate even higher populations.

Weed control: Pre-emergence aplication of Atrazine or Propazine at 0.50 a.i./ha + one late weeding would be more economical, safe and sure practice for controlling the weeds in sorghum, ultimately resulting in high grain yield.

Insect Control

Comprehensive pest control schedules have been developed based on extensive studies all over the country. The following recommendations provide guidelines for control of various pests and diseases as and when they occur. *Shoot fly*: The shoot fly damage has generally been observed in late sown kharif in all the sorghum growing areas, normally sown crops in rabi areas and monsoon crop in Tamilnadu. Where two crops of sorghum are taken in a year, the damage is likely to be heavy in both the crops.

(a) In kharif season, if the crop is sown as early as possible, with the onset of the monsoon it may escape shoot fly infestation. Higher seed rate (11 kg/ha) and uprooting and destroying the damaged seedlings, 10 to 12 days after germination, may significantly reduce the subsequent shoot fly injury.

(b) Where shoot fly is a serious problem, use sorghum seed treated with 5 parts (a.i.) carbofuran per 100 parts of seed. If carbofuran is not available use 5% disulfoton at 3.0 gm/metre row or 10% phorate granules at 1.5 gm/metre row. If carbofuran treated seed or disulfoton and phorate are not available, some control may be obtained in early kharif season by spraying the crop with carbaryl (50% WP) 2 kg, or endrin (20% EC) 1 litre, or a mixture of endrin (20% EC) 375 cc and methyl demeton (25% EC) 250 cc, or lindane (20% EC) 2 litres or dimethoate (30% EC) 250 cc in 450 to 500 litres of water per hectare. The crop should be sprayed twice, the first spray after 3 to 5 days of emergence of seedlings and the second 5 to 7 days after the first spray. Addition of a wetting agent in the sprays may give better results.

Stem borer: Uprooting the stubbles and burning them will reduce the possibilities of infestation.

(a) Apply granules of 4% endosulfan, 4% carbaryl or 2% lindane, two to three times at 10 days intervals, starting 20 days after emergence of seedlings. The rate of application for the three treatments should be 8, 12 and 15 kg/ha. Two applications will be sufficient in the states of Maharashtra, Andhra Pradesh, Tamilnadu and Mysore where borer is not very serious. The applications may be given 25 and 35 days after germination.

(b) Alternatively, the crop may be treated with spray formulations of the above insecticides at the same dose of active ingredients in 500 to 600 litres of water per hectare. With carbaryl or wherever mite is a problem, add 2 kg of wettable sulphur. Both the granules and the sprays should be directed towards the leaf whorls.

Earhead Pests

Midge: Burning of panicle residues and chaff obtained after threshing will destroy diapausing larvae of the midge which may otherwise become a source of infestation next year. If necessary, this may be made obligatory in the areas where heavy midge infestati is observed.

Uniform date of sowing, and sowing of only one variety should be recommended for a block.

For chemical control of the midge, spray the earheads before flowering (at about 50% panicle emergence) with endosulfan (35% EC) 1 litre, carbaryl (50% WP) 3 kg, or lindane (20% EC) 1.25 litres in 500 to 600 litres of water, per hectare. Repeat the spray after 4 to 6 days. Two per cent endosulfan dust or 10% carbaryl dust may also be used for midge control at 20 kg/ha. A 10% BHC dust at 20 kg/ha has also been reported to be effective from Maharashtra and Andhra Pradesh; give two applications as in the case of sprays.

For earhead bug and caterpillars at the milky stage, treat the earheads with 10% carbaryl dust with sulphur (for mites) 18 :2, or 10% BHC dust at 20 kg/ha.

Note: 1. The quantity of spray liquid mentioned is for bucket type sprayers; if back-packed mist blower is to be used, the quantity of water required will be about one-third, the quantity of insecticides added per hectare should be the same.

2. Proper precautions should be taken in using the poisonous chemicals.

Disease Control

Diseases have generally been not as serious as insect pests. The following recommendations will be useful in case of disease incidence.

(1) Seeds should be treated with either 'Thiram' or 'Agrosan' just before sowing since it is known that the fungicide deteriorates to a great extent on storage after treatment of the seeds.

(2) Where leaf spots and sugary disease are a problem in seed production fields, they may be sprayed with Zineb four times starting 30 days after sowing, boot leaf stage, 50% flowering and full flowering period. This has been found to be very effective in reducing the important leaf spot diseases as well as sugary disease.

(3) To control mouldiness occuring as a result of rains received at grain maturing stage, spraying with a combination of aureofugin and captan may be restored to.

Outlook

Present studies aim at improvements in grain quality and tolerance to insect pests. New hybrids and varieties derived from exotic × Indian crosses combine these desirable attributes besides high yield and they are on the verge of release to the farmers. Two improved hybrids and two varieties are already at the pre-release stage. Attempts are in progress to combine B-carotene and higher lysine contents in future varieties.

Spread of available varieties with the recommended production practices on a scale commensurate with the magnitude of the crop could certainly make the much needed dent on the currently stagnating, national average yields of sorghum.

The work reported in this article is based on information available in various disciplines of the All India Co-ordinated Sorghum Improvement Project.

PROSPECTS FOR ENHANCED RABI JOWAR PRODUCTION

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IN view of the widespread failure of kharif rains, particularly in the states of Maharashtra, Mysore and Andhra Pradesh, where the bulk of jowar area of the country is located, there is emphasis on the prospects for compensating this loss in sorghum production by enhanced efforts during rabi. The prospects for such efforts are outlined in the light of the available research findings.

Rabi Areas

For purposes of rabi, the following broad areas may be considered:

Late kharif

The Maghi areas in the district of Khammam, Warangal and Karimnagar and the Nandyal valley of Kurnool District in Andhra Pradesh, the late kharif areas of Tamilnadu and the Surat District of Gujarat State where the plantings commence in late August—early September constitute the late kharif or mid-season tract. This area is wholly rainfed.

Traditional rabi

Traditional rabi jowar area is predominantly concentrated in the Deccan plateau covering the states of Maharashtra, Mysore and Andhra Pradesh. Rabi jowar constitutes nearly one-third of the total jowar area in the country. Since the crop is grown in the winter (mid-September—mid-October plantings) and matures slowly in clear weather, rabi jowars have a premium in the market and are always priced higher than kharif jowars. The traditional rabi jowars are almost wholly rainfed and come up with the residual moisture stored in these black cotton soil areas.

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Irrigated summer season

The irrigated summer season (January-February plantings) is also clubbed under rabi for statistical purposes of the seasonal distribution of areas. This season is more analogous to the short-duration kharif and is predominantly distributed in Tamilnadu

Impact of Research Effort on Production

Earlier work under the accelerated sorghum project and the All India Co-ordinated Sorghum Improvement Project was concentrated on kharif jowars. Rabi jowar improvement work under the AICSIP is of recent origin. A brief account of the implications of available research results on enhancing rabi jowar production are outlined.

Late kharif

Traditional varieties grown during this season, viz PJ22K in Khamam and Warangal, N3, N5, etc. of Nandyal in Kurnool District of Andhra Pradesh and BP53 of Gujarat are late and mature in 5-5½ months. In a situation marked by absence of July and August rains, short-duration hybrids and varieties have a decided advantage. Since these jowars mature in a clear weather, there is no possibility at all for grain deterioration also. Hence emphasis has to be laid on cultivation of CSH-1, CSH-2, CSH-3, PSH-2 or Swarna during this season. Depending on the availability of seed, any of these varieties could be taken up with recommended fertilizer and insect control schedules. It is recommended that only one variety be taken up in each area. Multiplicity of varieties in the same region should be avoided to prevent midge incidence.

Traditional rabi

(a) *Varietal improvement.* M35-1 is the dominant variety in the entire region. This is known to be the most drought-resistant variety, also known for its grain quality.

Of the recent hybrids and varieties CSH-1 and BSH-2 did reasonably well provided shoot fly was controlled. In years characterised by drought (less of monsoon rains) the hybrids CSH-2 and CSH-3 being the earliest to mature during this season, gave satisfactory yields when locals and even M35-1 failed to make any grain. For example, at Bellary during the 71-72 rabi seasons, CSH-2 and CSH-3 yielded 1118 and 1097 kg/ha respectively when the locals completely failed. The comparative figures under extreme stress are summarised below:

TABLE I. PERFORMANCE OF EARLY HYBRIDS AT BELLARY DURING 1971-72 UNDER EXTREME STRESS

Variety/Hybrid	*Grain yield* (kg/ha)
CSH-2	1118
CSH-3	1097
CSH-1	893
PSH-2	689
Local (M35-1)	20

Of the recent varieties and hybrids tested, the following were promising: *Varieties*: R-16, R-24, RCR-408; *Hybrids*: M31-2A × LSR-1. The variety R-16 and the hybrid M31-2A × LSR-1 have superior grain quality. Extensive agronomic investigations have been planned and they have a chance of release fairly shortly. Seed supplies will not be available during this year.

(b) *Agronomy.* Considerable amount of work has been done on dates of planting of rabi jowar. Traditionally, rabi jowar is planted towards the cessation of the south-west monsoon around October 15. Very frequently absence of moisture in the top soil at sowing places a limitation of fertilizer application which is almost absent with the rabi jowar farmer.

Extensive trials have indicated that advancing the dates of planting to mid-September, and even earlier in some of the areas, facilitates application of fertilizers, results in improved crop stands and the ultimate yield increases to the order of 80—100%. The improved variety R-16 performed particularly well under early plantings.

All the fertilizer for rabi jowar (60 kg P_2O_5 and 60—80 kg N/ha) should be applied basally. A recommendation to this effect has been available from the 1971 and 1972 All India Co-ordinated Sorghum Improvement Project workshops held at Jamnagar and Nagpur respectively.

(c) *Insect and disease control*

Shoot fly. Shoot fly has been the major pest. It was observed that in areas where kharif and rabi do not overlap, the fly incidence was low in early plantings. In regions like Marathwada where kharif and rabi overlap, early planting has a decided advantage for yield provided shootfly is controlled. Seed treatment with carbofuran 5 gm (A.I.) per 100 gm of seeds or phorate 10% G in seed furrow at 1.5 gm/m or Thiodemeton 5% G in seed furrow at 3.0 gm/m gave effective control of shoot fly.

Sugary disease. Sugary disease of the panicle is likely to appear during winter months when temperatures are cool. If occuring it could be controlled with sprays of 0.2% Ziram or 0.2% Thiram at 50 per cent flowering. In case midge appears, this could be combined with carbaryl.

Irrigated Summer

Nearly four lakh acres of sorghum are grown under irrigation in Tamilnadu, plantings taking place in February. Prospects are also bright for irrigated summer crop in Andhra Pradesh and Mysore where plantings during the latter half of January or early February are highly rewarding.

(a) *Varietal improvement.* The short-duration CSH-1 and Swarna perform outstandingly well during this season. Since maturity takes place during summer months the grain is clean and of good quality. A new hybrid 2077A × CS3541 has done well during this season but seed will not be available during this year.

With adequate fertilisation (60 kg P_2O_5/ha and 80 kg N/ha), insect control and 4-6 irrigations, yields of the order of 5000-6000 kg of grain per hectare have been realised.

Potentialities for such sorghums exist in the Nagarjunasagar Project areas, the Krishna, Godavari deltas of Andhra Pradesh and the Tungabhadra Project areas of Andhra Pradesh and Mysore. Paddy fallows of these states, with facilities for 3-5 irrigations after harvest of paddy are also potential areas.

(b) *Intercropping studies.* During the last summer season intercropping studies involving groundnut as the major crop and sorghum, soyabean, sunflower and castor as intercrops were taken up. The maximum return per acre was obtained with groundnut-sorghum intercropping system which was superior to pure crop of groundnut.

The approximate distribution of summer irrigated groundnut is as follows:

State	District	Area (acres)	Source of irrigation
Andhra Pradesh	Nalgonda	90,000	Nagarjunasagar Project
	Guntur & Krishna	100,000	Nagarjunasagar Project
	Kurnool	85,000	Tungabhadra Low Level Canal and K C Canal
	Mahboobnagar	35,000	Rajoli Banda Diversion Scheme
	Chittoor	50,000	Tanks and Wells
	Anantapur	25,000	Tungabhadra Project High Level Canal
	Cuddapah	18,000	Wells
Mysore	Raichur	75,000	Tungabhadra Project
	Bellary	25,000	Tungabhadra Project High Level Canal
	Chitaldurg	65,000	Bhadra Project
	Shimoga	30,000	Tungabhadra Project and Bhadra Project
Tamil Nadu	South Arcot	100,000	Mostly under wells
	North Arcot	20,000	,,
	Coimbatore	32,000	,,
	Tanjore	21,000	,,

Source of statistics: Oilseeds Directorate, Hyderabad

In at least some of these areas, if groundnut could be intercropped with an early maturing sorghum like Swarna or CSH-1 in the proportion of 1/6 to 1/10 to groundnut, substantial sorghum yields could be obtained.

The seed rate of groundnuts should not be reduced but a row of sorghum could be planted after every 6 to 8 rows of groundnut. Variations are possible as 2 rows of sorghum to 12 or 16 rows of groundnut and so on.

Groundnut-sorghum intercropping should be concentrated in January plantings of groundnut since growth of sorghum will be slow during December.

Summary and Recommendations

In view of the failure of July-August rains, particularly in the predominantly jowar-growing states of Maharashtra, Mysore and Andhra Pradesh, a substantial shortfall in kharif production is expected. Consequently, ways and means for compensating this loss during rabi have become necessary. The following guidelines to be suitably modified to suit local conditions, could be useful in planning for this enhanced rabi production

1. *Rainfed rabi*

The production of rainfed rabi jowar is always a function of the amount and distribution of rainfall received during kharif season (South-West monsoon) since rabi jowar comes up with stored moisture in the profiles of the black cotton soils and almost no rains are received during crop growth. In view of the failure of rains during July-August and only one rainy month remaining ahead, the prospects for rainfed rabi will be fraught with difficulties.

1. The late kharif (*Maghi*) areas should be planted with early maturing hybrids as soon as the monsoon breaks

2. As a rule planting of traditional rabi jowars should be advanced by a month. Plantings should commence in early September in Sholapur-Bijapur belt and early to mid-September in parts of Andhra Pradesh and Mysore. This would enable application of adequate quantities of fertilizers at plantings and results in establishment of satisfactory crop stands. Besides, some rain during early crop growth period could be expected which would be beneficial. Such plantings enable the crop to mature before the soil profile gets depleted of moisture. Since seed may be a limitation with hybrids, traditional varieties could be used M35-1, CSH-1 and PSH-2 could all be used.

3. If plantings are delayed or if September rains are also inadequate resulting in early moisture stress, extremely early hybrids like CSH-2 and CSH-3 will give reasonable yields where the late locals are apt to fail. Depending upon the future rainfall pattern, these varieties could be capitalised under extreme stress.

4. Fertilisation in rabi should all be basal and should give 60 kg P_2O_5/ha and 60-80 kg N/ha.

5. Shoot fly control may be achieved by applying *one* of the following treatments: (a) seed treatment with carbofuran 5 gm (A.I.) per 100 gm of seeds or (b) phorate (Thimet) 10 per cent granules in seed furrow at 1.5 gm/metre row or Thiodemeton 5 per cent granules in seed furrow at 3.0 gm/metre row or adapting slightly higher seed rate and thinning affected plants three weeks after sowing.

6. Sugary disease of ears and midge if occurring may be controlled by 0.2% Ziram or Thiram spray alone or in combination with carbaryl (50% WP) 3 ' in 500 600 litres of water per hectare for midge control at 50 per cent flowering.

Irrigated Summer

While rainfed rabi production is dependent · preceding rains, prospects for additional production during irrigated summer may be considered assured possible to plan for a targetted additional production and every additional acre could yield 1-2 tons of grain. It is, therefore, suggested that this should be attempted in concentrated areas in Andhra Pradesh (Nagarjunasagar, Tungabhadra, Krishna and Godavari deltas), Mysore (Tungabhadra and Bhadra Project areas) and Tamilnadu (wells).

1. The early duration CSH-1, CSH-2 and Swarna could be grown in pure crops under the projects. The paddy fallows offer potential scope. It is necessary to provide price support here since the local people are not accustomed to consume jowar. Jowar grains from these areas could be procured and taken to jowar consuming areas.

The fertilizer and insect control schedules remain the same as described in the preceding paragraphs and 3-6 irrigations will be needed during crop growth. Plantings should be done from January 14th onwards to the first week of February.

2. There is a substantial area under irrigated groundnut in the states of Andhra Pradesh, Mysore and Tamilnadu. Groundnut plantings commence during December and extend into January-February. All areas where groundnut plantings commence from January onwards could have a component of the short-duration varieties or hybrid, viz. Swarna or CSH-1 or PSH-2 in the proportion of one row of jowar to 6-8 rows of groundnut. Seed rate of groundnut should not be reduced. The basal dressing of fertilizers should be common to both crops but jowar alone may get side-dressed at 30-40 days to give additional 30-40 kg N/ha. This would add a substantial amount of food and fodder without any major loss in groundnut production.

Prospects for any targetted additional production are greater during the irrigated summer in view of the time available for planting and also in view of the assured irrigation. There is apparently no risk involved.

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CYTOGENETICS OF SORGHUM

by

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CYTOGENETICS OF SORGHUM

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The classification of *Sorghum* continues to be controversial, yet all systems—classical, cytogenetical, commercial, numerical and biometrical, have their base in the Snowdenian system. Cytological evidence suggests that the division of *Sorghum* into two subsections Eu- and Para-sorghums is sound and natural in view of the basic differences in their karyotypes. Also justified is division of Eu-sorghum into the mostly tetraploid ($2n=40$) rhizome bearing perennial Halepensia and the annual 20 chromosomed Arundinacea. Excepting the diploid ($2n=20$) *S. propinquum*, the rest of the four Halepensia sorghums are tetraploids, their behaviour varying from segmental allo- to autopolyploidy.

Lack of major structural repatterning of chromosome complements of the different taxa, the inadequate role played by polyploidy, operation of disruptive selection and the often cross pollinated nature of the organism, make a satisfactory classification of the genus difficult. Available cytogenetic evidence makes it highly unlikely that the 31 cultivated 'species' listed by Snowden are all genetically isolated from one another and consequently there is no reason to consider each as a distinct species. Pooling all the Halepensia into one subspecies and the Arundinacea into another is also difficult to justify.

Three morphological types of supernumerary chromosomes occur in the Para-sorghum, *S. purpureo-serecium.* These are not reported in any of the cultivated forms. Their presence affects the male and female fertility to a marked extent and does not have any practical utility.

The behaviour of haploids and tetraploids of cultivated sorghums resemble those of other crops. Induction of polyploidy in cultivated sorghum does seem to have practical utility, although colchicine induced tetraploids are generally characterized by a high degree of sterility. This is because F_1 and F_2 generations from crosses of different artificial polyploids gave a decidedly better seed set as also colohiploids of an apomictic culture and this indicates that it should be possible to increase fertility of autotetraploid sorghum hybrids. Colchicine has also been shown to have a peculiar effect of somatic chromosome reduction in addition to its usual induction of polyploidy. Sorghum seedlings heterozygous for structural changes when treated with colchicine gave some plants homozygous for the chormosome markers.

For purposes of interspecific and intergeneric transfer, the genetic resources of sorghum include not only the diploid and tetraploid species of the genus but other genera like *Zea*, *Saccharum*, and *Sorghastrum* as well. However, our knowledge of the wild and weedy relatives in the genus *Sorghum* itself is quite limited. The cytogeneticist and the plant breeder could explore this total gene pool. The discovery of apomixis, the phenomenon of self-incompatibility and the diverse cytoplasmic and genetic sources of male-sterility could provide the tools to synthesise together the antagonistic demands of uniformity for immediate fitness and diversity for long term survival.

Problems of classification and origin of the major groups

Among the early attempts towards the classification of *Sorghum*, Snowden's

(1936, 1955) work is one of the most comprehensive and useful. Since then, several classifications have been proposed, notable among them being the cytogenetic classification of Garber (1950); the commercial classification of Vinall *et al.* (1936); the numerical classification of de Wet and Huckabay (1967) and Liang and Casady (1967), and the biometrical system proposed by Murty and his co-workers (1967). A general feature about these systems is that they take the Snowdenian system as the base. Yet none of these have become as popular as that of Snowden. More recently, a very simple and practical system of classification of the cultivated sorghums into five basic and 10 hybrid races which can be easily identified from morphological characters of the mature head and spikelet has been suggested by Harlan (1971*a*).

Several factors are responsible for the difficulties in classifying the sorghums. Basically, there are no major structural changes of the chromosomes. In the subsection *Para-sorghum*, chromosome complements of the species were morphologically similar in all phases of meiosis. No marked differences were evident so that any one complement would have been indistinguishable from the other. In the subsection *Eu-sorghum*, chromosome complements of the species were likewise morphologically similar in all phases of meiosis excepting chromosome number (Garber: 1944). However, Sharma and Bhattacharjee (1957) have found some structural differences of chromosomes existing between the different species of this genus. The karyotype of none of them corresponds exactly with that of the other. Minor differences at least are always noticeable. These differences may involve either relative size or position of primary and secondary constrictions. The number of chromosomes with secondary constrictions too has been found to vary, indicating the role of this change in evolution. However, detailed studies of pachytene chromosomes by Magoon *et al.* (1960, 1961, 1967) did not reveal any major differences among the chromosome complements of the different members of Arundinacea nor those of Halepensia.

Another feature in the cytogenetic evolution of the genus which contributes to the difficulties in classification is the inadequate role played by polyploidy. There are no doubt three ploidy levels in the genus represented by $n = 5$ (found only in Para-sorghum), $n = 10$ (cultivated and wild Arundinaceums) and $n = 20$ (Halepensia). Although it is speculated that the cultivated types are allopolyploids between two different 5-chromosome species, none of them have so far been identified. The Halepensia, however, represent either autopolyploids or amphiploids containing two very closely related genomes.

The role played by disruptive selection may also have been responsible for making a satisfactory botanical classification of sorghum difficult. According to Doggett (1970) cultivated sorghums were derived from wild sorghums by a process of disruptive selection, the changes being purely genetic, there being no chromosomal alterations. Furthermore, although sorghums are essentially self-pollinated, cross-pollination is quite frequent and the frequent occurrence of genetic and cytoplasmic male-sterility further promotes frequent gene flow resulting in a continuous rather than discrete variation (Rao : 1968).

Cytogenetic evidence strongly favours the division of the genus into two subsections, Eu- and Para-sorghums. Pachytene chromosomes in the Eu-sorghums are structurally differentiated with distinct centromeres, whereas in the rest of the sorghums, they are uniformly stained with acetocarmine with no accumulation of stain in any one region of the chromosome. Secondly, in species of the subsection Para-sorghum, the nucleolar organising chromosome was terminally attached to the nucleolus. The region of attachment was marked by a spheroidal bulge separated from the remainder of the chromosome by a narrow nonstaining band. In the species of the subsection Eu-sorghum the nucleolar chromosome was attached to the nucleolus at an intercalary point which did not appear to be morphologically distinguishable from the remainder of the chromosome. Furthermore, chromosomes of Para-sorghum are considerably larger than those of *Eu-sorghum* (Longley : 1937; Garber : 1944, 1950). There have been no reports of successful crosses of any cultivated or wild sorghums ($2n = 20$) with species of Para-sorghum having $2n = 10$ although several attempts have been made. These facts suggest that the two sections form natural groups. This cytological evidence has been corroborated from morphology. The same situation exists as regards the division of Eu-sorghum into the Halepensia and Arundinacea. The former are mostly tetraploid ($2n = 40$). and with the exception of *S. propinquum*, are rhizomatous and perennial. The Arundinacea are on the other hand, diploid ($2n = 20$), non-rhizomatous and mostly annual. Several workers do agree with Snowden in dividing the genus into sections and subsections, but disagreement arises in the delimitation of the species. Snowden has made a rather extensive splitting especially of the cultivated species. The 31 cultivated species recognised by him are more or less interfertile with practically no barriers to gene flow. The status of the subsection Halepensia is now more or less clear. It consists of 4 tetraploid and one diploid species (*S. propinquum*). The two genomes of the tetraploids have been repeatedly shown to have arisen from *S. propinquum* and either the wild or cultivated Arundinacea. *S. almum*, another member of the Halepensia is much more recent in origin. Parodi (1943) considered that it had arisen as a natural cross between one of the grass fodder sorghums and *S. halepense*. Endrizzi (1957), however, relying on his studies of *S. almum* and crosses of various diploid Arundinacea with Halepensia, concluded that *S. almum*, more probably arose from a cross between a cultivated grain sorghum and *S. halepense*. From these facts, it is obvious that the subsection Halepensia could not have conributed to the origin of the cultivated sorghums. Based on chromosome morphology of cultivated sorghums, some authors have suggested that they might have arisen through allopolyploidy between 2 basic archetypes, one with 5 short and the other with 5 long chromosomes, but today we have no experimental evidence for such a hypothesis. We are, therefore, left with looking for the origin of the cultivated sorghums from the wild diploid members.

Snowden (1936) believed that the wild African Arundinacea species, viz., *S. arundinaceum*, *S. verticilliflorum* and *S. sundanense* were the progenitors of the cultivated races. Doggett (1965, 1970) suggested from cultivated sorghums originated by disruptive selection from wild members in the Ethiopian region of Africa. However, de Wet and Harlan (1971) who recognise only 6 cultivated races suggest that ecological and geographical isolation probably gave rise to the 4 varieties of wild sorghums which gave rise to the cultivated races. They account for the morphological differences between the cultivated races as due to ethnological isolation.

Chromosome morphology

Somatic Chromosomes of sorghum have not received as much attention as the meiotic chromosomes. Venkateswarlu and Reddy (1956) observed the meiotic chromosomes in the root tip cells to exhibit differentiated segments in *S. subglabrescence*, a Eu-Sorghum. Sharma and Bhattacharjee (1957) observed structural differences of chromosomes between different cultivated races. The differences involved either relative size or position of primary and secondary constrictions. According to them such karyotypic differences can easily be considered as a criterion for the identification of the species.

Meiotic Chromosomes. In spite of several reports on the morphology of the meiotic chromosomes, our knowledge of sorghum chromosomes is still very limited. At *MI* there are no striking differences among the different chromosomes so as to distinguish them, although Huskins and Smith (1932) were able to recognize one pair which they called *A*-chromosomes. Longley (1937) has shown the differentiated nature of the chromosomes at pachytene. He noted that in the region of the centromere there was a clear area, the chromosomes being deeply stained on either side of it. The longest chromosome was attached to the nucleolus at a point near the centromere. Garber (1944, 1950) could distinguish between the Para- and Eu-sorghums on the differential staining reaction of the latter. Venkateswarlu and Reddy (1956) found that a critical study of the heavily stained proximal segments and the distal lightly stained regions, the relative lengths and arm ratios in the pachytene chromosomes was very useful in identifying each of the 10 chromosomes of the set. Studies on the pairing properties of the differentially stained parts show that synapsis takes place initially during early prophase in the heavily stained regions and is followed by the earlier separation of the split chromosomes in the same regions at diplotene. Several pachytene studies were also made by Magoon and his co-workers. All these studies indicate the differentiated nature of the Eu-sorghums and that the karyotypes of sorghum species and varieties may be distinguishable on the grounds of arm ratio, distribution of chromomeres and constrictions, relative lengths and stained and unstained lengths.

Polyploidy

Haploids have been reported generally in the progeny of hybrids (Brown :

1943; Kidd : 1952 ; Endrizzi and Morgan : 1955). Haploid sorghum plants are shorter and less vigorous than their diploid siblings. They can be distinguished by their relatively slender stalks, narrow leaves, small, highly sterile panicles and particularly by their small glumes. Spikelet structures within the outer glumes are reduced in size proportionately. Excessive side branching of haploids is probably caused by incomplete seed setting in a manner similar to that of diploid plants which have poor seed sets as a result of drought, midge damage or male sterility. The stomatal guard cells are measurably smaller than in diploid plants. Haploids are highly pollen sterile.

Meiosis in the haploids revealed for the most part univalents, but a considerable number of PMC's have 1-3 bivalents. Also in a single cell a trivalent has been observed (Table 1). The existence of bivalents in the haploid has been taken to indicate the duplicate nature of the genome of grain sorghum. The production of occasional diploid plants from haploids indicates that diploid nuclei with the full haploid complement of chromosomes are formed also during ovule development.

Triploids were observed by Price and Ross (1957) and by Schertz and Stephens (1965) from field populations and also from controlled crosses. Triploids were distinguishable from diploids of the same cultivar by differences in fertility, morphology and chromosome numbers. Triploids were highly sterile and had consistently larger stomatal guard cells. A mode of 9 trivalents per microsporocyte was noted. The progeny of triploids varied depending on the source of the seed.

TABLE 1—FREQUENCY OF CHROMOSOME ASSOCIATIONS IN HAPLOID SORGHUM

Author	*Chromosome configurations*				
	1 III+7I	*3V+4I*	*2 II+6I*	*1 II+8I*	*10 I*
Brown : 1943	0	1	2	13	134
Kidd : 1952	1	0	4	8	36
Endrizzi and Morgan : 1955	0	0	0	4	22

AUTOTETRAPLOIDS. Tetraploids forms of grain sorghum were induced by a number of authors (Chin : 1946 ; Ross and Chen : 1962; Schertz: 1962; Doggett : 1962, Magoon and Tayyab : 1968). Autotetraploid grain sorghums behave more or less like those in other crops. They are characterised by slow growth, dark green foliage with wavy margins, shorter but stouter straw, larger grains, greater protein content and varying degrees of male and female fertility.

An interesting cytological feature of autotetraploid sorghum is the lower frequency of univalents and trivalents. Compared to maize, the quadrivalent frequency is also less. This is even more so in an autotetraploid of an apomictic culture R 473 (Table 2). Chin (1946) found that in colchicine induced autotetraploid sorghum, 19% of the pollen grains were defective and the tetraploids were maturing later than the diploids. Similar rather high

TABLE 2—FREQUENCY OF CHROMOSOME ASSOCIATIONS IN AUTOTETRAPLOID SORGHUM

Author	*No. of cells*	*Chromosome configurations (Mean no. per cell)*			
		I	*II*	*III*	*IV*
Schertz : 1962	70	0.0—0.2	14—18	0.0 - 0.8	1.3—3.0
Doggett : 1964	—	low	7.5	low	6.22
Magoon and Tayyab : 1968	40	0.93	13.13	0.18	3.08
Murty *et al.* : (unpub.)	52	0.6	12.81	0.54	3.07

male and female fertilities were reported by various authors in tetraploids of different sorghum materials. Doggett (1964) found that the seed fertility of autotetraploid grain sorghums was doubled in F_1's of different autotetraploids and a similar mean set was obtained with a wider range in the F_2. Selection was continued to F_8 and stable lines with seed sets similar to that of the F_1 were obtained, but it was not possible to obtain lines of higher fertility. Rather large differences in seed sets between autotetraploid sorghum varieties were observed, but not so among the lines of a single variety. There are differences in the genotypic fertility control systems of sorghum which result in slight differences at the tetraploid level. The heritability estimate was 73%. The genotypic fertility control systems of the two lines used differed and complementary gene action accounted for the higher seed set of F_1 and for the subsequent behaviour of the cross under selection. The genes concerned must impose a consistent pattern of chromosome behaviour to account for the observed results (Doggett : 1964).

Ross and Chen (1962) found that autotetraploids of grain sorghum variety 'Experimental 3', a colchicine induced mutant *M*15 derived from it and an F_1 hybrid between these had respectively 0.5%, 35.5% and 56.9% fertility as indicated by seed set. The more fertile forms showed a slightly smaller number of quadrivalents, a slightly greater number of bivalents and a markedly smaller number of univalents at diakinesis. The occurrence of laggards at *AI* and micronuclei at quartet stage was likewise less in tetraploid 'Experimental 3'. Ross and Chen (1962) concluded that a mutation might have occurred in diploid *M*15, which affected its univalent number and higher fertility in the tetraploid form possibly through the occurrence of a higher number of chiasmata in the tetraploid condition. Since the increase in fertility in the mutant and the F_1 cannot be ascribed wholly to the lesser effect on chromosome imbalance in the gametes resulting from the decrease in number of univalents, either undetectable influences effecting imbalance or a genetic effect resulting from mutation may also be present.

Differences in fertility between autotetraploids have been ascribed to variations in chromosome behaviour (Darlington : 1937) at meiosis, or, where no cytological dissimilarities were descernible to genetic differences (Morrison and Rajathy ; 1960*a* and *b*). If the former holds good in sorghum, in autotetraploids of apomictic cultures theoretically one can expect higher seed fertilities since no meiosis is involved in the origin of the embryo sac. Murty and his co-workers (unpublished) induced autotetraploids in the apomictic culture R 473 and found very high pollen fertility (80-100%) comparable to normal diploids. Murty (unpublished) has also obtained evidence that at *MI* there is a directed orientation of quadrivalents resulting in a regular disjunction of the chromosomes and probably this accounts for the high degree of pollen fertility. A hypothesis was proposed by Garber (1954) that "if a species does not display directional orientation of the chromosomes in an interchange complex at *MI*, the quadrivalents in an induced (or spontaneous) autotetraploid of this species will likewise not display a directional orientation at the same stage, the two types of configurations occurring with approximately equal frequencies". Endrizzi's (1958) data on the types and frequencies of zig zag and open rings in the interchange of '*S. vulgare*,' on the types and frequencies of quadrivalents in the hybrids and in *S. almum* and the limited data in the autotetraploid '*S. vulgare*' of Chin (1946) suggested that directional segregation is a characteristic feature of the *Eu-sorghums*. Preliminary observations of Murty (unpublished) indicated a high degree of seed fertility in the apomictic cultures.

HIGHER POLYPLOIDS. Longley (1946) obtained octaploid forms of grain sorghum through the use of colchicine. He found that the octaploids behaved similar to the tetraploids. They were more slow growing and more sterile.

ANEUPLOIDY. Price and Ross (1957) produced aneuploids in grain sorghum from triploid × diploid crosses. Of 25 plants obtained, 9 were normal diploids, 9 were single trisomics, 1 was probably a tetrasomic, 1 was a triple trisomic, 1 seemed to be a tetrasomic quadruple trisomic complex and 1 was with undetermined chromosome number. They found no correlation of chromosome number with morphological characters of the plants or any noticeable increase or decrease in vigour due to extra chromosomes. However, Schertz (1966) was able to identify morphologically 5 trisomics: small glume, stiff branch, cone, large glume and bottlebrush.

B-chromosomes

B-chromosomes have been reported in the Para-sorghum, *S. purpureo-sericeum* by Janaki Ammal (1939). Subsequently, their occurrence was recorded by other authors (Darlington and Thomas : 1941; Garber : 1950). Janaki Ammal (1940) found that *B*'s occurred in 40% of the plants while Garber (1940) observed 38% plants as having *B*'s. Darlington and Thomas (1941) distinguished 3 types of *B*'s, the first of which were similar in length to those of the *A*-chromosomes. The second category were shorter than the

A-chromosomes while the third was a very long isochromosome. *B*-chromosomes do not pair with *A*-chromosomes but they pair among themselves, forming multivalents.

Janaki Ammal (1940) and Darlington and Thomas (1941) presented data correlating a decrease in the percentage of pollen fertility with an increase in the number of *B*'s. The indicated correlation suggested a direct proportion. Garber (1950) also found such a correlation but the decrease in pollen fertility was not proportional. In contrast to the material studied by Janaki Ammal and Darlington and Thomas, the data obtained by Garber (1950) indicate that *B*-chromosomes do not seem to influence appreciably the percentage of pollen fertility or seed set until 4 *B*'s are present.

Reddy (1958) distinguished between the *A* and *B*-chromosomes at pachytene with respect to their size, shape, sequence and stainability of the chromomeres composing them. The *A*-chromosome complement is characterized by the phenomenon of chromomere size gradient on either side of the centromeres with the exception of the short arm of the nucleolar chromosome which is considered to be controlled by the direct influence of the centromeres. Further, a definite structure in the centromere regions of both *A* and *B* chromosomes has been found conforming to a basic pattern. In the structural organisation of the centromeres at the microscopic level in both *A* and *B* chromosomes, there seems to be a marked difference. This finding leads to the conclusion that the causal factor underlying the abnormal behaviour of the *B*-chromosomes at mitosis and their nondisjunction at the second pollen mitosis is more likely to be due to their marked heterochromatic nature rather than due to inadequacy of the centromeres in them.

B-chromosomes have not been found in any other species of *Para-sorghum* or *Eu-sorghum*.

Male sterility, self-incompatibility and apomixis

Apomixis has been reported originally in grain sorghum in the F_4 segregates of a cross involving the tall Indian *Aispuri* to dwarf yellow endosperm derivatives. The report was based on non-germination of self-pollen and the development of embryo sacs from diploid nucleolar cells in the culture R 473 (Rao and Narayana : 1968). The stigmas of this culture remain fresh even several days after pollination. Hanna *et al.* (1970) reported facultative apomixis in a male-sterile polygynaceous sorghum line and contended that the evidence presented by Rao and Narayana was not conclusive enough to confirm apomixis. Rao and Murty (1972) have subsequently presented direct evidence for the presence of unreduced embryo sacs, the autonomous development of the endosperm and the diploid nature of the young endosperm in R 473. They have also observed a famiy segregating for male-sterility, self-incompatibility and apomixis. Rao *et al.* (1971) reported the occurrence of self-incompatibility in grain sorghum. They suggested the possible involvement of cytoplasmic factors governing the incompatibility reaction.

Recently, Murty and Rao (1971) have outlined the behaviour of apomictic cultures and the scope of their utilization in sorghum breeding. The apomictic culture R 473 contained both sexual and aposporous embryo sacs. Both were of the *Polygonum* type. Some male-sterile cultures of sorghum which are also apomictic have 4- and 5-nucleate apomictic embryo sacs in addition to the normal 8-nucleate embryo sacs.

Apomixis can be utilized in breeding, as in Buffel grass (Tiliafero and Bashaw : 1966). Although the inheritance of this phenomenon is different in different groups of plants, extensive studies on apomictic groups suggest that apomixis is controlled by a number of genes forming a genetically balanced system and that the overall process of apomixis is recessive to sexuality (Gerstel and Mishanec: 1950; Muntzing : 1958; Burton and Forbes : 1960). In grasses, however, there are indications of a certain degree of dominance (Harlan *et al.* : 1964; Tiliafero and Bashaw : 1966). In *Sorghum* recessive gene action is suspected. Some complementary gene action also seems to be involved, since neither of the parents of the apomictic cultures were apomicts themselves. Behaviour of offspring of crosses involving the two different types of apomixis (self-incompatibility based and male-sterility based) may provide some information on the genetics of this phenomenon and provide guide lines for its utilization in preserving heterozygosity. For detection of apomixis, studies of pollen germination in the case of "self-incompatible apomicts" and pollen fertility in the case of "male-sterile apomicts" may help confirm apomixis.

Apomixis may also help in tetraploid breeding. Autotetraploid sorghum has some desirable attributes but its cultivation is hampered by its sterility. Meiotic irregularities no doubt are responsible either in part or whole for this sterility. Since meiosis is circumvented in the apomicts, theoretically autotetraploid apomicts should be more fertile than those of sexuals. Diverse autoploid apomicts may be synthesized and a tetraploid breeding programme could be developed (Murty and Rao : 1971).

Mutation

Breeders are subjecting sorghum to radiations and chemical mutagens from time to time. Nirula *et al.* (1963) studied the interaction between the length and number of chromosomes, DNA content and nuclear volume in relation to radiosensitivity in *S. nitidum*, *S. purpureo-sericeum* and '*S. vulgare*.' Their results suggested that: (*a*) no direct relationship existed between chromatin length and DNA content in species characterized by chromosomes having distinct *eu*- and hetero-chromatic segments; (*b*) no well defined relationship may exist between nuclear volume, chromatin length and DNA content; (*c*) "tetraploid" *S. vulgare* with smaller chromosomes and lesser DNA is more resistant to radiation than the diploid Para-sorghum species.

Ramulu (1971) made cytological observations in M_1 plants treated with radiations and chemical mutagens to study the effects on types of chromosome associations, the frequency and type of other nuclear and nucleolar anomalies is 3 cultivated varieties (Co 11, Co 12 and Co 18) of Eu-sorghum. Reciprocal translocations having ring or rod configuration occurred in higher frequency than the other types of structural changes. A positive correlation between the percentage of M_1 plants carrying chromosomes with interchanges and the dose of mutagen was observed. The treatments with radiations induced not only a greater frequency of interchanges per cell but also a higher percentage of PMC's with quadrivalents than treatments with chemical mutagens.

In addition to chemical and physical mutagens, colchicine is found to have a peculiar mutagenic effect. Franzke and Ross (1952) found that after colchicine treatment of a true breeding sorghum variety, 'Experimental 3' variants without changed chromosome nun ber arose which bred true immediately. These variants were of different height, stem diameter, leaf width, seed size and yielded differently than the original untreated material They proposed that colchicine treatment caused the formation of a haploid chromosome complement by somatic reduction. This was later restored to the diploid number. To test this hypothesis sorghum seedlings heterozygous for structural chromosome markers (F_1 seedlings from crossing plants homozygous for different reciprocal translocations to distinguish members of 4 pairs) were treated with colchicine (Simantel and Ross: 1963). Two mutants homozygous for changed characters appearing among 90 survivors from 124 treated plants were homozygous for normal chromosome structure dissimilar from either parent. Since the possibility of either selfing or androgenic origin is, therefore, eliminated, the only way that the normal structure could have occurred would be by somatic reduction followed by doubling to restore the diploid number. Since unlinked genes were made homozygous, it was expected that somatic reduction involved the whole chromosome complement (Simantel and Ross : 1963).

Such colchicine induced mutants do not occur always. Their production requires infra red light, an optimum temperature and the genotype. The genotype is the most important factor. The variety 'Experimental 3' gives exceptionally high frequency of these mutants.

Outlook

Cytogenetics has made rapid progress in recent times. The release of rust resistant varieties 'Transfer' (Sears : 1956), and 'Compair' (Riley : 1968) in wheat and the release of the hybrid Hamber' in barley (Wiebe and Ramage : 1970) using balanced tertiary trisomics (BTT system) are some of the significant contributions. There is much scope for the cytogeneticist to be of help in the improvement of sorghum.

Sorghum is susceptible to a number of diseases and insect pests. The latter include especially shoot fly, stem borer and midge which are rather serious. The available germplasm has already been screened more or less with no optimistic results. However, not all the genetic resources have been tapped. Species in the genus *Sorghum* are so little understood that we do not know which of them can be crossed with cultivated sorghum. There seems to be no difficulty in hybridizing cultivated sorghum with its wild and weedy relatives since they are easily crossable and the hybrids are generally fertile. But problems arise when crosses are attempted with *Para-sorghum*. But if cultivated sorghum could be crossed with different genera, like *Saccharum*, *Zea* and *Sorghastrum*, one can reasonably expect that it could be crossed with additional species of sorghum (Harlan : 1971*b*). It is here that cytogenetics can solve problems of hybridization barriers and fertility.

Haploids occur in sorghum spontaneously with frequencies comparable to other crops and their frequency can also be increased through irradiated pollen, wide crosses, delayed pollination, etc. Their application in practical breeding is on the increase in important crops like rice, potato and tobacco. In sorghum, they may be utilised for a number of purposes like production of aneuploids and in isolating completely homozygous lines within a short span of time. Mutations induced in haploids are directly visible and could be of utility in mutation breeding.

Several attempts have been made to produce fertile autotetraploid grain sorghum. Autotetraploidy is less likely to be useful for a crop where the economic product is the seed, since autotetraploids are characterized by a high degree of sterility. But in sorghum, Doggett has shown that there is a scope for fertility improvement through crossing autotetraploids of different genotypes and also by repeated backcrossing to *S. almum* to incorporate its high seed setting. As has been pointed out already, apomictic sorghum strains may give better seed sets than sexual lines, since meiosis is circumvented in apomicts. The advantages of autotetraploidy in sorghum will be not only the increased grain size and protein content but also the slower dissipation of heterozygosity.

Apart from inducing polyploidy, colchicine also induces homozygosity by a peculiar process of somatic chromosome reduction. Through this process homozygous types can be recovered from structurally or genetically heterozygous material in a single step through colchicine which may be of importance in breeding.

Induction of mutations also has some scope in sorghum improvement. It will also be a valuable tool assisting in the solution of a variety of cytological and genetical problems.

The phenomenon of apomixis will go a long way in sorghum breeding in the developing countries by minimising the costs of hybrid seed. Although sorghum varieties equal in their yield potential to commercial hybrids are produced, hybrids will still have an advantage in having greater stability of performance. The phenomenon of apomixis is not a simple one in sorghum. We are yet to khow its genetics and even some aspects of its mechanics. The allied phenomenon viz. self-incompatibility could also have practical importance and is worth further investigations.

Apart from practical considerations, certain theoretical aspects of sorghum cytogenetics remain to be investigated. These include detailed studies of chromosome morphology in the *Para-sorghum*, the homologies, if any, between the genomes of the *Eu-* and *Para-sorghums*, identification of linkage groups and aneuploid analysis for the location of genes in particular chromosomes.

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GENETIC ANALYSIS OF SOME EXOTIC X INDIAN CROSSES IN SORGHUM VI. CHARACTER ASSOCIATION UNDER SELECTION

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IN a study of the nature of association of characters in F_2 populations of exotic × Indian crosses of sorghum, Harinarayana, Rao and Venkatraman (1971) noticed pleiotropic effects of height and maturity genes on yield as well as linkage. Subsequently, Reddy and Rao (1971), in a study of F_4 and F_5 populations, found that the direct effects of height and maturity on yield were still pronounced while the indirect effects were dissipated during the process of selection. In the present paper, the results of further studies on the nature of association between plant height, days to half-bloom and yield in nearly homozygous F_6 and F_7 populations, intermediate in height and maturity are evaluated in comparison with the parents and the hybrids from which they were derived.

MATERIALS AND METHODS

The material for the present study consisted of six groups of populations, the dwarf and early exotic parents (DE), late and tall Indian parents (TL), the three groups of crosses (F_1's) possible among them (DE × DE, DE × TL and TL × TL) and the productive intermediate selections (IS) derived from the exotic × Indian (DE × TL) crosses. The material, excepting the selections, was raised in a randomised complete block design with three replications during *kharif*, 1963. The selections (in F_6 and F_7 generations) were raised unreplicated during *kharif*, 1969. Data collected on five randomly chosen plants in each population on plant height (cm.), number of days to half—bloom and yield (gm/plant) were subjected to statistical analysis. The phenotypic and genotypic correlation coefficients were derived based on expectations. The correlation coefficients were partitioned into path coefficients following Dewey and Lu (1959).

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Results

The differences among the parental groups, DE and TL, and among their crosses were highly significant for all the characters including the comparisons, DE *vs.* TL and parents *vs.* hybrids (Table 1). Significant and positive phenotypic and genotypic correlations were observed in the DE and DE×DE groups for all pairs of characters except for plant height with days to half-bloom in the DE group (Table 3). On the other hand, the correlations between these characters though non-significant were negative in the case of TL and TL×TL groups except the one between plant height and yield. These associations agreed with the fact that the tall and late flowering (TL) parents were higher yielding than the dwarf and early flowering (DE) parents (Table 2).

Both the phenotypic and genotypic correlations between days to half-bloom and height, and days to half-bloom and yield were in opposite directions in DE×DE and TL×TL groups whereas the correlation between height and yield was positive in both the groups, the one in DE×DE being more than the one in TL×TL. The same observations were true for the parental groups, DE and TL also. But the non-significant and negative correlation between plant height and yield in the group DE×TL indicated that dwarf cultures isolated from this group would be capable of giving higher yields.

Table 1

Analysis of variance for some characters related to fitness and yield in different groups of sorghum

Source	DF	M.S.S.		
		Days to half-bloom	Plant height	Yield
Treatments	41	610·68	12428·28	2312·94
Parents	8	1453·09	19664·69	1642·30
DE	4	471·32	1279·98	394·80
TL	3	26·88	2690·78	236·50
DE vs TL	1	9658·78	144125·34	10849·66
Hybrids	32	416·16	9564·85	1449·94
DE×DE	8	438·62	1034·39	1227·31
DE×TL	18	30·38	3379·08	1221·37
TL×TL	4	199·86	1359·85	491·87
(DE×TL) vs (TL×TL)	1	3145·95	24859·90	1089·35
Rest	1	5316·04	206677·30	11538·20
Parents vs. Hybrids	1	96·27	46166·06	35294·30
Error	82	10·06	86·88	67·13

All m.s.s. are significant at 1% level.

TABLE 2

Yield, days to half-bloom and plant height in different groups of grain sorghum (means values)

Character	DE	DE×DE	DE×TL	TL×TL	TL	IS
Yield (gm./plant) (Y)	45·72	86·75	112·68	103·45	86·04	101·76
Days to half-bloom (X)	70·92	73·74	87·09	104·28	107·32	83·71
Plant height (cm.) (Z)	111·27	148·52	241·79	287·33	258·17	164·09

TABLE 3

Phenotypic and genotypic correlations between three important characters and the contributions to them through different paths of association in sorghum

Groups		r_{XZ}	P_{XY}	$P_{X\cdot Z\cdot Y}$	r_{XY}	P_{ZY}	$P_{Z\cdot X\cdot Y}$	r_{ZY}	P_{TY}
DE	P	0·7611	0·5517	0·3614	0·9131*	0·4749	0·4199	0·8948**	0·0713
	G	0·7971	0·5817	0·4403	1·0220**	0·5524	0·4636	1·0160**	–0·1557
DE×DE	P	0·8079**	0·7257	0·0912	0·8169**	0·1129	0·5863	0·6992*	0·1284
	G	0·8542**	0·7875	0·0670	0·8545**	0·0784	0·6727	0·7511*	0·2683
DE×TL	P	–0·4166	0·1932	0·0384	0·2316	–0·0921	–0·0805	–0·1726	0·9394
	G	–0·5157*	0·2997	0·0132	0·3129	–0·0255	–0·1546	–0·1801	0·9017
TL×TL	P	–0·6335	–0·6729	0·1334	–0·5295	–0·2105	–0·4263	0·2158	0·6823
	G	–0·6703	–0·7692	0·1851	–0·5841	–0·2762	0·5156	0·2394	0·6169
TL	P	–0·8891	–0·7677	0·3620	–0·4057	–0·4072	0·6826	0·2754	0·8006
	G	–1·1420**	0·5090	–1·0410	–0·5370	0·9115	–0·5813	0·3302	0·9699
IS	P	0·36**	0·0993	0·0807	0·18	0·2243	0·0357	0·26	0·9237

P=Phenotypic; G=Genotypic; T=Residual factors; *Significant at 5% level, **Significant at 1% level.

An analysis of the direct and indirect contributions of plant height and days to half-bloom to yield through path analysis makes the situation more clear. The direct effects of days to half-bloom and of height were high and opposite in direction in the DE, DE×DE and TL, TL×TL groups. In general, the percentage contribution of direct effects of days to half-bloom to yield was higher than that of height. On the other hand, the indirect effects of plant height *via* days to half-bloom on yield were considerable and positive. The position was reversed in the *IS* group.

These results suggest that the hybrid group DE×TL has acquired useful constellation of genes from both the parental groups which are markedly divergent in the important characters, days to half-bloom and height influencing fitness and yield. This statement derives further support from the observations that (a) the means of the DE×TL crosses and their derivatives (IS) were intermediate between those of DE and DE×DE on the one hand, and those of TL and TL×TL on the other, for days to half-bloom and height and (b) the mean yield of the DE×TL crosses was the highest followed by that of the TL×TL crosses (Table 2).

The residual effects were found to be high only in DE×TL, TL×TL, TL and IS groups (Table 3). This would imply that the role of related characters other than height and days to half-bloom was negligible in the DE and DE×DE groups. The size of the path coefficient due (Table 3) to residual effects in the selections (IS) and the DE×TL group indicated the importance of other characters and environmental effects which were felt more in tall parental group (TL) than in the dwarf parental group (DE).

Discussion

Prolonged natural selection in grain sorghums has resulted in the establishment of late and tall forms. The yield level of some of them is noteworthy at the single plant rather than at the population level; hybridization and selection among them did not markedly alter this situation which would imply that the genes for lateness and tallness were almost fixed under the continual action of natural selection. On the other hand, artificial selection for relatively dwarf and early forms could establish types which were superior in yield and general performance at a population level only, especially under intensive cultivation. Hybrids between these dwarf populations also gave attractive yields. Thus two isolated divergent forms were produced by the forces of natural and human selection.

In these two groups of populations, association of characters influencing fitness is of a different nature and magnitude. Significant and positive association between plant height, days to half-bloom and yield was present in the dwarf-early parents in contrast to the negative association present in the tall-late parents. The association in the DE×DE and the TL×TL crosses were similar to those in DE and TL. From this, one can postulate that, to obtain an ideal combination, one should preferably deal with dwarf derivatives in which certain degrees of lateness and of tallness are incorporated and with tall derivatives in which certain degrees of earliness and of dwarfness are introduced. Relatively low correlations, intermediate in nature, obtained in the DE×TL crosses and the productive selections (IS) made from them support such a hypothesis. Such intermediate selections represent populations with little or no association between the characters examined.

The results from the path coefficient analysis have emphasized the point that the direct contribution of days to half-bloom to yield is more pronounced than and opposite in direction to that of plant height in the DE×TL crosses, indicating the significant role of days to half-bloom in determining the yield potential. But the direct contributions of days to half-bloom and plant height were positive in DE and DE×DE groups and negative in TL and TL×TL groups, in general. It, therefore, appears that the constellation of genes for these characters in the DE and the TL groups were altogether or at least functionally different. Strong associations between characters in those groups would limit recombination and hence selection advance in the crosses within the groups. But, in the crosses between the groups, the cryptic genetic potential would be released by recombination, thus making the selection of highly productive populations possible, as shown by the performance of the intermediate selections (IS), isolated from the DE×TL crosses.

The near absence of associations between important characters in the intermediate selections is encouraging in view of the observed positive association between maturity and yield (Dalton, 1967) and the pleiotropic and probably limited linkage effects of the genes governing height and maturity (Harinarayana *et al.,* 1971). In fact, these intermediate selctions represent 'intermediate productive peaks'; in other words, they represent selections in the intermediate range whose yield potential is much above that of some of the checks.

A hybridization programme involving negative assortative mating as in the case of DE×TL appears to be most desirable to obtain promising recombinants breaking the undesirable linkages which frequently limit the genetic advance (Falconer, 1967). Such mating results in the release of cryptic genetic variability and the redistribution of genetic variance (Murty, Arunachalam, Doloi and Ram, 1972). In sorghum, natural and human selection has resulted in establishing extreme forms as TL and DE. On this base, a system of negative assortative mating as in disruptive selection could help to produce intermediate but highly productive populations as revealed in this study.

Such intermediate populations with little or no association between most of the yield components offer considerable scope for improvement both under natural and artificial selection. This was demonstrated by the significant role played by the intermediate populations between wild and cultivated forms (disruptive selection in nature) in the evolution of cultivated sorghums (Doggett and Majisu, 1968). Productive intermediate populations between groups of cultivated sorghums widely differing in height and maturity could be exploited either for direct cultivation or as bridge populations or both. Such promising intermediate selections are, at present, in the process of release for general cultivation.

SUMMARY

The nature of association between days to half-bloom, plant height and yield was examined in productive advanced generation selections and compared

with the dwarf-early and tall-late parents and their crosses. The correlations, both phenotypic and genotypic, were considerable in the parental groups and the within-group crosses, while they were low or negligible in intermediate selections and in the between group crosses.

The direct and indirect contributions of days to half-bloom to yield were more pronounced than those of the plant height. The direct effects were also of higher magnitude in the parental groups and their within group crosses. The vital role played by days to half-bloom in determining the yield potential was brought out.

Undesirable linkages and similar associations get dissipated in the intermediate selections from crosses between extreme forms. Thus, the intermediate selections, as revealed by correlations and path coefficients, have little or no association between yield components but have good yielding potential and represent 'intermediate productive peaks'. Some promising selections from such productive intermediate populations with no association between fitness components are in the process of release for general cultivation.

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GENETIC ANALYSIS OF SOME EXOTIC×INDIAN CROSSES IN SORGHUM VII. EVALUATION OF DERIVED LINES AS MALE PARENTS

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FIRST commercial sorghum hybrids in India were developed from exotic× exotic cross combinations (Rao, 1970). Even though some of the tall and late Indian sorghum varieties resulted in heterotic hybrids when tested against diverse females, the height and maturity differences in comparison with dwarf females and the agronomic limitations of taller hybrids imposed restrictions on their commercial worth. Rao, Rana and Tripathi (1968) suggested utilization of high yielding derived lines from the exotic×Indian crosses as female and male parents for hybrid development. Studies with exotic×Indian crosses have been in progress and their potentialities and limitations in developing high yielding lines have been discussed (Rao *et al.*, 1973). The present study attempts an analysis of changes in the magnitude of heterosis and combining ability when the derivatives of exotic×Indian crosses were used as restorer parents.

MATERIALS AND METHODS

The fourteen male parents used in the study were stable lines derived from exotic × Indian crosses. Nos. 166, 222, 326 were from IS 2954 × BP 53, 513 from IS 508 × BP 53, 648 from Kafir B × BP 53, 771, 772 and 811 from IS 3922 × *Aispuri*, 1146, 1220, 1227 and 1251 fromIS 3922 × Karad local, 1358 from R. 78 × M 35–1. IS 84 is an yellow endosperm *feterita*.

The female parents *viz.*, CK60A, 648A, 2219A and 3660A, all of which are dwarf and based on *milo* cytoplasm were crossed with the fourteen pollinator parents in a line × tester mating system. The resulting 56 crosses and four released hybrids as checks were grown in *kharif* season in randomized complete block design with three replications. The plot size was 3·00 × 1·35 sq. meters consisting three rows 45 cm apart. A fertilizer dose of 100 kg N, 60 kg P_2O5 and 60 kg K_2O per hectare was given. Nitrogen was applied in two split doses, half as basal and another half at knee high stage. Recommended plant protection measures were adopted for the control of shoot fly and stem borer. Irrigations were given as required. Observations were recorded on fifteen plants from central row of the three row plot. Days to 50 per cent bloom, plant height, grain yield and 100 grain weight were recorded.

RESULTS

Mean performance of hybrids averaged over females and males is presented in Table 1. The differences between crosses with derivatives and IS 84, the male parent of the most widely cultivated hybrid, CSH-1 were significant (Table 2). Partitioning of the hybrid sums of squares also revealed the potentialities of *kharif* and *rabi* varieties, differing in panicle morphology, in yielding

TABLE 1

Hybrid performance averaged over males and females and group means

Parents	Grain yield (gm.)	Days to flower	Height (cm.)	100–seed weight (gm.)
A. Females				
1. CK60A	62·9	72·8	205·6	2·80
2. 2219A	65·0	70·0	189·6	2·53
3. 648A	60·9	73·4	203·7	2·84
4. 3660A	65·2	73·1	240·4	3·00
B. Males				
1. 166	71·2	70·8	211·7	2·65
2. 222	68·9	75·3	192·9	2·36
3. 326	71·8	72·6	220·0	2·81
4. 513	72·0	74·2	256·0	3·43
5. 648	67·0	75·8	194·2	2·67
6. 771	73·0	73·0	204·2	3·06
7. 772	65·5	70·7	220·8	3·10
8. 811	54·8	79·2	307·5	3·08
9. 1146	62·9	69·1	195·4	2·86
10. 1220	53·9	66·6	178·3	2·86
11. 1227	55·0	71·8	195·8	2·44
12. 1251	49·4	79·0	181·7	2·17
13. 1358	79·9	70·4	215·0	2·98
14. IS 84	43·7	64·6	163·8	2·58
C. Group means				
Crosses with derivatives	65·0	72·9	213·3	2·81
Crosses with IS 84 (*feterita*)	47·7	64·6	163·7	2·58
Crosses with *kharif* derivatives (BP. 53 + *Aispuri* + *Karad local*)	63·1	73·2	213·2	2·80
Crosses with *rabi* derivatives (M. 35–1)	79·9	70·4	215·0	3·00
Crosses with compact panicle derivatives (BP. 53 + *Aispuri*)	68·1	73·9	226·0	2·90
Crosses with long panicle derivatives (*Karad local*)	55·3	71·6	187·8	2·60

superior male parents. The differences with respect to most characters studied were statistically significant. The percentage increase in average hybrid performance of male sterile lines over CK60A and that of males over IS 84 is given in Fig. 1. The female parents 2219A and 3660A showed only 3 to 4 % superiority for grain yield and 3660A showed 7 % superiority for grain weight over average hybrid performance of CK60A. Hybrids based on newly developed male parents from exotic × Indian crosses exhibited 13 to 83 % superiority for grain yield, 9 to 88 % for plant height and 3 to 23 % for flowering time over the

TABLE 2

Analysis of variance of crosses with exotic×Indian derivatives and IS 84 (feterita)

Source	DF	Mean sum of squares			
		Grain yield (gm.)	Days to flower	Height (cm.)	100-seed weight (gm.)
Replications	2	585·72	296·30	792·13	0·15
Entries	59	553·49**	71·40**	5828·24**	0·52**
Hybrids	55	580·99**	71·25**	6049·60**	0·52**
Crosses with derivatives	51	522·83**	58·70**	5945·91**	0·54**
Crosses with IS 84	3	61·94	48·75**	685·42	0·10
Crosses with derivatives *vs* crosses with IS 84	1	5104·82**	778·58**	27430·22**	0·47*
Crosses with *kharif* derivatives (BP. 53 + *Aispuri* + *Karad local*)	47	476·99**	60·21**	6241·28**	0·57**
Crosses with *rabi* derivatives (M. 35–1)	3	337·81**	26·97	3288·89**	0·32*
Crosses with *kharif* derivatives *vs rabi* derivatives	1	2849·24**	82·92**	34·73	0·03
Crosses with compact panicle derivatives (BP. 53 + *Aispuri*)	31	382·24**	36·60**	6092·44**	0·49**
Crosses with long panicle derivatives (*Karad local*)	15	335·91	101·82**	3864·13**	0·57**
Crosses with compact panicle derivatives *vs* long panicle derivatives	1	5913·15**	168·06**	46512·49**	2·90**
Checks	3	113·06	86·77**	1711·11*	0·71**
Hybrids *vs* checks	1	361·76	34·80**	6004·80**	0·02
Error	118	173·42	13·71	459·87	0·10

*Significant at 5%; Significant at 1 %

respectives averages for hybrids based on IS 84. Crosses with ten male parents were superior for grain weight, the range being 2·5 to 33·0% over IS 84 performance in crosses.

DISCUSSION

The problem of plateauing of yields in hybrids of self- as well as cross-pollinated crops has attracted the attention of geneticists and plant breeders. With particular reference to sorghum the need for adequate variability in the female parents (Rao, Rana and Tripathi, 1968), increasing variability in sub-tropical sorghums by utilization of tropical germ plasm through a conversion

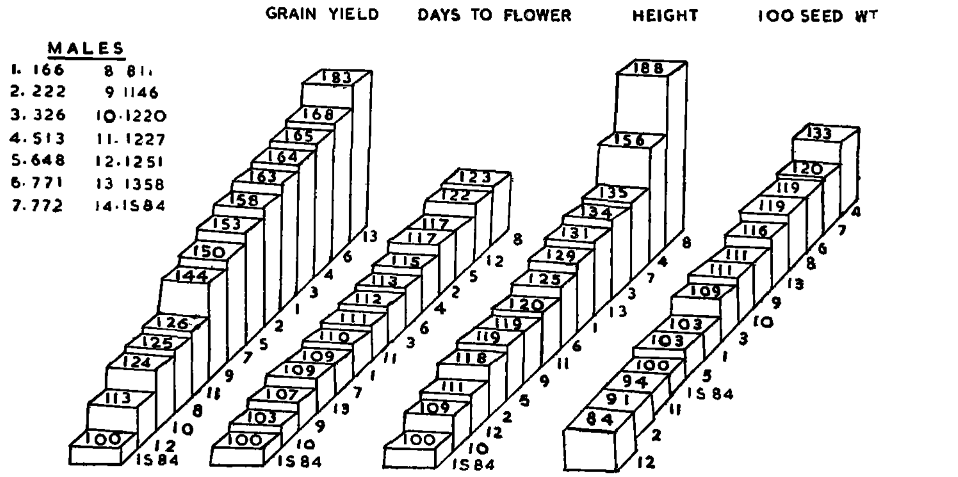

FIG. 1 PERCENT INCREASE IN AVERAGE HYBRID PERFORMANCE OF DERIVED MALES OVER IS84

programme (Rosenow, 1972), the practice of modified recurrent and other population improvement procedures (Maunder, 1972 and Gardner, 1972) have been suggested for attaining substantial yield increases over the presently available commercial hybrids.

Most tropical sorghums in general and Indian sorghums in particular are tall and late and need to be corrected for height as well as maturity before they could be utilized in hybrid development. It may be mentioned here that while Indian sorghum varieties like *Aispuri* and BP. 53 with compact panicles resulted in non-heterotic hybrids with CK60A (Rao, 1970), derived lines involving them as parents in an exotic × Indian crossing programme have resulted in superior hybrids. Compared to hybrids with IS 84, a selected yellow endosperm *feterita* which furnished the male parent for CSH-1, the first and most widely grown commercial hybrid widely grown in India, several of the hybrids with derived lines are very much superior in yield levels. Twenty three crosses were significantly superior in grain yield to CSH-1 and five crosses over CSH-2. However, most high yielding hybrids involving derived lines as males tend to be taller and later than those involving IS 84 indicating the perceptible positive effects of height and maturity genes on yield. But when compared to the original Indian parents there is considerable amount of reduction both in excessive height and late maturity, rendering these derivatives usable in a hybrid programme. There is also a gain in seed weight in some crosses with derivatives which was lacking in exotic × exotic crosses (Rao, 1970).

Amongst the *kharif* varieties, lines derived from compact headed types resulted in more heterotic hybrids compared to those derived from elongated panicle types. The derivative involving M. 35-1, a *rabi* variety yielded more heterotic hybrids than hybrids involving *kharif* derivatives. Thus the compact headed types and winter sorghums of India which have not been utilized in any hybrid programme so far offer potentialities for improving yield levels as well as seed weights of future hybrids.

As pointed out by Eberhart (1972) progress in the improvement of hybrids is proportional to the improvement in the breeding populations used as the source material for parental lines. Selected male parents derived from conventional hybridization programme involving exotic×Indian crosses have shown considerable progress in attaining higher yield levels and if this is combined with a matching improvement of the female parents, which are still low yielding compared to the males, yield levels of future hybrids could touch new heights.

Summary

Selected derivatives from exotic×Indian crosses which are relatively dwarf and earlier in maturity when used as male parents yielded hybrids superior in grain yield and seed weight compared to those resulting from IS 84, the male parent of CSH-1, the first and most widely cultivated commercial sorghum hybrid in India. Derivatives from a *rabi* (winter) variety and from compact panicle types resulted in superior hybrids when compared to those derived from *kharif* (monsoon) or elongated panicle types. Corresponding improvement of females, which is currently in progress, is expected to result in further hybrid improvement.

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GENETIC ANALYSIS OF SOME EXOTIC × INDIAN CROSSES IN SORGHUM VIII. F_1 ANALYSIS OF OVIPOSITIONAL NON-PREFERENCE UNDERLYING RESISTANCE TO SORGHUM SHOOT FLY

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Manipulation of the crop variety, which is part of the total agro-ecosystem, constitutes an important factor in insect management (Dahms, 1972). The primary mechanism of resistance to sorghum shoot fly (*Atherigona varia soccata* Rond.), which has been observed to be non-preference for oviposition and perhaps a low level of anti-biosis to the larva (Young, 1972), poses difficulties in its transference. The dwarf exotic sorghums are generally susceptible to shoot fly attack and the sources of resistance are mostly furnished by the tall and late Indian sorghums. The exotic×Indian crosses are, therefore, useful in combing resistance with desirable height, maturity and yield. Since both commercial hybrids and true breeding varieties of sorghum constitute the cultivars, a genetic analysis of resistance to shorghum shoot fly at the F_1 level as well as in segregating generations is meaningful. An F_1 analysis of shoot fly resistance is attempted in this paper and the behaviour in subsequent generation will be presented later.

Materials and Methods

Seven male steriles *viz.*, 2219A, 2947A, 36A, 418A, 648A, 1220A and 173A were crossed with eleven male parents. The first two females are of exotic origin, and the next four are derived from exotic × Indian crosses and all their A lines are in *milo* cytoplasm. The seventh female is a derived line in a different cytoplasmic source.

Eight of the male parents *viz.*, 148, 165, 221, 252, 434, 512, R–24 and FR–493 were stable derivatives from exotic × Indian crosses and the remaining three *viz.*, IS 84, CS 3541 and *Swarna* were pollinator parents of released hybrids and are of exotic origin.

The resulting 77 hybrids along with 18 parents and five released hybrids were grown in a randomized complete block design replicated three times. The experiment was grown during July, 1973 (*kharif*). The field was fertilized basally with 60 kg. N and 60 kg. P_2O5 per hectare. The plot consisted of three rows 5 meters long and 45 cm. apart. Soon after germination the seedlings were thinned to 15 cm. within the rows.

The natural infestation of shoot fly was high enough to cause differential mortalities. The damage to shoot fly was recorded as percentage of affected plants by shoot fly to the total plants in a plot

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one month after germination. The degree or resistance to shoot fly would thus be inversely proportional to the percentage of damage.

After angular transformation of data, the male, female and their interaction effects were estimated according to standard statistical procedures.

RESULTS

Mean mortality percentages are given in Table 1. The female parents showed 61 to 93% shoot fly damage while male parents varied from 48 to 99%. Three male parents *viz.*, 148, R-24 and FR-493 showed comparatively higher degree of resistance among all the parents. Among female parents, 36A and 173A provided better choice. Hybrids showed a range of 18 to 89% damage as compared to the average 62·6% damage in released hybrids. Crosses with 173A as female were generally superior. Similarly, crosses with 148 as male followed by 165 and R-24 showed less mortality. The average mortality of hybrids based on these males *i.e.*, 148, 165 and R-24 was less compared to hybrids with IS-84 and CS 3541, the male parents of released hybrids. Four crosses *viz.*, 173A×148, 173A×165, 173A×R-24 and 36A×148 showed only 18–26% damage. The performance of parents is a reasonably good indication of hybrid performance (Fig. 1).

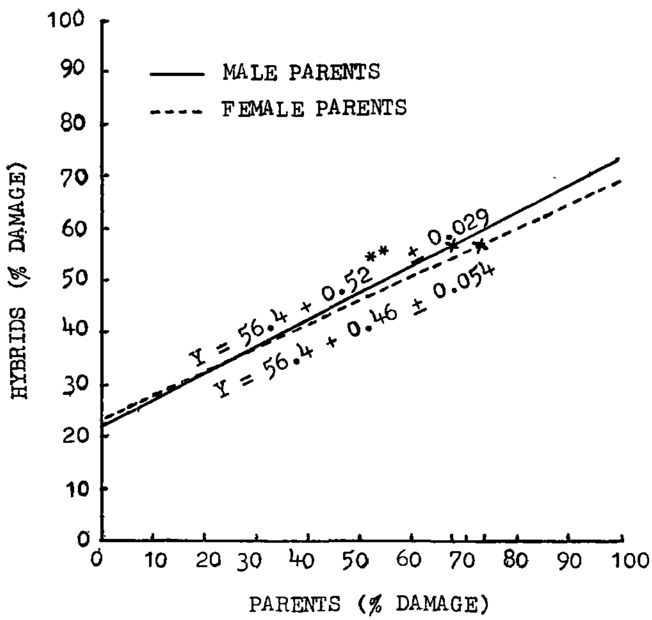

FIG. 1. Relationship of Shoot Fly Damage (%), in Parents and their Hybrids

Analysis of variance of parents, hybrids and different comparisons is given in Table 2. Significant differences were observed between crosses, parents and checks. The male parents and female parents also showed significant

TABLE 1

Mean shoot fly damage (%) in hybrids and parents.

Females / Males	148	165	221	252	434	512	R–24	FR–493	IS 84	CS3541	*Swarna*	Hybrid mean	Parental mean (♀)
2219A	45·0 (36·1)	41·0 (39·3)	53·0 (46·4)	58·0 (49·7)	55·0 (48·1)	45·0 (42·0)	44·0 (41·7)	58·0 (49·8)	65·0 (54·9)	56·0 (48·2)	41·0 (39·4)	51·0	72·0
2947A	32·0 (34·0)	70·0 (57·1)	79·0 (62·8)	81·0 (68·1)	64·0 (53·2)	60·0 (50·7)	53·0 (46·7)	71·0 (57·6)	74·0 (59·9)	82·0 (68·8)	51·0 (45·7)	65·1	77·0
36A	28·0 (31·1)	52·0 (46·3)	62·0 (52·2)	71·0 (57·3)	37·0 (37·1)	41·0 (39·6)	38·0 (37·8)	34·0 (35·2)	63·0 (52·7)	71·0 (59·0)	68·0 (55·8)	51·3	61·0
418A	35·0 (36·0)	43·0 (40·0)	64·0 (53·2)	60·0 (51·2)	53·0 (46·5)	66·0 (54·4)	56·0 (48·7)	60·0 (51·1)	48·0 (44·1)	52·0 (46·0)	75·0 (64·6)	55·6	93·0
648A	53·0 (46·7)	56·0 (48·5)	49·0 (44·4)	87·0 (71·7)	72·0 (58·5)	81·0 (68·3)	78·0 (62·6)	76·0 (61·0)	81·0 (64·5)	67·0 (58·0)	70·0 (56·7)	70·0	79·0
1220A	42·0 (40·3)	50·0 (44·8)	63·0 (52·9)	89·0 (73·7)	68·0 (55·3)	47·0 (43·5)	46·0 (42·5)	51·0 (45·7)	65·0 (53·9)	62·0 (52·0	70·0 (56·6)	59·3	78·0
173A	18·0 (25·2)	24·0 (28·7)	36·0 (36·4)	55·0 (47·8)	65·0 (53·7)	37·0 (36·9)	24·0 (29·2)	46·0 (42·7)	44·0 (41·8)	70·0 (57·0)	48·0 (43·6)	42·4	62·0
Hybrid mean	36·1	48·0	58·0	71·5	59·1	53·8	48·4	56·5	62·8	65·7	60·4		
Parental mean (♂)	48·0	62·0	76·0	99·0	58·0	72·0	51·0	52·0	75·0	76·0	70·0		

S.Em for transformed values 5·72.
( ) Transformed values.

TABLE 2

Analysis of variance for parents and hybrids for shoot fly damage

Source	DF	MSS
Replications	2	424·9
Treatments	99	346·3**
Crosses	76	322·9**
Female effects	6	1247·8**
Male effects	10	885·9**
Female × Male	60	136·6**
Parents	17	322·8**
Male parents	10	409·7**
Female parents	6	219·1*
Males *vs* Females	1	246·3
Checks	4	80·7
Crosses *vs* Parents	1	3710·8**
Crosses + Parents *vs* Checks	1	47·3
Error	198	89·3
	dead hearts (%)	
	Mean	Range
Female parents	73·1 (61·1)	61–93
Male parents	67·2 (56·7)	48–99
Parents	69·5 (58·4)	48–99
Hybrids	56·4 (49·2)	18–89
Checks	62·6 (52·8)	52–71

*Significant at 5%; **Significant at 1%; ( )Transformed values.

differences in per cent damage, but the males *vs* female parents comparison was not significant. Significant differences for crosses *vs* parents indicated heterosis for resistance. Hybrids were 13% less effected by shoot fly as compared to parents.

The female, male and female×male interaction effects were highly significant and their contribution to total hybrid sum of squares was 30·5, 36·1 and 33·4% respectively. Thus, female and male parents jointly contributed twice of their interaction sum of squares indicating that general combining ability may contribute approximately 66%.

DISCUSSION

When exotic sorghums and Indian sorghums are planted side by side, the former are highly preferred for oviposition averaging 8 eggs per plant with about 90% of the plant population infested with eggs when compared to 2 eggs per plant with 10 % of the plant population infested with eggs for Indian sorghums (Soto, 1972). The ultimate seedling mortality in a field crop due to dead hearts is a function of the intensity of insect infestation, plant growth rate and inherent genotypic differences. Depending upon these factors mortality rates vary in both susceptible and resistant lines, the differentials being generally well manifested under field conditions. Under infestation in green house even the resistant lines succumb almost totally.

While ovipositional non-preference mechanism of resistance would have an influence on the insect population of a given variety, its cumulative effect on the crop population as a whole will not be felt unless oviposition suppression factor is also operative when the preferred host is removed and the insect has no longer any choice (Dahms, 1972 and Soto, 1972). Present coverages of hybrid sorghums in India do not exceed 10 % of the total area and under conditions of shoot fly build up, particularly, in late *kharif* and some *rabi* plantings the hybrids are preferred by the shoot fly (Rao, 1972). If the hybrid reaction is similar to the local cultivars, at least the extra damage could be avoided. The males and females derived from exotic × Indian crosses besides being higher yielding (Rana, Tripathi, Kotaiah and Rao, 1974) could also confer advantages with respect to shoot fly reaction in hybrid combinations.

From the results presented, it is evident there is perceptible improvement for shoot fly reaction in some of the males and females which are derivatives of exotic × Indian crosses. Amongst females 173A and 36A and in males 148, 165 and R-24 are decidedly superior when compared to exotics and the rest of the derived parents. These derivatives have in their parentage the Indian varieties BP-53, PJ-16K, *Aispuri* and M. 35-1. There is also enough indication that parental performance for shoot fly reaction is a satisfactory indication of hybrid behaviour. In fact there is a slight improvement in hybrids obviously on account of seedling vigour.

There has been scepticism on the practical value of non-preference in developing resistant varieties (Blum, 1972). Developing weevil resistant alfalfa varieties inspite of strong environmental interaction (Busbice *et al.*, 1968) is an example where the non-preference mechanism has been made use of. Current evidence on performance of lines *per se* and comparitively low mortality percentages of hybrids averaged over such superior males indicating preponderance of additive gene action for ovipositional non-preference of sorghum shoot fly could be advantageously capitalised in hybrid breeding as well as line development.

Summary

A genetic analysis of ovipositional non-preference underlying resistance to sorghum shoot fly is attempted from a line × tester mating system where the parents used were exotics as well as stable derivatives from exotic × Indian crosses. Some of the derived males, females and hybrids involving them were

superior in shoot fly reaction when compared to exotics. The inheritance of ovipositional non-preference appears additive and the hybrids are generally superior compared to their parents. The parental performance is a good indication of the hybrid behaviour. Operation of ovipositional suppression factor could bring about a cumulative effect on insect population when the preferred host is removed and the insect has no longer any choice. Till such time, replacement of preferred types will itself be an advantage.

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SORGHUM MIDGE SUITABLE VARIETAL POLICY AND SURVEILLANCE ESSENTIAL

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SORGHUM midge (*Contarinia sorghicola*) was first observed in India as early as 1914. It was reported to have assumed the status of a pest during the 1960's in parts of south India where sorghums are cultivated almost throughout the year. Perceptible losses to sorghum production due to midge incidence were noticed during the kharif season in parts of Maharashtra and Karnataka over the past three years. This is a period when early maturing hybrid sorghums and late-maturing locals were being grown in close proximity in these areas. Hybrid sowings were also extended commencing from June and to late July resulting in continuous blooming which encouraged midge build-up on a large scale. The damage due to midge was largely confined to the late locals in the kharif season, the early hybrids having generally escaped damage. Late-planted hybrids also suffered midge damage since flowering took place during the period of midge build-up. In fact, it may be said that some of the gains made on sorghum production due to introduction of hybrids have been offset by midge incidence on late locals.

Analysis of the various factors associated with the incidence of midge *vis-a-vis* stabilizing and enhancing production of dryland sorghums in the country is, therefore, the chief problem.

Biology and Bionomics of Midge

On current evidence it appears that all major hosts of midge are the members of the genus *Sorghum*. Under favourable conditions midge completes its life-cycle in 14 to 16 days and hence 9 to 12 generations are possible during a season in areas where there are no extremes of temperature. The rate of multiplication under these conditions is extremely rapid. The eggs are laid by females in the flowering spikelets; each female laying about 30 to 100 eggs. The injury is caused by the larvae which feed on ovaries preventing normal seed development.

Midge fly and a damaged ear of sorghum

Studies on the incidence of midge in different parts of the country reveal that in north India and Deccan, peak midge breeding occurs from the second half of September to early October and it gradually declines as October progresses. In south India, around Coimbatore, midge breeds throughout the year. It may be said that the peak breeding time may not be universal but conditional. Availability of sorghum populations with overlapping flowering over a period of 15 to 20

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days, coupled with favourable climatic conditions provide breeding ground for midge before the damage assumes serious proportions on the later flowering populations.

This has been reported by Jotwani *et al.* (1972) and is also illustrated from the data obtained with a relatively photo-insensitive sorghum hybrid 'CSH-1' planted on different dates during kharif season (Tables 1 and 2).

TABLE 1. NUMBER OF GRAINS DAMAGED DUE TO MIDGE INFESTATION, KHARIF, 1968, DELHI (ANNUAL REPORT OF THE AICSIP)

Date of sowing	Average No. of grains damaged per 10 ears
July 12, 1968	576
July 17, 1968	952
July 22, 1968	1,383
July 27, 1968	2,139
August 1, 1968	3,552

TABLE 2. LOSSES DUE TO MIDGE INCIDENCE IN RELATION TO FLOWERING PERIOD, KHARIF, 1972, DELHI (ANNUAL REPORT OF THE AICSIP)

Date of sowing	Date of 50% flowering	Av. No. of adult midges /10 plants	Grain yield (qtl/ha)	% avoidable losses
July 6, 1972	September 5, 1972	1	67 12	0 0
July 12, 1972	September 8, 1972	2	55.54	17 3
July 18, 1972	September 15, 1972	8	21 28	68 3
July 24, 1972	September 21, 1972	100	6 01	91 0
July 30, 1972	October 5, 1972	37	19 90	70 4

It is seen that the flowering from mid-September to early October was the most vulnerable period and this was preceded by two sowings on which apparently the midge got multiplied. It may be generally stated that as flowering progresses, the populations which flower during the first 15 days tend to escape midge damage but provide the breeding ground rendering the later flowering populations vulnerable to midge damage.

Control

Varietal Policy. In several of the sorghum-growing states, traditional kharif varieties are late (5-5½ months to maturity), tall and in years of low rainfall fail due to drought. It has been spectacularly demonstrated during 1972-73 drought that early maturing hybrids and varieties could yield 20 to 30 quintals of grain per hectare when late local totally failed. In heavy rainfall seasons like the 1973 kharif, while the earlies did retain the yield advantage, the late locals were infested by midge and failed to set seed even though moisture was not the limiting factor.

It is, therefore, evident that early and late maturing varieties should not be grown side by side in the same region as adult midges will migrate from earlier flowering crop to the latter flowering ones. Hence it is essential that broad maturity zones be identified in each of the states and varietal diversity provided within an accepted maturity range. The sorghum programme has today both hybrids and varieties to aid such a policy.

The farmers are also very much conscious of the vulnerability of late locals to midge and are themselves coming forward towards a change to early varieties. This farmer attitude should be taken advantage of to bring about a rapid varietal change which will meet the dual needs of fighting drought and midge, and stabilization of sorghum production at a higher level under dryland conditions.

Presently available varietal diversity in relation to maturity groups for the kharif season is as follows:

Group	Days to flower	Hybrids/varieties
[illegible]	58-60	CSH-1, 199, CS 3541 and 370
[illegible]	64-66	CSH-1, Swarna and 302
[illegible]	68-70	CSH, CS 3541, 118 and 302
Medium	75-80	604 and 309

All hybrids and the varieties 118, CS 3541, Swarna and 370 are resistant/tolerant to downy mildew; 604, 118 and 309 to shoot fly and 116 to most leaf spots and stinger. In the transition zone of Karnataka and Maharashtra States, downy mildew susceptible varieties like 309 should be avoided.

Cultural Approach. Apart from growing varieties of diverse maturities, farmers tend to plant the same variety of sorghum over an extended period and this also results in an uninterrupted flowering situation similar to the one created by planting varieties of different maturities. After the advent of hybrids, there was a tendency for prolonged planting on account of their early maturity and relative insensitivity to photoperiods. Such a practice has accentuated the problem of shoot fly on hybrids and the midge mostly on locals and late-sown hybrids.

It has been very well demonstrated that plantings done immediately (a week to ten days) after the break of the monsoon in kharif do not suffer from shoot fly attacks and return high yields. As plantings are delayed there is a gradual decline in yield levels.

It is, therefore, necessary that farmers are educated to confine their plantings (varieties of a chosen maturity range) to a period of about 10 to 15 days after the break of the monsoon (usually before the first week of July in most parts). In case they are unable to plant within this period, they should be advised that growing sorghums at that stage may not be profitable and alternate crops like bajra, Setaria, sunflower, etc. may be more rewarding.

In addition to adjusting sowing date, the farmers should be strongly advised to immediately burn or plough in all trash and plant residues left after harvest. The infested undeveloped seeds form an important source of carry-over of the pest from season to season. As a matter of fact, this should be made obligatory in the endemic areas.

Surveillance. It is necessary to keep a constant vigil on the appearance of midge so that farmers can be warned about the control measures to be resorted to before the damage is done. Montaya (1965) developed a time-saving squeeze device to detect larvae on Johnson grass which could be used to predict midge infestation on sorghum. Some research of this type will be useful. It is necessary that a system of surveillance and monitoring of midge incidence should be developed in the sorghum-growing states to provide the necessary warning as soon as the midge build-up is expected in any area.

The rabi sorghums are so far free from midge, but a situation similar to kharif could develop and hence vigilance during rabi is also essential.

Chemical Control of Midge. Adequate data are available on chemical control of midge from All-India Co-ordinated Trials. Spraying of the ears before flowering (at bout 50 panicle emergence) with endosulfan (35% EC) one litre, carbaryl (50% WP) 3 kg, lindane (20% EC) 1 to 2 litres in 500 to 600 litres of water per hectare controls midge. Repetition of the spray after 4 to 6 days is desirable particularly where the panicle emergence is not uniform. Four per cent endosulfan dust or 10 per cent carbaryl dust or 10 per cent BHC dust at 20 kg/ha is also effective. Two applications will be necessary as in the case of sprays. The timing of the application is very important.

Resistance to Midge. Some work has been in progress on screening for midge resistance in the All-India Co-ordinated Sorghum Improvement Project. The results are, however, not very consistent. The lines IS Nos. 1510, 3472, 4114, 5230 and 6179 which have exhibited some consistency have been selected as promising resistant lines.

A variety SGIRL-MR-1 was registered in Georgia, USA, as midge resistant. Seeds of this variety have just been received and breeding programmes for midge resistance will be initiated.

Natural Enemies of Midge. Several Hymenopterous insects are known to parasitize midge. *Tetrastichus* sp. has been observed in India, *Eupelmus* sp. and *Aprostocetus* sp. in other countries. The parasitization, however, was not very heavy.

Observations recorded so far have shown that the build-up of the population of *Tetrastichus* sp. takes place quite late in the season. It is felt that one of the factors responsible for reduction in the midge population during the middle of October may be due to the increased activity of this parasite

The predator bug *Orius albidipennis* and spiders have also been recorded as important natural enemies of midge. More work on the parasites and predators of

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SORGHUM MIDGE

midge could be of great use in formulating the biological control programme for this pest.

Our greatest emphasis on midge problem has to be on avoidance. This could be achieved by a suitable varietal policy along with education of the farmer on confining plantings to a specified period. Surveillance during both kharif and rabi on midge build-up and forewarning of possible outbreaks is essential so that timely control measures, more or less on a war footing, could be taken up. Encouraging parasites and breeding for midge resistance could possibly provide answers in due course.

CONTINUED FROM PAGE 16

OUTBREAK OF WHEAT RUSTS

By growing wheat as a kharif crop favourable conditions are being created for good build-up of black and brown rust inoculum in the months of October, November and December in the heart of the country. This inoculum may present a threat to our normal sown crop in the main wheat belt.

In case early sowings cannot be avoided, as in Sanchore area, it is necessary to use only highly resistant varieties. Sanchore problem was aggravated by the susceptible 'Karchia' variety as this is evident from the survey report.

GENE ACTION FOR CONTENT OF AMINO ACIDS IN GRAIN SORGHUM*

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The nutritional quality of grain sorghum can be improved through increase in protein quantity and/or quality. Since there may be a negative correlation between lysine and protein, mere increase in protein content may not result in increased biological utilization. Thus, enhancement of nutritional quality in sorghum would involve increasing the concentration of essential amino acids particularly, lysine, threonine, methionine and cystine along with appreciable protein levels, and a reduction in the pellagrogenic property.

Adequate information regarding the genetic architecture of these important aspects is not available. The objective of the present study was to gather genetic information regarding the gene action in respect of content of protein and different amino acids in a 10-variety diallel cross of *Sorghum bicolor* (L.) Moench.

Materials and Methods

The experimental material and the aminoacid analysis have been detailed by Nanda and Rao (1975). Statistical analysis was as suggested by Hayman (1954).

Results and Discussion

Analysis of variance for content of amino acids (expressed as % of protein) indicated that the differences were not significant in respect of serine, cystine, histidine and arginine while significant variation existed for most of the other amino acids in the material under study. The regression of Vr on Wr for many amino acids was negative. Analysis was then conducted for different amino acids expressed as mgm per gram of grain material, a more realistic basis for assessing quality. It may be observed (Table 1) that the differences were significant expecting in the case of cystine, though methionine, another sulphur-containing amino acid, had significant variability.

The magnitude of additive variance was smaller than non-additive variance for most of the amino acids, the mean degree of dominance varying from 1·03

*Part of the thesis submitted by GSN for Ph.D. degree of the Indian Agricultural Research Institute, New Delhi.

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TABLE

Analysis of variance for different amino acids

Source	d.f.	Protein	Thr.	Ser.	Glu.	Pro.	Cys.	Gly.
Replications	1	0·14	0·29	29·81	20·66	2·05	3·38	0·95
Progeneis	44	9·11**	1·25**	4·96**	66·43**	15·96**	1·14	0·46**
Parents	8	5·97**	0·28	3·76	24·69	4·59**	0·24	0·35**
Hybrids	35	9·98**	1·50**	5·38**	75·48	17·90**	1·38	0·48**
P vs. H	1	0·69	0·01	0·04	83·61*	39·24**	0·01	0·68**
Error	44	0·95	0·26	2·38	17·77	2·40	1·17	0·10

TABLE

Estimates of components of genetic variation

Statistics	Protein	Thr.	Ser.	Glu.	Pro.	Cys.	Gly.	Ala.
$\hat{D}$	2·51 ±0·40	0·01 ±0·46	0·69 ±1·71	3·46 ±6·97	1·09 ±6·05	−0·47 ±0·72	0·13 ±0·08	0·34 ±5·88
$\hat{H}_1$	5·04 ±0·89	1·57 ±1·02	4·70 ±3·78	60·01 ±15·38	22·38 ±13·35	0·50 ±1·60	0·55 ±0·19	23·50 ±12·98
$\hat{H}_2$	2·94 ±0·76	1·19 ±0·87	4·43 ±3·25	45·16 ±13·22	16·63 ±11·48	0·70 ±1·37	0·39 ±0·16	15·70 ±11·60
$\hat{h}_2$	0·62 ±0·51	−0·05 ±0·58	−0·46 ±2·18	14·84 ±8·86	8·14 ±7·69	−0·23 ±0·92	0·13 ±0·11	2·33 ±7·48
$\hat{F}$	−3·76 ±0·94	−0·35 ±1·07	−1·02 ±4·00	−25·68 ±16·26	−1·88 ±14·11	−0·97 ±1·69	0·02 ±0·20	−3·88 ±13·72
$\hat{E}$	0·47 ±0·13	0·13 ±0·15	1·19 ±0·54	8·89 ±2·20	1·20 ±1·91	0·59 ±0·23	0·05 ±0·03	1·23 ±1·86
Mean degree of dominance	1·12	11·56	2·67	4·17	1·03	4·53	2·09	8·32
$H_2/4H_1$	0·15	0·19	0·24	0·19	0·19	0·35	0·18	0·17
$\frac{(4DH_1)^{0.5}+F}{(4DH_1)^{0.5}-F}$	0·31	−0·12	0·56	0·06	0·68	0·01	1·10	0·19
h^2/H_2	0·21	−0·04	−0·10	0·33	0·49	−0·33	0·33	0·15
r (Wr + Vr)/Yr	−0·851	−0·137	−0·682	−0·940	−0·585	0·513	−0·378	−0·547

for proline to 11·56 for threonine. It would appear that for producing a high quality line a breeding procedure utilising non-additive gene effects would be rewarding. There is only scanty information available on this aspect of quality breeding in grain sorghum. However, enough information is there to show

1

expressed as mg. per gm. of the grain material

Ala.	Val.	Met.	Lso.	Lys.	Leu.	His.	Tyr.	Arg.	Phe.	Asp.
4·21	4·80	0·01	0·74	0·15	7·02	0·02	0·10	0·77	1·54	0·21
17·90**	3·14**	0·41**	2·38**	0·22	44·06**	0·44**	3·69**	1·02**	5·82**	8·71**
3·13	0·72	0·44*	0·64**	0·22	10·16**	0·34*	1·22**	0·50	2·30**	2·41
21·42**	3·77**	0·41**	2·80**	0·21	51·13**	0·48**	4·32**	1·17**	6·67**	10·38**
12·84**	0·43	0·01	1·54**	0·58*	76·35**	0·05	1·39**	0·02	4·34**	0·44
2·45	0·55	0·24	0·27	0·15	2·97	0·17	0·35	0·36	0·72	1·86

2

for protein and amino acids

Val.	Met.	Iso.	Lys.	Leu.	His.	Tyr.	Arg.	Phe.	Asp.
0·08 ±1·02	0·10 ±0·04	0·19 ±0·85	0·04 ±0·03	3·59 ±16·22	0·08 ±0·05	0·44 ±1·32	0·07 ±0·15	0·79 ±1·65	0·27 ±2·70
4·80 ±2·24	0·69 ±0·09	3·05 ±1·88	0·18 ±0·06	58·79 ±35·81	0·63 ±0·34	4·55 ±2·91	1·03 ±0·33	5·65 ±3·65	9·56 ±5·95
3·07 ±1·93	0·59 ±0·08	2·17 ±1·62	0·14 ±0·05	41·53 ±30·78	0·46 ±0·29	3·27 ±2·50	0·76 ±0·28	4·38 ±3·13	6·59 ±5·11
–0·02 ±1·29	–0·04 ±0·05	0·29 ±1·08	0·10 ±0·04	16·17 ±20·62	–0·02 ±0·20	0·24 ±1·67	–0·07 ±0·19	0·70 ±2·10	–0·27 ±3·43
–0·07 ±2·37	0·19 ±0·09	–0·50 ±1·99	0·01 ±0·07	–8·59 ±37·85	0·09 ±0·36	–0·78 ±3·07	–0·25 ±0·35	–1·66 ±3·85	–2·69 ±6·29
0·28 ±0·32	0·12 ±0·01	0·13 ±0·27	0·07 ±0·01	1·49 ±5·13	0·09 ±0·05	0·17 ±·42	0·18 ±00·05	0·36 ±0·52	0·93 ±0·85
7·56	2·58	4·06	2·21	4·04	2·73	3·23	3·83	2·67	5·90
0·16	0·21	0·18	0·19	0·18	0·18	0·18	0·18	0·19	0·17
0·90	2·11	0·50	1·10	0·45	1·48	0·56	0·37	0·43	0·09
–0·01	–0·07	0·13	0·69	0·39	–0·05	0·07	–0·09	0·16	–0·04
–0·564	0·623	–0·328	0·537	–0·385	–0·576	–0·331	0·025	–0·303	–0·225

that most of the yield attributes are controlled by additive effects. For production of better quality and high yielding varieties it would, therefore, be necessary to take into account this type of variability along with the non-additive gene effects as has been suggested by the present study. However, quality traits like protein and different amino acids are very sensitive to environmental fluctuations. More reliable estimates have to be obtained by assessing over years/locations.

F-value is negative for most of the amino acids which indicated that recessive alleles were predominant in the material under study. In respect of glycine, methionine, lysine and histidine the reverse situation was true. This finding is substantiated by the ratio $(4DH_1)^{0\cdot5}+F/(4DH_1)^{0\cdot5}-F$ which was less than 1 for the amino acids where F was negative. It may be observed that for glycine, methionine, lysine and histidine the ratio was 1·10, 2·11, 1·10 and 1·48 respectively. It may be concluded from these data that for glycine and lysine there was almost equal proportion of recessives and dominants whereas for methionine there were two dominant genes or gene groups for each recessive gene or gene group. Similarly in respect to histidine the ratio of dominant and recessive was 3 : 2. Correlation between (Vr+Wr) and Yr was negative for all the amino acids except cystine, methionine, lysine and arginine, where recessive alleles would give higher manifestation, Asymmetry of the proportion of alleles for different aminoacids in the population was also indicated by the ratio $(H_2/4H_1)$, which was different from 0·25 in most of the cases. The estimates of number of effective factors involved and showing dominance relationships was low. Such estimates would always be minimal in a diallel cross (Jinks, 1954).

Summary

Aminoacid (both as per cent of protein and mg. per gram of grain) analysis in a 9×9 diallel cross of sorghum indicated significant variation for most of the amino acids. It was observed that, in general, most of the amino acids were predominantly governed by non-additive gene effects. Degree of dominance ranged from 1·03 for proline to 11·56 for threonine. The estimates of F and other statistics indicated that recessives were more frequent. Correlation coefficient between (Vr+Wr) and Yr showed dominant genes were positive for all the amino acids excepting cystine, methionine and lysine in which case the situation was reverse. The breeding methodology for better quality and high yielding varieties has been discussed.

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GENETIC ANALYSIS OF SOME EXOTIC × INDIAN CROSSES IN SORGHUM. IX. NUTRITIONAL QUALITY AND ITS ASSOCIATION WITH YIELD[1]

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CEREAL diets can be improved substantially by use of high yielding varieties, increase in the protein level of cereals by application of nitrogenous fertilizers, selection of cereal varieties with a higher protein content and improved protein quality, transfer of protein quality genes like opaque-2 and accelerated development and selection for optimum protein composition of cereal varieties. In recent years high lysine sorghum varieties of Ethiopean origin have been reported (Singh and Axtell, 1973). Based on the variability available in some exotic × Indian crosses for protein, essential aminoacids, β-carotene and for yield attributes, an attempt is made to study the genetic basis for the simultaneous improvement of nutritional quality and grain yield in sorghum.

MATERIALS AND METHODS

The material comprised six dwarf exotic varieties, IS 511, IS 859, IS 2954, IS 2031 and IS 3797 and *Swarna,* two Indian tall grain sorghum varieties, IS 4522 and R 168, a fodder variety A-1-14-8 with high protein content in grain, and a dwarf selection R 1661 from an exotic × Indian cross IS 3678 × *Maldandi,* and the 45 possible F_1 hybrids (without reciprocals) grown in a randomized block design with 4 replications at Delhi,. The material was grouped into talls and dwarfs in each block to avoid shading effects and randomization was carried out within each group. The plot consisted of a single row of 3 m. length spaced 75 cm apart with a spacing of 15 cm between plants. Observations were made on 5 random plants within each row. All agronomic practices were uniform.

The analysis of nitrogen and 17 amino acids was carried out at Purdue University according to standard procedures. Nitrogen was determined by microkjeldal technique after defatting the sample. For aminoacid composition hydrolysed samples were run on Beckman Model 121 amino acid analyser. Tryptophan estimations were done by standard procedures at the National Institute of Nutrition, Hyderabad. For determination of total yellow pigments and β-carotene standard procedures were used. The intensity of colour was read in Klett's colorimeter using 420 mμ filter and the amount of carotene and total yellow pigments were determined from standard curve.

Combining ability analysis was carried out according to method 2, model 1 of Griffing (1956).

RESULTS

Variability for nutritional and yield attributes

From the range of variation (Table 1) it will be seen that the hybrid values

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TABLE 1

Means and ranges for protein, 18 aminoacids, carotene and yield attributes in 55 genotypes

Sl. No.	Attribute	Means		Ranges		FAO provisional protein pattern (Essential amino-acids)
		Parents	Hybrids	Parents	Hybrids	
1.	Protein (%)	14·12	14·51	12·16–18·31	11·63– 19·25	—
2.	Lysine (% of protein)	1·86	1·67	1·51– 2·13	1·35– 2·29	4·3
3.	Threonine ,,	3·01	2·96	2·74– 3·26	2·38– 4·27	3·3
4.	Methionine ,,	1·09	1·05	0·62– 1·47	0·33– 1·63	1·7
5.	Cystine ,,	1·02	0·97	0·90– 1·34	0·61– 3·28	1·7 (half cysteine)
6.	Isoleucine ,,	3·85	3·95	3·55– 4·08	3·52– 5·72	4·3
7.	Leucine ,,	14·05	15·08	13·30–14·90	13·82– 22·98	4·9
8.	Phenylaline ,,	5·19	5·36	4·80– 5·79	4·90– 7·85	2·9
9.	Tyrosine ,,	4·39	4·43	4·23– 4·60	3·93– 6·73	2·5
10.	Valine ,,	5·05	5·09	4·12– 5·58	4·13– 6·71	2·8
11.	Tryptophan ,,	0·67	0·91	0·67– 0·91	0·72– 0·98	1·1
12.	Serine ,,	3·96	3·80	2·02– 4·94	1·69– 5·74	—
13.	Glutamic acid ,,	23·47	24·87	21·56–25·60	17·38– 37·15	—
14.	Proline ,,	8·22	8·98	7·34– 8·97	7·75– 13·59	—
15.	Glycine ,,	2·98	2·77	2·40– 3·30	2·27– 3·68	—
16.	Alanine ,,	9·54	9·73	8·65–10·72	7·33– 14·54	—
17.	Histidine ,,	2·08	1·98	1·61– 2·48	1·39– 2·68	—
18.	Arginine ,,	3·42	3·33	2·90– 3·77	2·84– 4·36	—
19.	Aspargine ,,	7·06	7·08	6·35– 7·67	5·20– 10·30	—
20.	β-carotene (μg/100 g)	—	—	12·83–60·60	8·46– 63·97	—
21.	Yield (gm/plant)	37·81	58·29	6·91–88·41	1·27–120·44	—
22.	100 seed weight (gm)	2·78	3·17	1·08– 3·49	1·79– 4·08	—
23.	Grain hardness (kg)	8·01	8·95	3·70–10·94	3·70– 11·21	—

transgress parental values for almost all the characters. It is also seen that with the exception of lysine, there is adequate variability for essential aminoacids to match the FAO protein standard.

There is significant variation (Table 2) among the parents only for protein, yield attributes and glycine but not for essential aminoacids. On the other hand amongst hybrids, besides protein and yield attributes, significant differences exist for essential aminoacids, threonine, methionine, isoleucine, leucine, phenylalanine, tyrosine and valine. The parent *vs.* hybrid comparison is significant for lysine, leucine and phenylalanine amongst essential aminoacids in addition to yield attributes and glutamic acid, proline and glycine.

Nature of gene action

From Table 2, it is observed that with the exception of methionine, isoleucine, leucine, phenylalanine, tyrosine, glutamic acid, proline, alanine where specific combining ability (*sca*) is significant or predominates in magnitude over *gca*, additive gene action is more important for all other attributes. The *gca* is significant for protein, lysine, threonine among the essential aminoacids.

Association between yield and nutritional attributes

Amongst the significant negative correlations are those of protein with yield, seed size and grain hardness; lysine with isoleucine, cystine, leucine, leucine with methionine; carotene with protein, methionine and cystine; seed size with threonine and yield with cystine.

The following significant positive correlations are observed: yield with seed size and grain hardness; grain hardness with seed size and lysine; methionine and lysine; isoleucine and threonine; leucine with protein, threonine and isoleucine; carotene with lysine, threonine, isoleucine and leucine.

Discussion

Viewed against the FAO provisional protein pattern, the sorghum germ plasm furnishes adequate variability for essential aminoacids in addition to β-carotene all of which could be combined with high yields. The inheritance of protein, lysine, threonine, tryptophan and carotene amongst nutritional attributes and grain yield, seed size and grain hardness amongst yield attributes is also additive in general. Results of inheritance studies of protein and lysine by Collins and Pickett (1972 a, b) and β-carotene by Singhania, Rao and House (1970) based on diallel mating system are in general agreement with the present investigations. Thus opportunities for recombining nutritional attributes with yield are in the realm of realization.

An examination of the association between yield and nutritional attributes reveals the following desirable associations: yield and grain size, yield and grain hardness, lysine and methionine, lysine and threonine, methionine and grain yield, leucine and lysine, leucine and methionine, β-carotene and threonine. These associations thus offer scope for increasing of lysine, methionine and carotene along with grain yield. A simultaneous reduction in leucine is also feasible.

SUMMARY

Variability and nature of gene action in the inheritance of nutritional attributes, *viz.*, protein, 18 aminoacids, β-carotene and yield attributes, *viz.*, yield per plant, seed size and grain hardness and the association between nutritional and yield characters were studied in a diallel mating system involving 10 parents representing exotic, Indian and derived lines of sorghum.

Viewed against the FAO protein pattern and in the light of recent discovery of high lysine sorghums, there is adequate variability for essential aminoacids and β-carotene in the genus sorghum. Protein, lysine, threonine, tryptophan and β-carotenen, grain yield, seed size and grain hardness are predominently additive in inheritance. The positive associations of lysine, methionine and β-carotene with grain yield offer opportunities for recombining high yields with high nutritional quality.

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GENETIC ANALYSIS OF SOME EXOTIC×INDIAN CROSSES IN SORGHUM X. INHERITANCE OF RESISTANCE TO SORGHUM SHOOT FLY

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Analysis of ovipositional non-preference underlying resistance to sorghum shoot fly indicated that some of the parents derived from exotic×Indian crosses and hybrids involving them were superior in shoot fly reaction compared to the susceptible exotics; the parental performance was a good indication of the hybrid behaviour (Rao *et al.*, 1974). The present study based on large F_2 populations derived from a diallel mating system and a cross involving F_1, F_2 and back-cross generations is an attempt to analyse the nature of inheritance of resistance to sorghum shoot fly (*Atherigona varia soccata* Rond.).

Materials and Methods

The material for the first experiment comprised eleven parents, three exotics (IS 3922, IS 2031 and IS 3687), three Indian varieties (*Aispuri*, BP 53 and M. 35–1) and five derivatives from exotic × Indian crosses (512, 148, 604, R–16 and R–24) and the 55 F_2 populations derived from all possible matings (without reciprocal) among them. The material was grown during *kharif* 1973 in randomized blocks replicated three times. Each plot had three rows of 10 m. length spaced 45 cm apart.

In a second experiment, parental, F_1, F_2, BC_1 and BC_2 generations of the cross 512 × IS 9985 and its reciprocal were studied; IS 9985 is a shoot-fly susceptible, bold seeded *caudatum kaura* from Sudan while 512 is a moderately resistant line derived from the exotic × Indian cross (IS 508 × BP 53). This experiment was also laid out during *kharif*, 1973 in randomized blocks replicated twice. A total plant population of 130-180 plants in case of parents, F_1's and backcrosses and 407–535 plants in F_2 were analysed.

Basal fertilization was at the rate of 60 kg N and 60 kg P_2O_5 per hectare. Shoot fly incidence was high enough to cause differential mortalities. Shoot fly counts recorded 30 days after germination as percentages and the angular transformed values were statistically analysed according to procedures of Griffing (1956) and Hayman (1958).

Results

Analysis of means and frequency distribution

Mortality percentages due to shoot fly damage in individual crosses and group behaviour of parents and F_2's are presented in Table 1. Analysis of variance revealed significant differences among parents and F_2 progenies (Table 2). The parents *vs* progenies comparison was not significant which was meaningful because both the parental and F_2 progenies included equally resistant or susceptible populations.

The progenies of the crosses 148 × IS 3687 and R-24 × *Aispuri* exhibited least mortality counts followed by those of 604 × R-16, 604 × M. 35-1 and 604 × 148 (Table 1).

TABLE 1

Group comparisons of shoot fly damage in parents and F_2 progenies

Group	Average plant population (no.)	Per cent damage			
		Actual values		Transformed values	
		Mean	Range	Mean	Range
Parents					
Exotics	1266	64·4	33 5–88·9	54·3	35 3–70·5
Indian	1198	22·5	20·0–26·7	28·3	26·5–31·1
Derivatives	1212	22·9	25·2–51·5	34·8	30·1–45·8
F_2 Progenies					
Exotic × Exotic	1350	56·3	45·5–67·6	48·6	42·4–55·3
Indian × Indian	1293	23·4	16·2–27·1	28·7	23·7–31·3
Exotic × Indian	1269	37·7	24·9–56·8	37·7	29·9–48·9
Exotic × Derivatives	1323	47·9	11·7–61·5	43·6	20·0–51·6
Derivatives × Indian	1257	25·0	12·2–34·4	29·8	20·4–35·9
Derivatives × Derivatives	1284	32·2	18·5–40·6	34·3	25·5–39·6
C.D. 0·05				10·4	

The group comparisons indicated exotics to be the most susceptible, the Indian parents and the derivatives being the least susceptible (Table 1). Amongst F_2 progenies, exotic × exotic crosses had the highest mortality counts followed by exotic × derivative, exotic × Indian, derived × derived, derived × Indian and Indian × Indian in that order.

The various mortality classes fit a normal distribution (Fig. 1) with a mean of $36 \cdot 7 \pm 1 \cdot 19$ mortality ($\chi^2 = 9 \cdot 19$, $P > 7 \cdot 05$). In the absence of complete resistance to shoot fly, the progenies exhibiting mortalities less than atleast one standard deviation from the mean are considered tolerant while those exceeding this limit as susceptible.

COMBINING ABILITY

The mean squares and estimates of variances indicated predominance of general combining ability, specific combining ability being non-significant (Table 2). The *gca* effects of parents revealed that the exotic parent IS 3687 tolerant to shoot fly has the capacity to transmit this character. While the Indian parents and derivatives generally exhibited negative *gca* effects indicating

TABLE 2

Analysis of variance for treatmental differences and combining ability and estimates of combining ability variances and effects for shoot fly damage in sorghum

Source	D.F.	M.S.S.
Blocks	2	1029·89
Treatments	65	285·53**
Parents	10	602·58**
F_2 progenies	54	231·27**
Parents *vs* progenies	1	44·88
Error	130	51·08
Gca	10	1478·85**
Sca	55	67·80
Estimates of combining ability		
$\hat{\sigma}^2$ gca		36·18*
$\hat{\sigma}^2$ sca		5·57
$\hat{\sigma}^2\hat{e}$		17·03
Gca effects of parents		
IS 3922		+10·42**
IS 2031		+11·96**
IS 3687		–0·22
Aispuri		–6·64**
BP 53		–2·46
M. 35–1		–6·10*
512		+0·43
148		–3·70
604		–4·55
R–16		–1·07
R–24		+1·97
S.E. (*Gca*)		1·86

*Significant at 5% level; **Significant at 1% level.

their resistance for shoot fly, the derivatives 148 and 604 were apparently the best parents for transference of shoot fly resistance.

GENE EFFECTS

Studies based on parental, F_1, F_2, BC_1 and BC_2 generations of the cross 512×IS 9985 revealed that the differences due to generations were significant, while the reciprocal differences were not. The gene effects were, therefore, averaged over reciprocals. The relative magnitudes of the gene effects point to additive and additive×additive interaction effects to be more important,

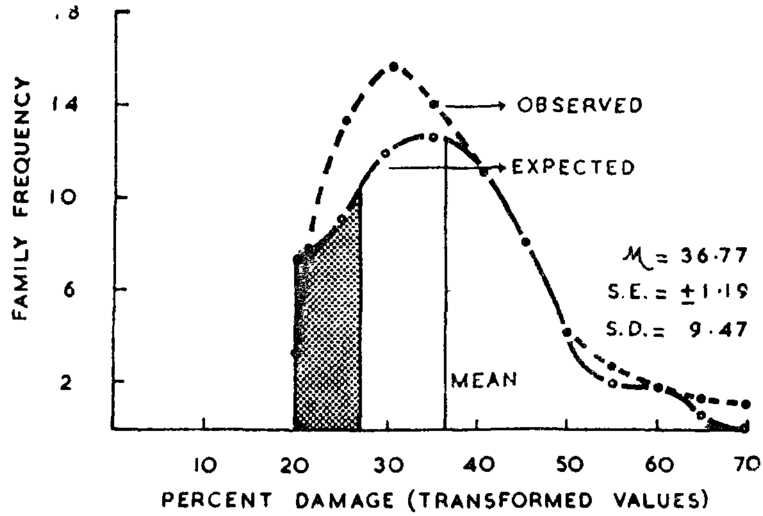

FIG. 1. Frequency distribution of F_2 families for shoot fly damage, shaded portion indicating the area where selection for shoot fly resistance is effective.

TABLE 3

Means of parents, F_1, F_2 and back crosses and gene effects for shoot fly damage

Generation	Per cent damage	Gene effects	
1. P_1 (512)	29·7	$\hat{m}$	35·7
2. P_2 (IS 9985)	50·2	$\hat{d}$	–5·6
3. F_1	38·6	$\hat{h}$	–11·4
4. F_2	35·7	$\hat{i}$	–10·0
5. BC_1 ($F_1 \times P_1$)	30·4	$\hat{j}$	4·6
6. BC_2 ($F_1 \times P_2$)	35·0	$\hat{l}$	34·3
$H=[\hat{h}-\hat{i}]-[\hat{d}-\hat{j}]$			–8·8
Heterosis over mid parent (%)			–3·5
Inbreeding depression (%)			7·5

S.E. for generation means 3·02.

thus bringing out the importance of *gca* (Table 3). Heterosis for % dead-hearts was in the negative direction indicating that the hybrids will be less affected than parents.

Discussion

While the greater susceptibility of the exotic sorghums to shoot fly has been well documented, evidence on the genetic basis of resistance has been meagre. Blum (1969) reported that the size of the shoot fly population has the most pronounced effect on both absolute and relative rates of oviposition in various sorghum genotypes and suggested selection of non-preferred genotypes under extreme infestation. Studies of Rao *et al.* (1974) indicated that under field conditions, where the mortalities ranged from 20–90%, some derivatives between exotic × Indian crosses exhibited relatively less mortality and that the parental values could be used to predict F_1 hybrid performance. This itself is an indication that resistance to shoot fly is additive in inheritance.

Present studies based on sizable F_1 populations confirm that ovipositional non-prefernce is additive in inheritance, *sca* variance being of negligible proportion. Estimates of gene effects furnished further confirmation that inheritance of shoot fly resistance is mostly additive. Derivatives like 148 and 604 besides being dwarfer and earlier than *Aispuri* from which they were derived are tolerant to shoot fly and high yielding. Based on their performance in All-India trials, they have been recommended for release and general cultivation in some parts of India. They are also likely to be highly useful in future breeding programmes.

The frequency distribution of the different mortality classes closely fits the normal curve. Since absolute resistance is lacking, selection for shoot fly resistance may best be carried out under reasonable levels of infestation. Selection of resistant types may be confined to families which exhibit mortalities one standard derivation below the population mean.

The characteristic way in which the mortalities gradually decreased from 65 to 23% in the order exotics, exotic × exotic, exotic × derivative, exotic × Indian, derivative × Indian, Indian × Indian and Indian further confirms that the resistance is due to gradual accumulation of desirable alleles rather than due to one or two major genes.

Earlier studies inovlving parental and F_1 generation together with the present study on large F_2 populations and generation means provide evidence for the genetic basis and its utility in developing sorghum genotypes combining shoot fly resistance with other attributes.

Summary

Genetic analysis of resistance to sorghum shoot fly based on large F_2 populations from a diallel mating system involving exotic, Indian and derived lines as parents and gene effects estimated from generation means revealed that inheritance of shoot fly resistance is predominantly additive. Among derived lines 148 and 604 which have the tall and late Indian variety *Aispuri* in their parentage are tolerant to shoot fly besides being early, dwarf and high yielding. Based on their overall performance they have been recommended for general cultivation in parts of India.

There is a characteristic gradation in the order of shoot fly incidence from the susceptible exotics to the tolerant Indian varieties, the frequency distribution closely fitting the normal curve. In the absence of total resistance to shoot fly, selection under conditions of reasonable infestation in families where mortality percentages are one standard deviation below the population mean is likely to be effective.

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GENETIC ANALYSIS OF SOME EXOTIC×INDIAN CROSSES IN SORGHUM XI. SELECTION FOR SHOOT FLY RESISTANCE

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Analysis of ovipositional non-preference underlying resistance to sorghum shoot fly indicated that the hybrids were generally superior to their parents and that parental performance was a good indication of hybrid behaviour (Rao *et al.*, 1974). Further studies based on large F_2 populations and gene effects revealed that the inheritance of shoot fly resistance is predominently additive (Bala Kotaiah, Rana ,Tripathi and Rao, 1975). The present studies based on F_2 and F_3 progenies derived from them and some advanced generation material outline the progress from selection and isolation of genotypes combining shoot fly resistance with agronomic desirability.

Materials and Methods

The material for first experiment consisted of :

Parents: BP 53, M. 35–1, 148 (IS 3687 × *Aispuri*), 512 (IS 508 × BP 53), R–16 (IS 2950 × M. 35–1) and R–24 (R–78 × M. 35–1).

The F_2 of the following five crosses along with the respective F_3 progenies were grown: 148 × 512, R–16 × 512, 512 × M. 35–1, R–16 × BP 53 and R–24 × R–16. The number of F_3 progenies studied were 18, 15, 11, 9 and 17 respectively. Only agronomically desirable F_2 plants and the F_3 progeny derived from them were selected for the present study. 302, 604, *Swarna*, CSH–1, CSH–3 and CSH–5, were used as checks.

The material was grown in randomized blocks replicated 3 times during *kharif*, 1973. Within a replication randomization was done first between the four groups (parents, F_2, F_3 and checks) and later within each group. The total population studied ranged between 500–540 plants for each F_2 and 160–180 plants for each parent and F_3 progeny. The restricted randomization was necessitated on account of the fact that non-preference is the major mechanism and would bring out generation differences.

The second experiment was designed to study the group behaviour of exotic, Indian and derived lines from exotic × Indian crosses in advanced generations to incidence of shoot fly. A randomized block design with 4 replications was used. Within the replications the groups were assigned at random and the lines within the group were also randomized. Each plot had a population of 100–120 plants per replication. The material in the different groups comprised:

Indian: IS Nos. 1054, 1082, 2123, 2146, 3962, 4283, 4646, 4664, 5030, 5469, 5480, 5490, 5566, 5615, 5642, 5826, 8315 BP 53, *Aispuri*, *Karad local.*

Exotic: IS Nos. 84, 2031, 2954, 3687, 3922, *Swarna* and CS 3541.

B-lines: CK 60B, 2077B, 2219B, 2277B, 2947B, 3660B, 3691B (all based on exotics); 36B, 173B, 418B, 1146B, and 1220B (based on exotic × Indian derivatives).

Hybrids: CSH–1, CSH–2, CSH–3, CSH–4, CSH–5, 36A × 148, 648A × 148, 648 × R–24 and 2947A × 148.

Derivatives from Exotic × Indian crosses: 3, 94, 141, 148, 168, 171, 232, 269, 285, 302, 302–3, 302–6, 302–7, 303–7, 305, 311, 329, 370, 434, 461, 492, 555, 561, 562, 565, 573, 604, 614, 651, 654, 655, 661, 670, 702, 713, 882, 902, 1088, 1201, C–5, R–16, R–24, (all promising in *kharif*): R–20, R–30, R–33, R–147, 1329, No. 40, 76, 78, 79, 83, 116, 118, 168, 187, 198, FR–169, FR–173, FR–178, FR–194, FR–632, FR–645, FR–681 and FR–681–2 (all promising in *rabi*).

The exotic and Indian groups included parental lines used in crossing programmes from which the derived lines were obtained.

The mortality percentages were recorded 30 days after germination and statistical analysis was carried out after angular transformation. Components of genetic variance, D and H, were estimated following Jinks and Mather (1971).

RESULTS

BEHAVIOUR OF PARENTAL, F_2 AND F_3 GENERATIONS

Comparison of mortality percentages of different generations revealed that while the means are about the same, the range of variation differed markedly (Table 1). Analysis of variance established that while the differences for dead-

TABLE 1

Means and ranges of shoot fly mortalities for parents, F_2 and F_3 progenies transformed (angular) values

Generation/Cross		Mean (degrees)	Range (degrees)
Parents		33·56	24·5–47·0
F_2 progenies		32·41	28·5–37·7
F_3 progenies		34·56	17·2–55·6
R 16 × BP 53	F_2	33·70	—
	F_3	33·68	27·3–52·1
512 × M 35-1	F_2	28·53	—
	F_3	28·56	15·2–43·9
148 × 512	F_2	30·06	—
	F_3	32·35	20·3–48·2
R 16 × 512	F_2	37·56	—
	F_3	40·56	25·5–54·3
R 24 × R 16	F_2	32·36	—
	F_3	36·13	22·1–44·3
S.E. ±		4·69	

heart percentage among F_2's are not significant, the differences among and between F_3 progenies are highly significant (Table 2). The F_3 generation, therefore, offers considerable scope for selection and establishment of resistant progenies. All the five crosses offer scope for selection of shoot fly tolerant lines. The regression coefficient for mortalities of F_3 progenies on F_2 means is $1·319 \pm 0·2703$.

The frequency distribution of F_3 progenies (Fig. 1) for mortalities closely fits the normal curve ($\chi^2=2·42$, $P > ·05$). When population mortality ranged between 6·7–67% (15°–55°), progenies exhibiting mortality percentages

TABLE 2

Analysis of variance for shoot fly damage (transformed values)

Source	D.F.	M.S.
Replications	2	172·07
Entries	86	215·49**
Parents	5	193·12*
Segregating progenies (F_2+F_3)	74	188·58**
Parents *vs* segregating progenies	1	11·96
F_2 progenies	4	35·07
F_3 progenies	69	199·25**
F_3 (linear)	1	3564·27**
F_3 (non-linear)	68	149·77**
Bet. F_3 families	4	797·08**
Within F_3 families	65	162·46**
Within R 16 × BP 53 F_3	8	162·02**
Within 512 × M. 35–1 F_3	10	178·44**
Within 148 × 512 F_3	17	141·44**
Within R 16 × 512 F_3	14	233·29**
Within R 24 × R 16 F_3	16	113·07*
F_2 *vs* F_3 progenies	1	66·48
Checks	5	35·10
Residual	1	3425·29**
Error	172	21·98

*, **Significant at 5% and 1% level.

between 6·7–20·0% (15°–26°) could be considered resistant to shoot fly. It could also be seen from Table 1 that while the F_2 and F_3 mean mortalities are comparable, some of the F_3 progenies exhibited greater resistance.

GENETIC ADVANCE

Heritability estimates and genetic advance or gain from selection (GS) are given in Table 3. Heritability was around 25%. Selection of F_3 progenies showing less than 20% (26·7°) damage (Fig. 1) resulted in 10% selection intensity. The selection of these 10% superior progenies would be expected to result in nearly 10% improvement in the level of resistance in F_4 generation. A shift in selection pressure from 10% to 5% resistance progenies would not change expected F_4 mean substantially.

GROUP COMPARISONS OF SHOOT FLY REACTION

The means, ranges and analysis of variance for the different classes of materials studied is presented in Table 4. The between-group differences are

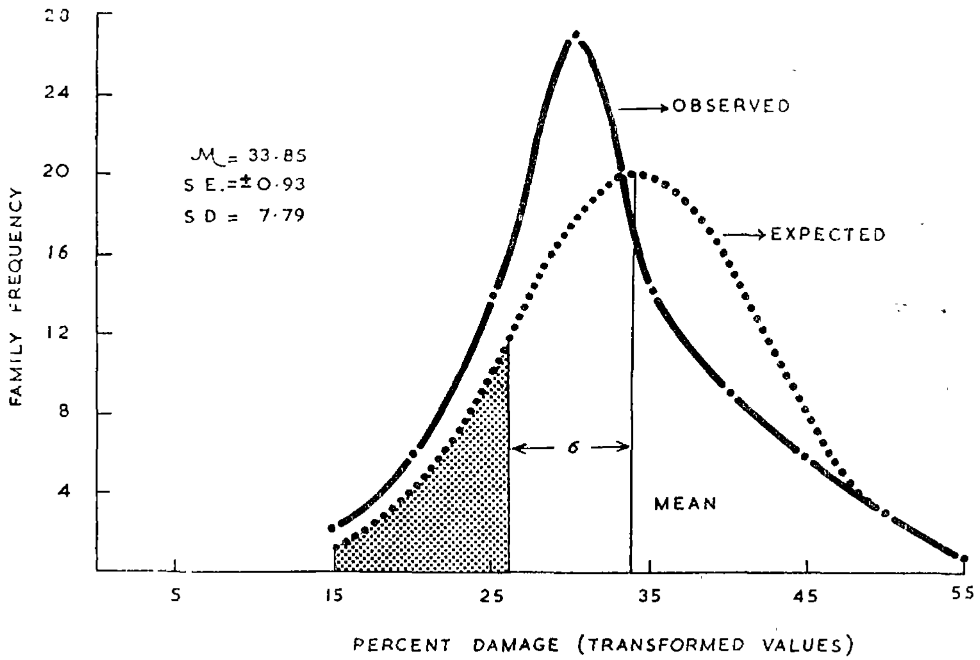

FIG. 1. Frequeney distribution of F_3 families for shoot fly damage, shaded portion indicating the area where seleotion for shoot fly resistance is effective.

TABLE 3

Heritability (h^2) and gain from selection (GS) in F_3 families for shoot fly resistance

Method	h^2	i=10%		i=5%	
		GS	EXP $\bar{F}_4$	GS	EXP $\bar{F}_4$
1.	22·57	–3·40	31·16	–3·98	30·58
2.	27·00	–2·10	32·46	–2·45	32·11

1. $h^2 = \hat{\sigma}^2_g(1) \quad \hat{\sigma}^2_g(1) + \hat{\sigma}^2\delta + \hat{\sigma}^2_e$

2. $h^2 = \hat{D}/\hat{D}+\hat{H}+\hat{E}$

i = Intensity of selection

highly significant. On the other hand, the differences within Indian parents are not statistically significant. Amongst exotics and hybrids, if IS 3687 and 36A×148 are eliminated from their respective groups, there are no significant within group differences. With the exception of 36B, the scope for selection

TABLE 4

Analysis of variance, means and ranges of different groups of parents for percent shoot fly damage (Transformed values)

Source	D.F.	M.S.	Range	Mean
Replications	2	733·15	—	—
Treatments	112	378·87**	—	—
Bet. groups	4	5551·44**	—	—
Within Indian parents	19	75·09	24·96–43·19	35·09
Within Exotic parents	6	452·52**	34·96–69·74	62·36
Within B-lines	11	83·20	49·27–69·47	61·68
Within hybrids	8	175·77*	32·96–58·05	51·24
Within derivatives	64	214·67**	36·33–68·40	52·14
Error	224	62·66	—	—

*, **Significant at 5% and 1% level.

amongst B-lines is not also much. The differences between derivatives are highly significant and offer maximum scope for selection of resistant lines.

DISCUSSION

Transference of resistance to sorghum shoot fly, which is primarily due to ovipositional non-preference, from the tall and generally late Indian varieties to dwarf, semi-dwarf and early maturing forms is apparently feasible since inheritance appears to be largely additive (Bala Kotaiah *et al.*, 1975). Parental performance is indicative of scope for recovery of resistant lines in segregating generations (Rao *et al.*, 1974). While F_2 mortalities enable identification of potential crosses, differences among susceptible and resistant lines become established by the F_3 generation and selection thereafter could result in further improvement and stabilization of resistance as has been accomplished in some of the advanced generation progenies. The significant regression of mortality percentages of hybrids on parents (Rao *et al.*, 1974) and F_3 on F_2 as reported in this paper is further proof of the genetic nature of this character. Estimates of heritability (narrow sense) for shoot fly resistance obtained by two methods place it at about 25%. Selection intensity below 10% may not be of much utility. Since absolute resistance is yet to be encountered, levels of selection of resistant lines may be confined to progenies exhibiting 6·7–20%, when mortalities of segregating populations range from 6·7–55% under field conditions. The study thus furnishes a measure for selection of resistant progenies.

That non-preference for oviposition is a major mechanism of resistance to sorghum shoot fly is borne out by the significant group differences now established. The exotic dwarfs are generally more susceptible to shoot fly with the exception of IS 3687. The Indian varieties are generally more tolerant; there is little difference among the Indian varieties. The derivatives from exotic × Indian crosses, the 'B' lines and commercial hybrids all of which are important from plant breeding considerations exhibit significant differences indicating that shoot fly resistance could be combined with agronomic desirability. 36-B among the 'B' lines, 36-A × 148 among hybrids and 148, 168, 329, 604, R-16 among derivatives which are being recommended for general cultivation exhibit shoot fly resistance comparable to the Indian parents. Several other dwarf and semi-dwarf derivatives, 3, 141, 171, 311, 370, 492, 555, 562, 573, 702, 882, 1188, R-30, R-33, R-147, 1329, FR-169, FR-173 FR-632 and FR-681, which are in advanced yield trials also exhibited reasonable levels of tolerance to shoot fly.

SUMMARY

Differences between shoot fly susceptible and resistant progenies get established from F_3 generation. Heritability estimate for shoot fly resistance is about 25%. Selection of progenies exhibiting 6·7–20% (15°–26°) mortality when mortalities range between 6·7–67% (15°–55°) results in isolation of resistant progenies. Selection intensities below 10% may not result in increased gains.

Exotic, Indian and derived lines when grown in their respective groups exhibit significant group differences indicating non-perference for oviposition to be the primary mechanism for shoot fly resistance. Resistant lines of economic worth have been isolated through selection in exotic × Indian crosses. 36A among male steriles and its B-line, 36A × 148 among commercial hybrids, 148, 168, 329, 604 and R-16 among the derivatives combine resistance to shoot fly with agronomic attributes and are being recommended for general cultivation.

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GENETIC ANALYSIS OF SOME EXOTIC×INDIAN CROSSES IN SORGHUM. XII. LINE PERFORMANCE IN RELATION TO HETEROSIS[1]

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THE use of *per se* performance of lines as a method of screening inbred lines of corn has been advocated (Genter and Alexander, 1962; Lonnquist and Castro, 1967). In barley, Gebrekidan and Rasmusson (1970) recommended the use of cultivar *per se* performance in initial screening of potential cultivars. In sorghum Whitehead (1962) observed *gca* and line *per se* performance may be relatively more important for evaluating parents of hybrid sorghum. An effort is made to relate the performance of derived males from exotic×Indian crosses with the performance of their corresponding hybrids.

MATERIALS AND METHODS

Five females, 21 males and the resulting 105 hybrids were grown in randomised blocks replicated three times at three locations, Parbhani, Dharwar and Yemmiganur during *kharif* 1970. Data from these experiments was used to study the relationships between performance of male parents and hybrid performance.

RESULTS

The correlation coefficients between line *per se* performance of males and their corresponding hybrids are given in Table 1.

It will be seen that there is a close relationship between male performance and hybrid performance at all the locations. For grain yield the correlation was not significant at Yemmiganur. This is attributable to the generally poor performance of the males and reduced seed set at this location. In general, the hybrid performance is positively correlated with performance of lines *per se*.

Since the female parents are few in number and the average yields of females over males are not significantly different, correlation of female performance with hybrid performance was not assessed.

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TABLE 1

Phenotypic correlation coefficients between line per se *performance and mean test cross performance*

Character	Correlation coefficients			
	Parbhani	Dharwar	Yemmiga-nur	Overall locations
1. Mature plant height	0·9176**	0·9026**	0·8419**	0·9108**
2. Days to 50% bloom	0·8411**	0·4989*	0·7904**	0·8080**
3. Panicle length	0·8626**	0·8518**	0·9021**	0·9466**
4. Grain yield per panicle	0·9033**	0·5309*	0·1749	0·4966*
5. Hundred grain weight	0·7335**	0·4284	0·5611**	0·6876**
6. Number of grains per panicle	0·4491*	0·5625**	0·4731*	0·6478*

*Significant at 5% level; **Significant at 1% level.

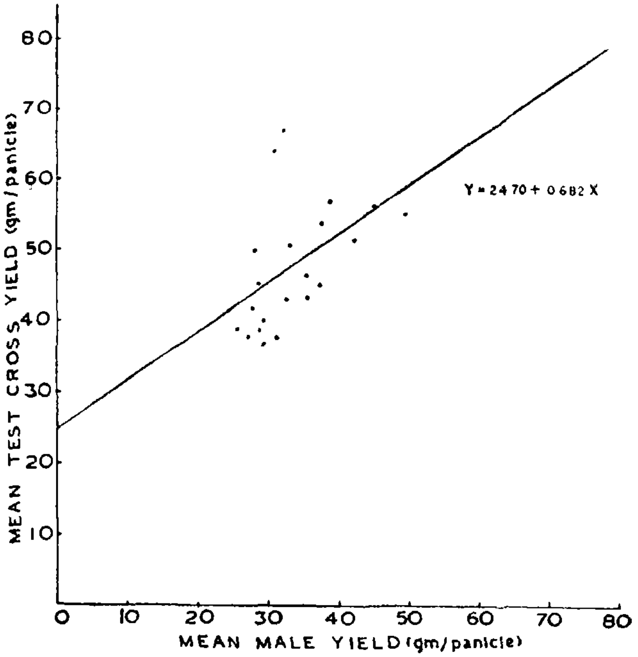

FIG. 1. Regression of test cross performance on male performance.

Test cross yields showed positive regression on male yields (Fig. 1).

DISCUSSION

Correlation studies between parental (males) performance and test cross performance reveal significant positive association for all characters except grain yield at one location. Analysis of the regression of test cross yields on parental yields (Fig. 1), also showed that the two are positively associated.

The validity of the supposition that more accurate evaluation of general combining ability can be made among early generation inbred lines on the basis of progeny performance than on the basis of test cross performance depends to a large extent on the nature of gene action involved in heterosis. If, as is generally accepted, heterosis results primarily from additive effects of dominant genes, progeny performance of early generation inbred lines should evaluate their general combining ability better than test crosses.

The present study is essentially an evaluation of males *per se* performance and its relation to test crosses, since the females did not exhibit enough variability. The results bring out that a preliminary evaluation of lines *per se* would provide an effective test of potential parents and subsequent test cross evaluation of high×high lines could yield highest yielding hybrids as was observed in barley (Upadhyaya and Rasmusson, 1967).

Whether parents should be tested and selected in the same environment in which their progeny is to perform is an important question (Falconer and Latyszewski, 1952). In the present study, the correlations are more pronounced at Parbhani where the expression of parents was the best. The hybrids, on the other hand, performed well at all locations. Hence, parents selected on the basis of their performance *per se* under ideal conditions could yield superior hybrids whose performance may be expected to be superior over a range of growing conditions.

Summary

Evaluation of male *per se* performance and its relation to test cross yields revealed that line *per se* performance could profitably be utilized as an effective preliminary test for potential parents. Subsequent evaluations could be based on test crosses. There are indications that parents selected on the basis of their performance under favourable conditions of a single environment could result in hybrids of general superiority over varying environments.

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RAINFALL FLUCTUATIONS AND CROP YIELDS

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IN recent years, there has been growing interest in possible weather changes and their influence on crop yields. The year 1972–73, during which widespread drought occurred in India and several other regions of the world, is often cited as an important case study.

While the limits of rainy season and consequently the crop growing period in a given region could reasonably be well defined, rainfall fluctuations within the seasons are less definable; statistical probabilities of droughts do not provide for prediction of the behaviour of the current crop season. On the other hand, crop production strategies selected on the basis of performance in the most droughty years might provide built-in safeguards for unforeseen low and/or fluctuating rains encountered during a crop season.

Sorghum popularly known as *Jowar* constitutes the major food crop of the semi-arid tropics almost wholly grown under rainfed conditions. Traditional sorghums grown in black soil areas of the Deccan and Central Indian plateaus are of 5–5½ month duration while the rainy season is of about 100–110 days duration commencing towards the later half of June and terminating before the end of September or middle of October in most parts.

During 1972–73, the long duration traditional sorghums suffered during flowering and thereafter. The *rabi* (October-February) sorghums, which grow and mature primarily on stored profile moisture, either could not be sown in time or failed to yield for want of adequate reserve soil moisture. However, the early maturing hybrids and high yielding varieties of sorghum of 95–110 days duration, as against 150-day locals, when planted in time, and well managed, gave satisfactory yields during *kharif*. Similarly an early maturing hybrid CSH-1, when planted earlier in *rabi* season under proper management, also returned very satisfactory yields. It appears, therefore, that years like 1972–73 need not create a scare for rainfed agriculture and a choice of suitable genotypes, together with appropriate management practices, could still return average yields several times higher than all-India averages which are presently very low for most rainfed crops. The purpose of this paper is to analyse the rainfall-yield relationships of some superior sorghum 'hybrids' and 'varieties' grown under good management, during 1972–73 *kharif* and *rabi* seasons with focus on the controllable and manageable part of the variation in yield so as to realise satisfactory agricultural yields in spite of rainfall fluctuations.

1972–73 KHARIF SEASON

Multiple regression analysis utilising: (1) total rainfall during the year, (2) the number of rainy days and (3) the coefficient of variation in the monthly rainfall at each of the locations, as auxiliary variates, was attempted to study the relationship between rainfall attributes and grain yields. The set of 29 locations, from which data were available provided a reasonably representative sample of the environments, in which the sorghum crop is being grown and will continue to be grown in the country. The regression analysis has been carried out separately, for each of the high yielding hybrids and varieties. In the case of hybrids and varieties, where regression coefficients associated with rainfall attributes were significant, the coefficients have been recalculated, after deleting the less important auxiliary variates. If the proportion of variation attributable to the rainfall characteristics is small, the capacity of the genotype to withstand drought will be greater.

The mean yields, the total rainfall, the number of rainy days and the coefficient of variation in the monthly rainfall are presented in Table I. The analysis of variance and the values of the regression coefficients are presented in Tables II and III, respectively.

The genotypes 302 and 604 among the varieties, and CSH-1, CSH-3 and CSH-5 among the hybrids seem to be less dependent on the vagaries of rain as compared with the rest of the varieties and hybrids, *Swarna*, CS-3541, CSH-2 and CSH-4. The contributions of the number of rainy days (x_2) and the coefficient of variation in the monthly rainfall (x_3) to the variation in the yield of sorghum is larger than that of total rainfall (x_1) as could be seen from the significant values of b_2 and/or b_3 in the case of *Swarna*, CS-3541, CSH-2 and CSH-4. In other words, the analysis suggests that yield of sorghum is influenced more by the number of rainy days and the distribution of monthly rainfall rather than the total rainfall. The negative values of b_3 or b_3' indicate that larger values of coefficients of variation adversely affect yields.

The percentage of variation, ascribable to rainfall attributes, is shown in Table IV. The amount of

TABLE I

Mean yields (kg/ha) of varieties and hybrids during 1972–73 kharif, *total rainfall, number of rainy days and coefficient of variation(%) in the monthly rainfall*

Sl. No.	Location	Varieties: Swarna	CS 3541	302	604	$S.E._m$ (kg/ha)	Hybrids: CSH-1	CSH-2	CSH-3	CSH-4	CSH-5	$S.E._m$ (kg/ha)	Total rainfall mm (x_1)	No. of rainy days (x_2)	c.v. (%) of monthly rainfall (x_3)
1	Parbhani	4592	30[illegible]3	6326	3322	239	5701	4163	4133	5550	5171	342	524·9	44	126
2	Jalgaon	3322	3032	3148	3811	353	2621	3040	3471	2994	3699	425	650·0	38	135
3	Karad	3179	3640	2635	2345	313	4316	4053	3662	4374	4233	309	367 8	55	152
4	Kolhapur	3356	3356	3761	4398	215	3868	5102	4115	3292	4444	446	439·4	63	147
5	Buldhana	2511	2751	3796	2426	398	3860	1853	3486	4008	4754	440	463·4	35	148
6	Nagpur	3329	3570	4398	3358	283	3309	2551	2990	3309	3022	262	546·4	54	147
7	Yeotmal	3655	3402	4349	2619	128	4862	2593	3521	4994	4860	308	699·1	59	129
8	Dharwar	4467	3378	3176	3880	397	6057	5400	5615	4995	6737	448	722·44	73	97
9	Bagalkot	1555	1540	1514	1808	168	2125	1052	773	2073	2335	185	491·5	40	113
10	Arbhavi	3543	3271	3938	3210	295	4230	4576	3934	4181	4675	326	429·2	32	99
11	Gangavati	5069	3102	5683	5752	420	5426	5426	6645	7346	6340	477	313·5	41	114
12	Rajendranagar	4485	4898	5142	3079	279	5023	2421	4107	4902	[illegible]185	445	419·9	36	102
13	Anantapur	674	75	447	1075	1151	1037	1057	800	810	706	157	557·3	37	138
14	Yemmiganur	3746	2439	3573	5576	331	7201	4688	5374	6574	9029	833	394·4	27	100
15	Navsari	4080	3358	3857	3065	266	4166	3663	4300	2650	5521	281	963·9	59	172
16	Surat	2095	2196	2111	1973	233	2200	2097	2353	2395	2727	226	791·7	35	173
17	Deesa	1828	818	1147	444	240	2104	1963	2629	2172	1622	239	366·0	18	205
18	Gwalior	1943	2978	2886	2587	259	4831	2264	3651	282	4624	426	864·0	31	234
19	Khargoan	1974	2110	1721	1936	265	1691	1535	1217	2547	2412	230	392·5	33	164
20	Chindwara	2731	3339	2951	243	309	3251	1284	2609	3539	3284	420	671·1	37	209
21	Indore	4492	3620	5021	3486	312	5860	5464	5788	5942	7144	383	679·(	52	216
22	Powerkheda	1594	2025	1661	2523	150	2942	2269	2592	2707	3109	245	908·4	44	226
23	Coimbatore	4010	3847	2551	5166	320	4736	5218	4792	4361	3347	408	962·0	48	127
24	Bhavanisagar	4525	3390	3760	3258	243	4816	5334	5405	4959	6219	300	1384·2	49	160
25	Tindivanam	1910	1426	973	957	202	2571	2278	2194	2998	2386	307	839·2	46	131
26	Pudukottai	4339	3753	4305	3108	160	5304	5147	5476	5500	5342	276	1014·0	58	102
27	Vallabhnagar	3330	2555	3879	2480	293	3018	2405	2416	2338	2778	352	311·8	27	166
28	Jhansi	2693	2372	2519	2694	212	2921	2158	1677	1252	3582	291	743·5	31	225
29	Kanpur	822	864	598	1478	144	2665	1456	2224	2050	2286	227	475·4	27	182
	Mean	3098	2765	3166	2830	130	3886	3224	3530	3710	4268	111	634 0	42·4	153·1

TABLE II

Regression analysis

Source	d.f.	Mean sum of squares — Varieties: Swarna	CS 3541	302	604	Hybrids: CSH-1	CSH-2	CHS-3	CSH-4	CSH-5
Regression	3	4568929*	2763627*	3619974 (NS)	4049214 (NS)	4327697 (NS)	8597944†	5772548 (NS)	64[illegible]1259*	5653567 (NS)
Deviation from regression	25	1106086	915198	2085786	1580066	1983491	1595692	1953846	2102004	3793649

* Significant at 5% level. † Significant at 1%. NS Not significant.

TABLE III

Regression coefficients

Regression coefficient	Varieties				Hybrids				
	Swarna	CS 3541	302	604	CSH-1	CSH-2	CSH-3	CSH-4	CSH-5
b_1	−0·51 (NS)	0·11 (NS)	−0·88 (NS)	0·05 (NS)	0·40 (NS)	0·72 (NS)	0·84 (NS)	−0·05 (NS)	0·50 (NS)
b_2	42·83*	57·91*	38·99 (NS)	22·73 (NS)	32·79 (NS)	53·17*	39·16 (NS)	28·73 (NS)	31·12 (NS)
b_3	−7·69 (NS)	−2·88 (NS)	−6·35 (NS)	−12·17 (NS)	−9·53 (NS)	−10·21 (NS)	−9·36 (NS)	−15·33*	−12·86 (NS)
b_2'	46 09†	41·31†	..	..	..	68·25†	..	..	..
b_3'	..	..	..	..	..	..	..	−18·02†	..

* Significant at 5% level. † Significant at 1% leavl. NS=Not significant.

Note: b_1, b_2 and b_3 represent the coefficients of regression associated with total rainfall. number of rainy days, and the coefficient of variation (c.v.%) in the monthly rainfall respectively.

b_2' Coefficient of regression associated with the number of rainy days after deletion of the total rainfall and coefficient of variation in the monthly rainfall.

b_3' Coefficient of regression associated with coefficient of variation in the monthly rainfall after deletion of total rainfall and number of rainy days.

TABLE IV

Percentage of variation accounted for by regression

Percentage of variation	Varieties				Hybrids				
	Swarna	CS 3541	302	604	CSH-1	CSH-2	CSH-3	CSH-4	CSH-5
With variables x_1, x_2 and x_3	33·1	26·0	17·2	23·5	20·7	39·3	26·2	26·9	15·2
With x_2 alone (after deleting x_1 and x_3)	23·8	25·4	..	..	..	32·9	..	..	..
With x_3 alone (after deleting x_1 and x_2)	..	..	..	..	..	..	..	22·2	..

Note: x_1=Total rainfall, x_2=Number of rainy days, x_3=The coefficient of variation in the monthly rainfall (c.v. %).

variation in yield ascribable to rainfall is mostly determined by the number of rainy days and/or the coefficient of variation in the monthly rainfall within the limits of rainfall received. What is more important is that in none of the cases studied, the variation ascribable to rainfall characteristics exceeds 40% of the total variation. This shows that still a large proportion of the total variation in yield, upto 85% over the locations, is attributable to causes other than fluctuations in rainfall as discussed later.

1972–73 RABI SEASON

In view of the low rainfall received during the early months of June, July and August and the anticipated low production of sorghum during *kharif* season, it was thought that possibilities of compensating for *kharif* losses may be explored in the *rabi* sorghum belt.

The low rainfall preceding the *rabi* season resulted in low levels of profile moisture which was apt to adversely influence the *rabi* production. Keeping this in mind a *rabi Jowar* production campaign based on the following principles was suggested: (1) Advancing dates of planting well into early September, without waiting for the traditional sowing dates in October so that the crop has a chance of getting some rain during early growth period; (2) Growing early maturing 100-day hybrids in place of 120–135 day locals; (3) All basal fertilization; (4) Full crop stands and (5) Seed treatment with a chemical, carbofuran, to prevent damage by sorghum shoot fly, a seedling pest. The whole programme was oriented towards earliness, so that the crop was raised during the period September–mid December instead of the traditional October–February.

A well directed programme of this type in one District of Andhra Pradesh, Khammam, over about 50,000 acres undertaken by the Department of Agriculture was an unqualified success. This was partly due to the somewhat favourable rains received during early crop growth period. While weather

TABLE V

Number of crop cutting experiments and mean grain yield in different Samithies of Khammam District, Andhra Pradesh—Rabi *1972–73*

S. No.	Samithi	No. of experiments conducted CSH-1	Local	Grain yield (kg/ha) CSH-1	Local	% over local
1.	Wyra	3	3	4490	1318	340
2.	Khammam	3	3	4983	2109	236
3.	Burgampad	2	..	4457	..	..
4.	Kothagudam	6	6	4915	1233	398
5.	Yellandu	5	4	2683	1297	207
6.	Bhadrachalam	1	1	4571	1186	385
7.	Tirumalayapalem	8	4	4235	1742	243
	Mean			4239	1477	287

analysis of this region is not available, yield data obtained by the Department of Agriculture from crop cutting experiments (Table V), speak for the efficacy of the programme.

Besides, there is considerable experimental evidence accumulated over years in the *rabi Jowar* belt, that advancing dates of planting, during *rabi* enables certain genotypes (varieties or hybrids) respond better to higher seed rates and all basal fertilization, thereby, providing insurance against drought and also result in much higher levels of production.

PLANNING FOR RAINFED AGRICULTURE

Rainfall analysis by itself does not provide for prediction about the behaviour of the immediate cropping season. On the other hand, analyses based on more successful experiments and profitable farmer experience during the worst years encountered is more positive and could provide for development of cropping plans which could be least risky if the rains are subnormal and highly profitable if rains are normal. The current analysis is an attempt in this direction.

Genotype alterations involving reduction of duration, reduction of total dry matter and its more efficient distribution between stalk and ear (economic product), adjustments in times of sowing, maintenance of optimum plant populations, use of fertilizer, plant protection measures and practice of suitable systems of cropping, ratooning, etc., all of which are in the realm of human control could enhance productivity levels and impart stability to production in rainfed agriculture. During 1972–73, sorghum yield levels in well managed experiments and with several farmers were of the order of 25–30 q/ha against the national average of 5 q/ha in normal years and near total failure during 1972–73.

A point of significance in planning for rainfed agriculture emerges here. Attempts at enhancing agricultural productivity do realise the role of environmental barriers and the need to transgress 'error' (environmental) limits. Yet, the targetted yield increases planned more particularly for rainfed agriculture are frequently within the limits of environmental error and do not provide for the much needed increments of a larger magnitude. A breakthrough in rainfed agriculture can, therefore, be expected only by planning for large quantum jumps rather than for slow and graded annual targets which are within the realm of environmental fluctuations. This approach may all the more be necessary, in the initial years since the present all-India averages for most rainfed crops are less than 500 kg/ha and the available know-how has the potential to elevate the national averages several fold.

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GENOTYPE-DENSITY-YIELD RELATIONSHIPS IN SORGHUM

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IT is generally known that plant density plays an important role in determining the yield of any crop per unit area. With a view to obtain rapid preliminary information on the response of sorghum genotypes, seventeen wide ranging densities from 36,000 plants/ha to 717,000 plants/ha were considered and an experiment was conducted during *khrif* 1971 with two varieties of sorghum *viz.*, *Swarna* and 148 and a hybrid CSH-1 in a 'Fan Design' suggested by Bleasdale (1967). The results of the experiment are presented in this paper.

MATERIALS AND METHODS

The details of the 'Fan' layout is provided in Fig. 1. Quadratic, reciprocal quadratic and Bleasdale's simplified equations were fitted to the data and the optimum density determined in each case so

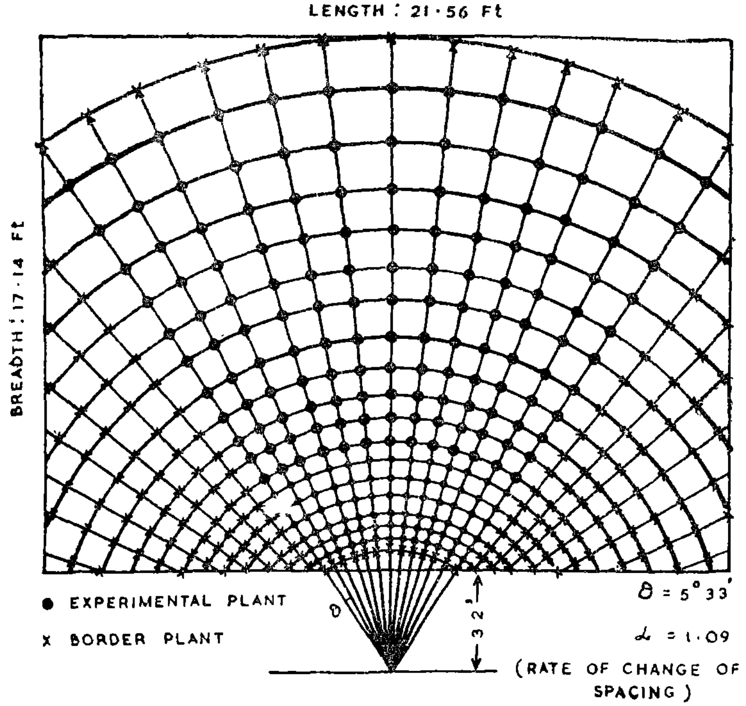

FIG. 1. Fan Design.

that the range of densities so obtained will serve as a guide-line for planning a regular experiment to determine not only the optimum density but also the optimum arrangement of plants in the field at a chosen density. Care was taken to see that fertilizer and moisture did not impose any limitations on yield by providing a uniformly high level of N, P and K and regular irrigation.

Results and Discussion

The data on plant density and the corresponding yield are given in Table 1. The yield of CSH-1 has gradually increased from 4,100 kg/ha to 12,620 kg/ha as density increased from 36,000 to 7,17,000 plants/ha. In the case of *Swarna* also, the yield has constantly increased from 3,420 kg/ha to 10,110 kg/ha with the increase of density from 36,000 to 7,17,000 plants/ha. The situation appears to be different in the case of variety 148 where the yield initially increased from 3,175 kg/ha to 7,380 kg/ha with the increase in density from 36,000 to 1,96,000 plants/ha, but has fallen considerably with further increase of density.

Table 1

Plant density and yield of sorghum

Plant density (10^5 plants/ha)	Yield (kg/ha)		
	CSH-1	Swarna	148
0·36	4100	3420	3175
0·44	4638	3750	3475
0·53	5141	4040	3875
0·63	5512	4450	4230
0·77	6021	4830	4780
0·92	6513	5150	5130
1·11	7215	5660	5730
1·34	7812	6070	6265
1·62	8360	6420	6770
1·96	8976	6840	7380
2·36	9440	7200	7360
2·84	9770	7620	7270
3·43	10701	8010	6860
4·13	11233	8330	6940
4·89	11340	8410	6260
5·98	11960	8790	5740
7·17	12620	10110	5730

The relationships fitted together with the optimum densities, maximum yields and the multiple correlation coefficients are presented in Table 2. The results indicate that there is not much to choose between the three types of yield density relationships fitted in as much as they provided equally high values of multiple correlation coefficients. The optimum densities suggested by the three

TABLE 2

Equations fitted, optimum densities, maximum yields and multiple correlation coefficients

CSH-1				SWARNA				VARIETY 148			
Equation fitted	Optimum density (10^5/pl ha)	Maximum yield (kg/ha)	R/r	Equation fitted	Optimum density (10^5 pl/ha)	Maximum yield (kg/ha)	R/r	Equation fitted	Optimum density (10^5 pl/ha)	Maximum yield (kg/ha)	R/r
$Y = 4{\cdot}04$ $0{\cdot}6719 -$ $0{\cdot}2205P^2$	6·06	12,134	R=0·981	$Y = 3{\cdot}52 +$ $1{\cdot}7233P -$ $0{\cdot}1265P^2$	6·81	9389	R=0·971	$Y = 3{\cdot}25 +$ $2{\cdot}1163P -$ $0{\cdot}2659P^2$	3·25	7460	R=0·881
$1/W = 0{\cdot}0065 +$ $0{\cdot}0083P -$ $0{\cdot}0002P^2$	*	—	R=0·985	$1/W = 0{\cdot}0064 +$ $0{\cdot}0126P -$ $0{\cdot}0005P^2$	*	—	R=0·961	$1/W = 0{\cdot}0079 +$ $0{\cdot}0083P +$ $0{\cdot}0012P^2$	2·56	6919	R=0·997
$1/\sqrt{W} = 0{\cdot}0981 +$ $0{\cdot}0216P$	4·54	10,860	r=0·984	$1/\sqrt{W} = 0{\cdot}1097 +$ $0{\cdot}0253P$	4·33	9012	r=0·980	$1/\sqrt{W} = 0{\cdot}0958 +$ $0{\cdot}0367P$	2·61	7112	r=0·998

R=multiple correlation coefficient; r=correlation coefficient; Y=yield (kg/ha); P=density (10^5 plants/ha); W=yield/plant (gm); *=optimum density does not exist in this case.

equations were, however, not as close as the coefficients of multiple correlation. In a situation like this, it would be difficult to arrive at a definite conclusion on the optimum density to be adopted. However, these preliminary results can be utilized advantageously for planning a regular experiment covering a range of densities including the different optimum densities indicated by the equations fitted in a manner that standard statistical tests of significance could be applied before deciding on not only the optimum density, but also the optimum arrangement of plants between and within the rows for a chosen level of desnity.

Although, at present, a plant density of not more than 2,00,000 plants/ha is being adopted generally, the results of this preliminary experiment indicate that the yield of sorghum could, perhaps, be increased significantly by increasing the plant population, at least to the level of 4,00,000 plants/ha. Although the data indicate possibilities of obtaining higher yields with still denser population levels, in actual practice this may be possible only under very favourable soil and weather conditions. The results in respect of the variety 148 indicating the optimum density between 2,60,000 to 3,90,000 plants/ha did not conform to

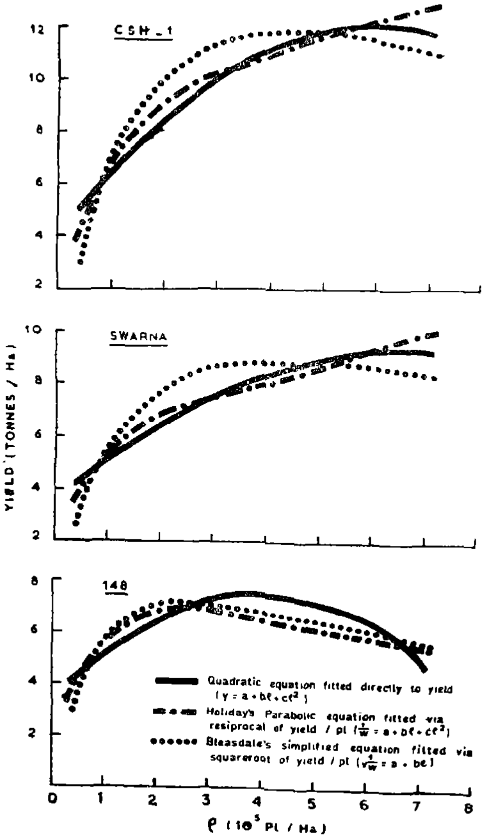

FIG. 2. Yield density relationships.

the pattern observed in the case of *Swarna* and CSH-1. This clearly establishes genotypic differences for density response. The variety 148 is a dwarf line derived from a cross between an Indian variety *Aispuri* and a dwarf exotic IS 3687. Unlike the elongated panicle types like CSH-1 and *Swarna*, it has a compact earhead and the compact headed types may have a ceiling in plant density beyond which the yields tend to fall. Fig. 2 provides a description of the different yield density relationships fitted.

Since the optimum density for a given crop is likely to be a function of factors such as the level of fertility, the availabe moisture in the soil, the amount of sunlight intercepted etc., future experiments of this nature will also need to consider the effect of variation in the growth factors on optimum density.

Although, the results obtained from the 'Fan Design' cannot be subjected to rigorous statistical tests of significance because of the inherent limitation owing to the lack of randomisation over the various densities under consideration, they still provide rapid preliminary information on the nature of yield density relationship at a very less expense.

Summary

With a view to obtain preliminary information on the genotype-yield-density relationships in sorghum an experiment was conducted in the 'Fan Design' suggested by Bleasdale (1967) with 17 densities varying from 36,000 to 7,17,000 plants/ha with two varieties of sorghum *viz.*, *Swarna* and 148 and a hybrid CSH-1. Three types of yield density relationships *viz.*, the quadratic, the reciprocal quadratic and the Bleasdale's simplified equation have been fitted. It has been found that the three equations are equally satisfactory in providing a good fit to the yield-density data. It has been concluded that a plant population of at least 4,00,000 plants/ha in the case of *Swarna* and CSH-1 may be desirable although a still denser population has been indicated by one of the equations fitted. In contrast with this, it appeared that a plant population of about 2,50,000 plants/ha may be enough to realise maximum yields in the case of the variety 148.

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CHANGING CONCEPTS AND PRACTICES OF CROPPING SYSTEMS

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GENOTYPIC changes, genotype-environment interactions and manipulation of cropping systems furnish opportunities for: (a) risk cover if rainfall is subnormal and greater profitability in case of normal weather; (b) biological fixation of nitrogen; (c) increased production of protein per hectare enabling upgradation of nutritional status of cereal diets and (d) greater efficiency in land use and agricultural productivity.

Intercropping Systems

Intercropping systems involve growing together two or more species with the assumption that two species could exploit the environment better than one. With particular reference to dryland agriculture, an intercropping system needs to be designed in such a way that in case of unfavourable weather at least one crop will survive to return economic yields thereby providing the necessary insurance against the unpredictable weather. In case the year happens to be normal with respect to rainfall, the intercropping system as a whole should prove to be more profitable than growing either of the crops.

If the two species grown together are mutually beneficial, there is co-operation. Competition exists when they tend to be mutually harmful and this competition is for water, light, nutrients and there is also interaction among two or more competing factors. These relationships, co-operation and competition are density dependent. At low densities there is co-operation, there is a point of neutral relationship and active competition comes into play as density increases. Competitive ability is inherited but yield and compatibility could be independent.

With these basic principles, the design and development of an intercropping system in drylands offers the following alternatives: choice of crops, choice of type within a crop and choice of planting arrangements.

Choice of crops and varieties

Depending upon the area of operation, a choice of crops amongst cereals, oilseeds, pulses, etc, could be made. In particularly drought-prone areas, crops like castor and pigeon-pea with a perennial tendency and different developmental rhythms offer greater risk cover. Cereal-legume, oilseed-legume, cereal-oilseed combinations, combinations of shallow and deep-rooted crops, etc., could be chosen. Intercropping system could also be conceived for nutritional upgradation of human and cattle feed rations of dryland areas.

Plant types of different heights, maturities, canopy growth habits, growth rates, etc, are available in most crop species and could be chosen depending upon the requirement of the system. In fact, crop ideotypes suitable for a system of crops could be bred.

In the present studies, dwarf erect-leaved sorghum like 'Swarna' has definite advantages for intercropping as against the traditional tall and late sorghums. Similarly, in pigeon-pea 'Hy-3A' with no basal branching and concentrated heavy terminal bearing exhibited decided genotypic advantages over traditional branching types like Type 21. In case of castor, genotypes like '157-B' with a dwarf habit and converging branches and '413A' with erect petioles and long spikes are amenable for intercropping while the traditional tall types are almost ruled out. In soybean, the short-duration determinate types have decided advantages over long-duration indeterminate types.

The competitive effects of one crop on the other (Table 1) provide opportunities for selection of least competing crops for inclusion in the systems.

Genotype-density interactions

Using systematic designs, the genotype density interactions of sorghum, castor and groundnut have been studied. It was seen that dwarf genotypes like 'Swarna' and 'CSH-1' in case of sorghum, '157-B' in case of castor are more amenable for density manipulations unlike traditional tall types.

Choice of planting patterns

Several alternative planting patterns are feasible. Data on the paired versus uniform planting system indicate that pairing had some advantage in some cases (Table 2).

In case of crops where pairing of rows has an advantage, the space between pairs could be utilised for an additional crop. Several alternative planting patterns combined with suitable population densities could also be conceived.

Some economic intercropping systems

Experiments on the development of efficient intercropping systems based on combinations of cereal (sorghum), pulse (pigeon-pea, soybean) and oilseed

TABLE 1. COMPETITIVE EFFECTS OF VARIOUS INTERCROPS ON THE YIELD (kg/ha) OF THE MAIN SORGHUM AND GROUNDNUT CROP

Intercrops	*Yield of main crop*	*Percentage of main crop yield with intercrops*
	Sorghum as main crop	
Kharif 1971		
Soybean (Bragg)	4078	88.0
Groundnut (TMV-2)	3610	78.0
Pigeon-pea (T-21)	2674	57.7
Castor (224)	2654	57.3
Sunflower (Sunrise)	1049	22.6
Sorghum Pure crop	4631	100.00
Kharif 1973		
Soybean (EC 2587)	7318	96.6
Groundnut (TMV-2)	6975	92.1
Pigeon-pea (Hy-3A)	6846	90.4
Sorghum Pure crop	7571	100.0
	Groundnut as main crop	
Summer 1972		
Soybean (Bragg)	2640	82.5
Sorghum (Swarna)	1070	33.4
Sunflower (EC 68414)	1075	33.6
Castor (413-A)	1540	48.1
Groundnut Pure crop	3200	100.0
Kharif 1973		
Soybean (EC 2587)	1556	89.9
Sorghum (302)	867	50.1
Castor (413-A)	1333	77.0
Pigeon-pea (Hy-3A)	1645	95.0
Groundnut Pure crop	1731	100.0
	Castor as main crop	
Kharif 1973		
Soybean (EC 2587)	815	82.7
Groundnut (TMV-2)	944	95.8
Sorghum (302)	710	72.1
Pigeon-pea (Hy-3A)	1161	117.9
Castor Pure crop	985	100.0

TABLE 2. GRAIN YIELDS (q/ha) IN UNIFORM *VS* PAIRED ROW PLANTINGS

Crop	*Uniform*	*Paired row*
Sorghum**	44.7	47.9
Groundnut*	21.7	24.6
Castor	13.2	9.8

*Mean of three locations and three seasons

**Mean of two seasons

(castor and groundnut) were carried out to study their total productivity, economic profitability and nutritional efficiency. Appropriate genotypes with low competitive effects were chosen for every crop.

(a) Sorghum as Main Crop. In experiments with sorghum as a main crop, the plant density of sorghum was 1,48,000 plants/ha with a row spacing of 45 cm and hill spacing of 15 cm for the uniform row treatments. In the paired row planting treatments, the spacing within a paired row of sorghum was 30 cm and that between the two paired rows was 60 cm. Data on grain yields of sorghum and the intercrops, along with the economics and nutritional efficiency of the intercropping systems are presented in Table 3.

During both 1971 and 1973 seasons, sorghum yields in the paired row plantings were found to be on a par with those in uniform row plantings. The reduction in yields of sorghum was not significant when it was intercropped with soybean, groundnut and pigeon-pea. Compared with a normal-sown pure sorghum crop, its intercropping with soybean raised the total grain production up to 26 per cent followed by intercropping with groundnut and pigeon-pea. Higher economic returns were obtained in sorghum+soybean and sorghum+pigeon-pea intercropping systems.

From nutritional view point also, estimated data on total protein yield obtained from these systems showed a favourable trend as against growing a pure sorghum crop. Cereal-legume mixtures contain proteins of superior nutritive value as they mutually supplement the deficient amino acids as compared with those of either cereal or legume proteins. Intercropping of sorghum with soybean, groundnut and pigeon-pea resulted in the increase of lysine yield up to 219, 77 and 76 per cent respectively.

Thus, from economic as well as nutritional aspects, sorghum-soybean, sorghum-pigeon-pea and sorghum-groundnut intercropping systems were found to be highly profitable.

(b) Groundnut as Main Crop. In the experiments with groundnut as a main crop, the plant density of groundnut was 2,22,200 plants/ha with a spacing of 30 cm between rows and 15 cm between hills for uniform row treatments. In the paired row treatments, the spacing within a paired row groundnut was 15 cm, whereas that between the two paired rows was 45 cm. Data on the yield of groundnut and the intercrops along with the economics and nutritional efficiency of the intercropping systems are presented in Table 4.

Pod yields of groundnut in the paired row planting pattern were on par with those obtained with uniform row planting. Though soybean and pigeon-pea did not reduce the pod yield to a significant extent, there was a significant yield reduction of groundnut by sorghum. However, due to high sorghum yields obtained, the loss in the groundnut yield was compensated

Systems	Yield (kg/ha)			Returns* (Rs/ha)		Estimated yield of total proteins (kg/ha)	Estimated yield of lysine (kg/ha)
	Sorghum	Intercrop	Total	Total income	Net profit		
Kharif, 1971							
(1) Sorghum Pure (148)	4123	—	4123	3532	2132	410	9 75
(2) Sorghum Paired Row	4189	—	4189	3578	2178	420	10 05
(3) Sorghum 'PR' + Pigeon-pea (T-21)	3440	430	3870	3482	1760	439	14 25
(4) Sorghum 'PR' + Groundnut (TMV-2)	4454	430	4884	4160	2395	561	14 70
(5) Sorghum 'PR' + Soybean (Bragg)	4454	761	5215	4702	3102	772	31 12
Kharif 1973							
(1) Sorghum Pure (302)	6772	—	6772	6772	5698	677	16 20
(2) Sorghum Paired Row	7571	—	7571	7571	6545	757	18.15
(3) Sorghum 'PR' + Pigeon-pea (Hy-3A)	6846	875	7721	8421	7121	876	28.75
(4) Sorghum 'PR' + Groundnut (TMV-2)	6975	182	7157	7521	6068	749	18.45
(5) Sorghum 'PR' + Soybean (EC 2587)	7318	407	7725	7806	6622	907	28.57

* Based on prevailing prices in respective seasons
PR = Paired row

TABLE 4. GROUNDNUT—ECONOMICS OF INTERCROPPING

Systems	Yield (kg/ha)			*Returns (Rs/ha)		Yield of total protein (kg/ha)	Yield of lysine (kg/ha)
	Groundnut	Intercrop	Total	Total income	Net profit		
Summer 1972							
(1) Groundnut Pure (TMV-2)	3000	—	3000	2400	1316	810	29 02
(2) Groundnut Paired rows	3200	—	3200	2560	1490	864	31.05
(3) Groundnut 'PR' + Soybean (Bragg)	2640	750	3390	3012	1682	1035	45.73
(4) Groundnut 'PR' + Sorghum (Swarna)	1070	6263	7333	5714	4161	915	25.35
Kharif 1973							
(1) Groundnut Pure (TMV-2)	1355	—	1355	4065	2510	359	12.82
(2) Groundnut Paired rows	1731	—	1731	5193	3650	467	16.87
(3) Groundnut 'PR' + Soybean (EC 2587)	1555	660	2216	5460	3712	714	33.23
(4) Groundnut 'PR' + Sorghum (302)	867	5102	5969	7703	5797	734	20.40
(5) Groundnut 'PR' + Pigeon-pea (Hy-3A)	1645	1530	3175	7689	5797	780	37.57

* Based on prevailing prices in respective seasons
'PR' = Paired row

resulting in highest total production in the system. Groundnut-sorghum and grondnut-pigeon-pea systems registered an increase of 340 and 144 per cent, respectively in total grain production over that from a pure groundnut crop. Similarly, highest net profits were obtained in these two systems. Groundnut pigeon-pea system was found to be superior in total protein yield quantitatively as well as in protein quality (lysine

TABLE 5. CASTOR—ECONOMICS OF INTERCROPPING (*KHARIF* 1975)

Systems	*Yield (kg/ha)*			*Returns (Rs/ha)**	
	Castor	*Intercrop*	*Total*	*Total income*	*Net profit*
(1) Castor Pure (413-A)	1327	—	1327	3317	2017
(2) Castor/Groundnut (TMV-2) (3:1 ratio)	1154	503	1657	4394	279.
(3) Castor Sorghum (302) (3.1 ratio)	750	2765	3515	4840	2990
(4) Castor/Pigeon-pea (Hy-3A) (3:1 ratio)	1213	435	1648	3815	2415

* Based on prevailing prices in the season

yield), followed by groundnut-soybean intercropping system. Thus, the efficient intercropping systems for groundnut were identified as groundnut-sorghum, groundnut-pigeon-pea and groundnut-soybean systems.

(c) Castor as Main Crop. In the experiments with castor as a main crop, the plant density of castor was 55,500 plants/ha. Growing castor and intercrops in alternate strips in a 3:1 ratio was found to yield more economic returns than growing it in a paired row planting pattern. Data on the yield of castor and the intercrops along with the economics of the intercropping systems are presented in Table 5.

Intercropping of castor with pigeon-pea did not reduce the castor yields to a significant extent as compared to its intercropping with sorghum. However, the high yields obtained with sorghum compensated the loss in castor yields resulting in higher total productivity. Thus, castor-sorghum system as a whole was found to yield high economic returns followed by castor-pigeon-pea intercropping system.

Some of the profitable intercropping systems for drylands were found to be—(1) Sorghum-soybean, (2) Sorghum-pigeon-pea, (3) Sorghum-groundnut, (4) Groundnut-sorghum, (5) Groundnut-pigeon-pea, (6) Groundnut-soybean, (7) Castor-sorghum, and (8) Castor-pigeon-pea.

In each system, appropriate crop ideotypes have been used. Computation of economics, total proteins produced per hectare together with an analysis of the amino acid balance, the advantages of nitrogen fixation when legumes are used in such systems, or the greater risk cover in sub-normal years and greater profitability under normal conditions—all favour the practice of such intercropping systems. It is, however, necessary to view these systems differently from traditional mixed cropping systems where a certain proportion of one crop is mixed with a certain proportion of other frequently, amounting to growing two crops in respective strips. The significant point in the present systems is that suitable genotypes are chosen, the population of the main crop is not sacrificed and its yields do not suffer when compared with pure stands and the yields of intercrop are always a bonus.

Ratooning/Relay/Multiple Cropping Systems

The advent of early hybrids and varieties of sorghum could be taken advantage of to considerably enhance land productivity. The predominently black soil belt of sorghum sustains traditional 5-6 month tall varieties. The substitution of a 3-month hybrid or variety ensures assured yields under sub-normal rains and in case of adequate rainfall a ratoon or a second crop like safflower, chick pea, etc., are feasible. The conversion of the sorghum tract to a single maturity also eliminates insect problems like midge besides enhancing productivity.

Ratooning. Where one or two protective irrigations are possible or where soil moisture conditions permit as some black soil areas where monsoon extends into October, hybrids and high-yielding varieties of sorghum could be successfully ratooned. When the sorghum crop is cut to the base and 2-3 healthy tillers are permitted to mature under good management, the ratoon yields are as good and sometimes better than the main crop. The ratoon matures about 15 days earlier than the plant crop and there is saving in cultivation costs.

Sorghum-Safflower/Sorghum-Chick-pea. The 100-day sorghum hybrids or varieties ripen towards the end of September or early October. As soon as a shower is received during this stage, safflower could be hand-dibbled in between standing sorghum rows. After the harvest of the sorghum crop, the safflower picks up and the yields are satisfactory. Such opportunities exist in long-duration sorghum tracts of Kotah division of Rajasthan, Indore and Bhopal division and other heavy black soil districts of Madhya Pradesh, the kharif black soil belt of Maharashtra and parts of Andhra Pradesh and Karnataka.

Similarly, oppo[illegible]unities for planting chick-pea crop after harvest of so[illegible]um also exist in this black soil belt and enables two crops where normally a single long-duration sorghum is taken.

Groundnut/Safflower. Groundnut has been rather risky during kharif in black soils. Yet this is practised in several states. In one of the studies, groundnut rows have been paired and full seed rate of groundnut

CONTINUED ON PAGE 15

The grain yield data of paddy at 14 per cent moisture have been given in Table 1 and have also been shown in the histogram.

TABLE 1. GRAIN YIELD OF PADDY (q/ha)

Treatments	N_0	N_{40}	N_{80}	N_{120}	Mean
Fallow	26.4	38.6	55.6	60.1	45 2
Green manuring	56.4	63.1	73.0	77.1	67 4
Mean	41.4	50.9	64.3	68 6	
Average response q/ha	—	9.5	22 9	27 2	
Kg grains per kg N		23.7	28 6	22.7	

C.D. at 5%—Fallow v/s G.M.=3 9, Nitrogen=5 5 q/ha

Without nitrogen application, green manuring gave higher paddy yield by 30 q/ha than that after fallow giving 26·4 q/ha. Nitrogen response was found significant up to 80 kg/ha. On an average, application of 40, 80 and 120 kg N/ha increased the yield over control by 9·5, 22·9 and 27·2 q/ha, each kilogramme of nitrogen producing 23·7, 28·6 and 22·7 kilogramme additional grains, respectively. Paddy yields after green manuring without nitrogen (56.4 q/ha) and at lower dose of 40 kg N/ha (63·1 q/ha) were found slightly higher than after fallow even with higher doses of 80 kg N (55·6 q/ha) and 120 kg N/ha (60.1 q/ha), respectively. The study indicates that the effect of *dhaincha* green manuring on paddy was equal to 80 kg applied nitrogen after fallow. A lot of economy in the use of fertilizers can be effected by practising green manuring.

CONTINUED FROM PAGE 7

CROPPING PRACTICES

was used. In between pairs, a short-duration soybean has been grown since soybean does not compete very much with groundnut. After harvest of soybean, safflower was dibbled in place of soybean while groundnut was still standing. After harvest of groundnut, safflower grew faster thereby adding an additional crop. Such a system is both an insurance against possible groundnut failures and provides additional income if the year is normal.

Opportunities for increased land use through various cropping systems are under assessment in the black soil sorghum tract under the All-India Co-ordinated Sorghum Improvement Project and at the IARI Regional Research Station, Hyderabad.

CSV-3 (370), a high-yielding sorghum variety

SORGHUM PRODUCTION PROGRAMME

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AMONGST food crops grown under rainfed conditions, sorghum occupies the largest area, 18 million hectares, which is more than the total area under wheat in the country. This fact merits serious consideration in the formulation and implementation of production programmes aimed at increasing the overall food production in the country. Opportunities for enhancing sorghum production illustrate possibilities for elevating agricultural yields in rainfed areas which constitute 70 per cent of India's cultivated area.

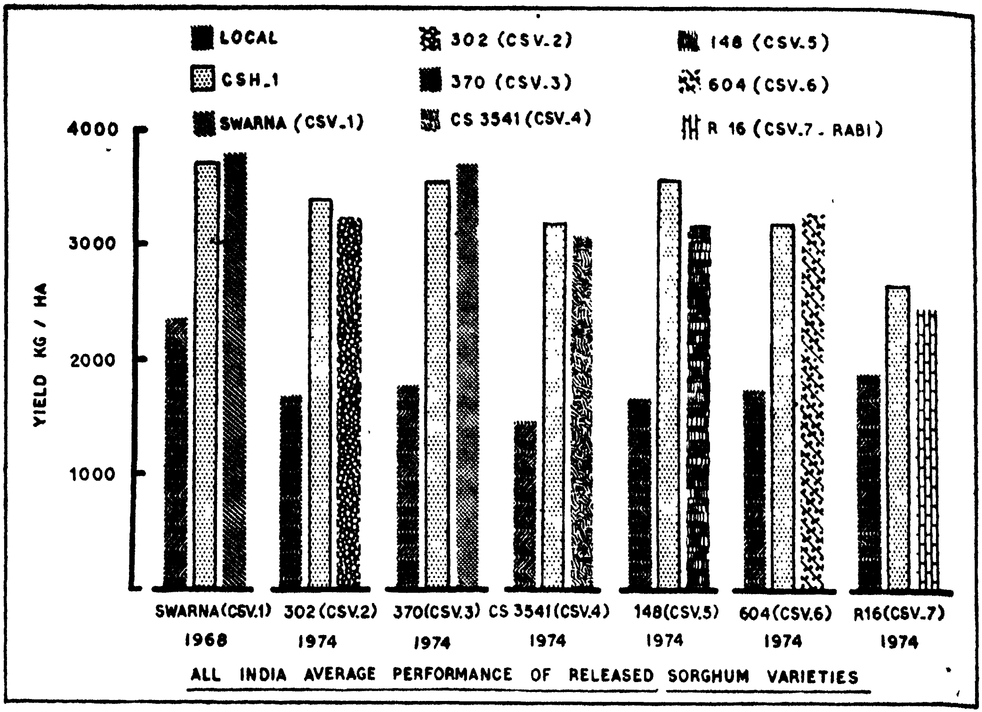
Fluctuations in coarse grain production continue to have an adverse influence on overall food position. It has been very well established that in years of normal as well as subnormal rainfall, a varietal change with moderate inputs can result in yield levels of 25 to 30 quintals of sorghum grain per hectare. In fact, non-monetary inputs including the variety, the seed costs of which are small and management practices coupled with judicious use of monetary inputs like fertilizer and pesticides could accomplish this objective.

Rainfall Fluctuations and Crop Yields

In recent years, there has been growing interest in possible weather changes and their influence on agricultural yields. While the limits of the rainy season in a given region could be well defined, rainfall fluctuations within the season are less predictable. In traditional rainfed agriculture the crop-growing period far exceeds the rainy season rendering such long-duration crops and varieties particularly vulnerable in years of subnormal rainfall.

Sorghums in India are almost wholly grown as rainfed crops and their yields depend on monsoon fluctuations. The prevalence of tall and long-duration varieties which tend to expend most of their energy in the production of vegetative matter coupled with the almost total absence of fertilizer application and the tradition of growing sorghums under low populations render them low yielders even in normal years and uncertain yielders in abnormal years.

Kharif. In years of low and erratic rains, as experienced during 1972-73 over the major sorghum belt, grain yields of the new hybrids and varieties during the **kharif** season have been of the order of 25 to 30 q/ha against the spectre of near total failure of late locals. Based on yield data of 1972-73 from 29 locations all over the country, an



analysis of the various factors influencing yield reveal that not more than 30 per cent of the total variation in yield appears to be vulnerable to the rainfall fluctuations while the remaining 70 per cent is controllable through the use of suitable hybrids and varieties, optimal levels of fertilization, maintenance of plant populations, timely sowing, management and minimum of plant protection measures.

Rabi. During the rabi season of 1972-73 characterized by low profile moisture resulting from scanty rainfall during kharif organized programmes based on early maturing hybrids, advanced dates of planting and all basal application of fertilizer brought out the potentialities of stabilizing rabi yields at satisfactory levels of 20 to 40 q/ha (Table 1).

The physiological efficiency of the new hybrids and varieties when grown in different seasons as reflected by the distribution of dry matter between ear and stalk speaks for their advantages over traditional varieties in which 70 per cent of the total dry matter gets accumulated in the stalk. Majority of the new varieties have more than 50 per cent of the dry matter accumulated in the ear. During rabi which represents a relatively greater stress environment, the total dry matter produced by hybrids is low when compared with kharif, but more than half of it gets accumulated in the ear. The moisture utilization by hybrids during rabi is, therefore, more efficient.

Thus the climatic vulnerability of the traditional late-maturing varieties and the advantages of relatively early maturing hybrids and varieties in normal as well as abnormal years has been well borne out by our experience. The consistency of performance of the new hybrids and varieties with a production potential of 20 to 30 q/ha even in unfavourable years and 40 to 60 in favourable years on experimental fields as well as vast stretches of farmers' holdings has been well documented. There is no place or justification for 150-165 day varieties which still predominate in most parts of the country. The only way to elevate and stabilize grain sorghum production under inevitable and inescapable climatic fluctuations is by replacing the traditional locals with the new hybrids, varieties and management practices. Genotype alterations involving reduction of duration, reduction of total dry matter and its more efficient distribution between stalk and ear (economic product), adjustments in times of sowing, maintenance of optimum plant populations, use of fertilizer, plant protection measures and practice of suitable systems of cropping, ratooning, etc., all of which are in the realm of human control could enhance productivity levels and impart stability to production in rainfed agriculture. During 1972-73 sorghum yield levels in well managed experiments and with several farmers were of the order of 25 to 30 q/ha against the national average of 5 q/ha in normal years and near total failure during 1972-73. In fact, we are better prepared to face a drought than a late wet season.

High-yielding Hybrids and Varieties

Current farmer demands for an early hybrid like CSH-1 in preference to late locals to escape drought as well as damage due to midge should be taken cognizance of and capitalized upon to elevate and stabilize sorghum production. Two hybrids CSH-1 and CSH-4 are presently cultivated on a fairly large scale during kharif. The new hybrids, CSH-5 and CSH-6 (2219A×CS 3541) offer considerable promise for kharif season and hybrid seed production is catching up. For the rabi season, besides CSH-1 and CSH-4, the experimental hybrids 36A×148 and 36A×PD 3-1-11 exhibited considerable promise. They have now been recommended for pre-release multiplication.

Hybrid seed production needs certain skills and it is a repetitive process since the farmer has to renew the seed each year. In view of the vast area to be covered, emphasis has been laid on the development of high-yielding varieties whose multiplication rate is rapid and the seed could be used over years taking adequate care to maintain purity standards. Seven such varieties with yield levels comparable to hybrids have been developed and six of them CSV-2 (302/303), CSV-3 (370), CSV-4 (CS 3541), CSV-5 (148/168), CSV-6 (604) and CSV-7R (R-16) were released only during last year, that is 1974. 'Swarna' (CSV-1) was released during 1968. These high-yielding varieties have the added advantages of low seed cost, rapid and easy seed multiplicity both during the season as well as in off-season. There is also scope for natural spread.

Suitable hybrids and varieties for different states are presented in Table 2. They have the potential to yield 25 to 30 quintals/ha under average growing conditions and 50 to 60 q/ha under better management.

Present efforts are aimed at incorporating greater levels of pest and disease tolerance and greater response to fertilizers so that production levels are stable even under low levels of management generally encountered with dryland crops.

Varietal Spread: Maturity Orientation and enblock Transformation. The diffused spread of new varieties tends to enhance shoot fly attack on new varieties and increased midge incidence on locals particularly during the kharif season. Distributing hybrids and varieties of approximately same maturity in consolidated blocks could almost eliminate or minimise the pest damage. A total varietal transformation based on diversity within a maturity group should be the first step over which further improvements could be built up.

Presently available varietal diversity in relation to maturity groups for the kharif season is given in Table 3. All the hybrids and varieties classified as early and flowering in 58 to 70 days could be treated as one maturity group.

All hybrids and the varieties CSV-5 (148/168), CSV-4 (CS 3541) are resistant to downy mildew; CSV-6 (604), CSV-5 (148/168) and 329 to shoot fly and CSV-5 (148-168) to most leaf spots and striga. In the transition zone of Karnataka and Maharashtra States, and parts of Tamil Nadu downy-mildew-susceptible varieties like CSV-2 (302-303) and CSV-6 (601) should be avoided.

Components of Production

Time of Sowing. Sowing with the onset of monsoon during kharif eliminates shoot fly attack and returns high yields. This involves no money but continuous education to the farmers and propagation by extension agencies.

Plant Population. Unlike locals, about 1,80,000 to 2,00,000 plants per hectare are essential if we are to realise the full potential of high-yielding varieties and hybrids and this could be accomplished by using a seed rate of 10 to 12 kg/ha. Seed costs are relatively low and in case of varieties they could be much lower. A plant at every 4" to 6" in rows spaced 18" apart is essential.

Fertilizer Use. In addition to use of compost and farm-yard manure, 30 to 40 kg N and 30 to 40 kg P_2O_5 per hectare in the form of inorganic fertilizers to the high-yielding varieties would return per kg of nitrogen three times more grain yield than locals. In black soils all nitrogen and P_2O_5 could be applied basally whereas in light-textured soils, nitrogen should be given in two doses, half basal and the other half at 30 to 40 days after sowing. Applying available fertilizer to high-yielding varieties in itself results in efficiency of fertilizer use. Nitrogen responses are optimum up to 80 to 100 kg N/ per hectare and should be applied when fertilizer supplies are not limiting.

Pest Avoidance and Pest Control. Most sorghum pests can be avoided. Planting with the onset of monsoon avoids shoot fly. Enblock coverages and varietal choice of similar maturing types would avoid midge. Both these aspects need only education and changes in the emphasis of extension efforts. If planting is necessary during shoot fly build-up seed treatment with carbofuran 5 parts (A.I.) for 100 parts of seed gives effective control.

Stem borer damage can be checked by one or two applications of granules of 4 per cent endosulfan, 4 per cent carbaryl or 2 per cent lindane in the whorls.

Midge is effectively controlled by spraying earheads before flowering (at about 50 per cent panicle emergence) with endosulfan (35 per cent EC) one litre, carbaryl (50 per cent WP) 3 kg, lindane (20 per cent EC) 1 to 2 litres in 500 to 600 litres of water per hectare. Repetition of the spray after 4-8 days is desirable. Four per cent endosulfan dust or 10 per cent carbaryl dust or 10 per cent BHC dust at 20 kg/ha is also effective. Two applications will be necessary as in the case of sprays.

Pre-emergence application of Atrazine 0.5 kg (AI.)/ha followed by a late weeding controls weeds.

Production during Rabi

The rabi jowar yields are generally lower compared to kharif. Since most rabi jowars depend on residual soil moisture and practically no rains are received during crop growth, their yields are a function of kharif rains and in years when late monsoon rains fail, rabi yields tend to get further reduced.

As stated earlier, during 1972-'73 rabi season, an earliness oriented crash programme based on early-maturing hybrids, advancing dates of planting by about 20 to 30 days, all basal fertilisation and carbofuran seed treatment paid adequate dividends in the district of Khammam in Andhra Pradesh and compensated for most of the losses in sorghum production suffered in other districts of the state. These principles have large applicational value for the single-cropped rabi tracts.

The dominant rabi jowar variety M.35-1 does not respond very much to advanced dates of planting whereas the hybrids and CSV-7R (R-16) exhibited superiority over M.-35-1. If kharif rains are low resulting in low profile moisture content, switching to hybrids like CSH-2 and CSH-3 which flower in 55 to 58 days in rabi could avoid total losses and return satisfactory yields. CSV-7R (R-16) is desirable only under advanced planting since in some of the charcoal rot endemic areas this disease occurred under stress. The experimental hybrid 36A × 148/168 besides being tolerant to shoot fly does not lodge even under conditions when heavy soils develop cracks.

Rabi production programmes should, therefore, lay emphasis on choice of varieties as well as management. Introduction hybrids in rabi could confer stability to production. A rabi production programme should, therefore, stress on:

(a) Advancing dates of planting by at least 20 to 30 days in all single-cropped rabi areas.

(b) Choice of CSV-7R (R-16), CSH-1, CSH-4 or 36A × 148/168 and 36A × PD 3-1-11 under advanced dates of planting and choice of CSH-2 or CSH-3 when profile moisture is very low at the time of planting. A shift to hybrids during rabi is generally advantageous.

(c) A seed rate of 10 kg/ha to furnish full stands.

(d) Carbofuran seed treatment.

(e) All basal fertilization (40-50 kg N and 40 to 50 kg P_2O_5/ha)

Sequence cropping of sorghum followed by safflower under rainfed conditions

Intercropping

In intercropping studies with sorghum as main crop the plant density of sorghum was 1,48,000 plants/ha with a row spacing of 45 cm and hill spacing of 15 cm for the uniform row treatments. In the paired row plantings, the spacing within a paired row of sorghum was 30 cm and that between the two paired rows was 50 cm.

During 1971 and 1973 seasons, sorghum yields in the paired row plantings were found to be on par with those in uniform row plantings. The reduction in the yields of sorghum was not significant when it was intercropped with soybean, groundnut and pigeonpea. Compared to a normal-sown pure sorghum crop, its intercropping with soybean raised the total grain production by 26 per cent followed by intercropping with groundnut and pigeonpea. Higher economic returns were obtained in sorghum+soybean and sorghum+pigeonpea intercropping systems.

From nutritional view point also, estimated data on total protein yields obtained from these systems showed a favourable trend as against growing a pure sorghum crop. Cereal-legume mixtures contain proteins of superior nutritive value as they mutually supplement the deficient amino-acids as compared to those of either cereal or legume proteins. Intercropping of sorghum with soybean, groundnut and pigeonpea resulted in he increase of lysine yields up to 219, 77 and 76 per cent, respectively.

Thus, from economic as well as nutritional aspects, sorghum-soybean, sorghum-pigeonpea and sorghum-groundnut intercropping systems were found to be highly profitable.

Ratooning/Relay/Multiple Cropping

The advent of early hybrids and varieties of sorghum could be taken advantage of to considerably enhance land productivity. The predominantly black soil belt of sorghum sustains traditional 5-6 month tall varieties. The susbstitution of a 3-month hybrid or variety ensures assured yields under subnormal rains and in case of adequate rainfall a ratoon or a second crop like safflower, chickpea, etc., is feasible. The conversion of the sorghum tract to a single maturity also eliminates insect problems like midge besides enhancing productivity.

Ratooning. If one or two protective irrigations are possible or under adequate soil moisture conditions as in some black soil areas where monsoon extends into October, hybrids and high-yielding varieties of sorghum could be successfully ratooned. When the sorghum crop is cut to the base and 2-3 healthy tillers are permitted to mature under good management, the ratoon yields have been as good and sometimes better than the main crop. The ratoon matures about 15 days earlier than the plant crop and there is saving in cultivation costs.

Sorghum-Safflower/Sorghum-Chickpea The 100-day sorghum hybrids or varieties ripen towards end of September or early October. As soon as a shower is received during this stage, safflower could be hand-dibbled in between standing sorghum rows are planted immediately after harvest of sorghum crop. After the harvest of the sorghum crop, the safflower picks up and the yields are satisfactory. The essential precaution to be taken in relay planting is that after safflower is planted in a standing crop, sorghum should not be allowed to stand in the field for more than a week. Otherwise, safflower will rush to elongation stage without the rosette stage and if this happens safflower fails.

Similarly opportunities for planting chickpea crop after harvest of sorghum also exist in this black soil belt and enables two crops where normally a single long-duration sorghum is taken.

Such opportunities exist in long-duration sorghum tracts of Kotah division of Rajasthan, Indore and Bhopal divisions, and other heavy black soil districts of Madhya Pradesh, the kharif black soil belt of Maharashtra, parts of Andhra Pradesh and Karnataka. An estimated 4 million hectares out of 18 million hectares under sorghum is potential double crop area under normal rainfall and economic returns are assured for a single crop in years of subnormal rainfall.

Off-season Seed Multiplication

The recent availability of equally high-yielding varieties comparable to commercial hybrids in yield levels enables rapid seed multiplication.

TABLE 1. RAINFALL FLUCTUATIONS AND SORGHUM YIELDS, RABI 1972-73

Sl. No.	*Samithi*	*No. of experiments conducted*		*Grain yield (kg/ha)*		*per cent over local*
		CSH-1	*Local*	*CSH-1*	*Local*	
1.	Wyra	3	3	4490	1318	340
2.	Khammam	3	3	4983	2109	236
3.	Burgampad	2	—	4457	—	—
4.	Kothagudem	6	6	4915	1233	398
5.	Yellandu	5	4	2683	1297	207
6.	Bhadrachalam	1	1	4386	2051	214
7.	Tirumalayapalem	8	4	4235	1742	243
	Mean			4239	1477	287

Courtesy: Andhra Pradesh Department of Agriculture

Since seed of most of the recommended varieties has been generated in all states, a procurement drive in kharif followed by further multiplication during January planting under irrigation could provide seed to cover at least 70 to 80 per cent of the jowar area in the respective states. Planning for summer seed production in a matter of 2 to 3 years should form an important item of seed programmes.

Production Programmes

Sorghum production programmes during kharif and rabi seasons should, therefore, emphasise on:

(1) Management inputs like time of planting, optimal plant populations coupled with a policy of enblock coverage with varieties and hybrids of approximately similar maturity periods and confining the use of available fertilizers to high-yielding hybrids and varieties only.

(2) Generating adequate quantities of seed of new varieties and hybrids during kharif and off-season (January plantings under irrigation) to cover at least 70 to 80 per cent of the area under jowar in the respective states over a 2 to 3 years period. If kharif harvested seed is used, its germinability should be assured particularly if it happens to be caught in rains at harvest.

(3) Practice of ratooning or multiple and relay cropping systems in areas of retentive black soils with assured rainfall so as to enhance land use capability.

Sorghum is almost wholly a rainfed crop and a shift from late locals to earlies is a must to stabilise production in normal and abnormal years and also to enhance the productivity of sorghum lands through manipulation of the cropping system as a whole. Varietal transformation by itself as the first step will correct for current drawbacks and open up unlimited opportunities in the realm of cropping systems.

Planning for Rainfed Agriculture

A point of significance in planning for rainfed agriculture emerges here.

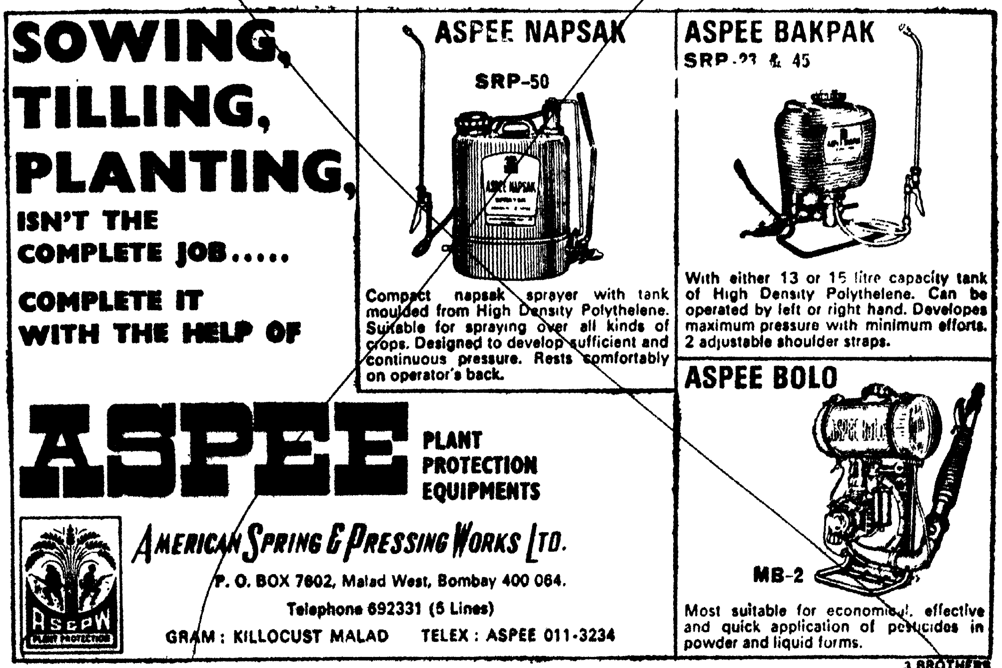
TABLE 2. VARIETAL RECOMMENDATIONS FOR DIFFERENT STATES

States	*Hybrids*	*Varieties*
	KHARIF	
Maharashtra	CSH-1, CSH-4, CSH-5, CSH-6	CSV-2 (302/303), CSV-3 (370), CSV-4 (CS 3541(, CSV-5 (148/168), CSV-6 (601), CSV-1 (Swarna)
Karnataka	CSH-1, CSH-2, CSH-5, CSH-6	CSV-3 (370), CSV-5 (148/168), CSV-4 (CS 3541), CSV-1 (Swarna)
Andhra Pradesh	CSH-1, CSH-5, CSH-6	CSV-3 (370), CSV-4 (CS 3541), CSV-1 (Swarna), CSV-2 (302/303), CSV-6 (601), 329
Madhya Pradesh	CSH-1, CSH-5, CSH-6	CSV-3 (370), CSV-2 (302/303), CSV-4 (CS 3541), CSV-6 (604)
Rajasthan	CSH-1, CSH-5, CSH-6	CSV-3 (370), CSV-2 (302/303) CSV-4 (CS 3541), CSV-6 (604)
Gujarat	CSH-1, CSH-5, CSH-6	CSV-3 (370) ,CSV-2 (302/303), CSV-6 (604)
Uttar Pradesh (Bundelkhand region)	CSH-1, CSH-5, CSH-6	CSV-2 (302-303), CSV-3 (370), CSV-4 (CS 3541), CSV-6 (604)
Tamil Nadu	CSH-1, CSH-5, CSH-6	CSV-4 (CS 3541), CSV-5 (148/168)
	RABI	
Maharashtra	36A×148/168, 36A×PD 3-1-11, CSH-1, CSH-4, (CSH-2 and CSH-3 when profile moisture is very low)	M. 35-1, CSV-7R (R-16) (for early planting only)
Karnataka	CSH-1, 36A×148/168, 36A×PD 3-1-11	M. 35-1, CSV-7R (R-16) (for early planting only)
Andhra Pradesh	CSH-1, 36A×148/168, 36A×PD 3-1-11	CSV-2 (302/303), CSV-4 (CS 3541), CSV-5 (148/168) (for *maghi*), CSV-7R (R-16)
Tamil Nadu	CSH-1, 36A×148/168, Kovilpatti tall, CSH-5, CSH-6, 36A×PD 3-1-11	CSV-4 (CS 3541), CSV-5 (148/168)
Gujarat	CSH-1, 36A×148/168, 36A×PD 3-1-11	CSV-7R (R-16)
	SUMMER IRRIGATED	
Tamil Nadu	CSH-1, CSH-5, CSH-6	CSV-1 (Swarna), CSV-5 (148/168)
Karnataka and Andhra Pradesh	CSH-1, CSH-5, CSH-6	CSV-1 (Swarna), CSV-5 (148/168)

While all scientific attempts to break the environmental barrier to productivity fully realise that environmental fluctuations do exist and the attempted increases in yield levels should transgress the 'error' (environmental) levels to be meaningful, the targetted yield increases planned more particularly for rainfed agriculture, are within the limits of environmental errors. Thus, the planned yield increases are within environmental limits and do not provide for the much-needed breakthrough. A breakthrough can be expected in rainfed agriculture only by planning for large quantum jumps rather than for slow and graded annual targets which are within the realm of environmental fluctuations. This approach may all the more be necessary in the initial year since the present national averages for most rainfed crops are less than 5 q/ha and the available know-how has the potential to elevate the national averages several fold

TABLE 3. MATURITY GROUPS IN RELATION TO VARIETAL DIVERSITY

Maturity group	*Days to flower*	*Hybrids/Varieties*
Early	58-60	CSH-1, CSH-6, CSV-3 (370)
Early	64-66	CSH-4, CSV-1 (Swarna), CSV-2 (302/303)
Early	68-70	CSH-5, CSV-4 (CS 3541), CSV-5 (148/168)
Medium	75-80	CSV-6 (604), 329



NEW APPROACHES TO CLASSIFICATION, EVALUATION AND EXPLOITATION OF WORLD COLLECTIONS OF SORGHUMS AND PENNISETUM

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GENETIC analysis of nearly 12,000 accessions each of sorghum and *Pennisetum* each was made using various biometrical methods for different plant characters. Multivariate analysis in sorghum indicated that the major characters influencing divergence in this crop are flowering time in combination with photosensitivity, height and panicle morphology. Combined with regression analysis and taking into account the evidence on the role of residual heterozygosity in new gene combinations, the sorghums could be classified into nine complexes, the maximum diversity being between *S. roxburghii* and *S. conspicuum, durra* and *subglabrescas, durra* and *Cernum,* and *neruosum* and *Cernum.*

The nature and magnitude of differentiation between sorghum populations could be traced, to a limited extent, to karyotypic differences but these were caused more due to restriction of recombination from linkage or pleiotropy and divergence under disruptive selection in overlapping areas. The karyotypic differences have been found mainly between para-sorghums and eu-sorghums.

Association analyses in crosses between diverse groups have shown restriction of recombination for height, maturity and panicle shape. Restriction on recombination and gene flow and temporal isolation as well as selective elimination of certain recombinants appear to have played a major role than gross chromosomal differentiation in cultivated sorghums.

The dwarfing genes in sorghum acted in an additive manner not only for height but also for maturity and different doses of dwarfing genes along with four maturity genes reduced the flowering time from 90 days to 44 days. In *Pennisetum,* on the other hand, dwarfing has not been found related to maturity, but in this crop, introduction of dwarfing has generated diversity for tillering, maturity, ear size and leaf number.

Developmental trait such as synchrony in tillering, early vigour, early maturity and rapid transfer of energy are specially advantageous and intermating for these characters in early segregating generations leads to the development of populations having wider adaptation.

Some primitive forms of sorghum have high protein content and its combination with free threshing habit has rémained restricted to some types like *conspicum* and *zera-zera.* In *Pennisetum* large grain types are distributed in several geographical regions, while in sorghum large seeded types are adapted only to low moisture areas.

In sorghum, yield, plant height, number of secondaries and days required for 50% bloom are highly correlated, while 100-grain weight is adversely associated with number of secondaries, while panicle length is positively associated with number of secondaries. However, since most of these associations are due to linkage, it was possible to change them through selection in F_6 and F_7 generation after making crosses between Indian and exotic lines.

The G.C.A. estimates showed a negative association with 50% bloom, plant height and yield in dwarf sorghums, while no such effects could be associated in *Pennisetum.*

The African types had a higher genetic load for some recessive chlorophyll mutations (albinos) as compared to the Indian genotypes, while the Indian lines had higher genetic load of xantha and striped.

PATTERNS OF EVOLUTION AND CENTRES OF ORIGIN OF ORNAMENTALS

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In contrast to the crop plants, some of which were domesticated 10,000 years or more, the ornamentals do not have a history of more than 500 years of domestication. Their evolutionary record can be found and the gene pools of their related species can be established and analysed.

Most of the cultivated ornamental plants are confined to a single species and the variability is mostly caused through mutation, as well as the differences in ploidy levels. Most of the polyploid ornamentals belonging to a single species are autoploids and preserved by vegetative reproduction or agamospermy.

Some species of ornamental plants have evolved from two or more (some times upto 8 or 10) different species which permits extensive gene exchange between wider groups and a large range of genotypic variability results by recombination as well as mutations. In the cases of plants like Bougainvillea, Canna, Narcissus etc. the parental types were diploids, while amaryllis, iris, rose etc. evolved as a result of crossing between diploids and polyploids, and intercrosses among polyploids such as *Chrysanthemum* × *morifolium*, *Dahlia* × *variabilis*, *Viola* × *wittrockiana* have been possible. The plants resulting from these crosses are highly polymorphic and distinguishable from their ancestors.

The centres of origin of ornamental plants almost parallel the centres of origin of the cultivated plants as defined by Vavilov. However, the ornamentals have remained more mobile and now appear to be cosmopolitan and not indigenous to any particular region. The differences between the wild and cultivated forms are well defined and usually the cultivated varieties of ornamentals

NITRATE REDUCTASE IN SORGHUM I. VARIATION IN CULTIVARS DURING GROWTH AND DEVELOPMENT

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THE importance of nitrate reductase in the nitrogen metabolism of plants is well recognized (Beevers and Hageman, 1969) and its characteristics have been reported. More recently, the importance of the enzyme has been demonstrated in relation to total reduced nitrogen, protein content and yield in some crop plants (Croy and Hageman, 1970). Even in those plants in which part of their nitrogen requirement is met through nitrogen fixation, the role of nitrate reductase appears to be important (Harper, Nicholas and Hageman, 1972; Shanthakumari and Sinha, 1974). However, some authors have failed to demonstrate the occurrence of appreciable NR activity in extracts from tissues containing nitrate such as plants grown under shaded conditions or mature leaves (Hageman, Flesher and Gitter, 1961 and Zieserl, Rivenbark and Hageman, 1963). According to Sinha, Rajagopal and Balasubramanian (1974) close relationship between total nitrogen and photosynthesis may not have much to do with NR activity. One of the aims of breeding programs in cereals and millets is to obtain response to nitrogen application. This in turn seems to be associated with nitrate reductase activity in maize (Hageman, Leng and Dudley, 1967) and wheat (Croy and Hageman, 1970; Nair and Abrol, 1973). Therefore, an assessment of variation in this character and its response to nitrogen and other environmental factors is essential.

MATERIALS AND METHODS

Sorghum genotypes maintained at the Indian Agricultural Research Institute, New Delhi were used. Some of these were inbred lines which had been successfully used in the production of commercial hybrids. There were also some hybrids and varieties which had been released for cultivation. Plants grown for the study of nitrate reductase during growth and development were given 100 kg/ha phosphorus. Since the soil was not deficient in potassium, no potash was applied. NR activity was determined at five different stages, namely, the seedling, panicle differentiation, anthesis, anthesis+10 days and anthesis +25 days, in 1972 and 1973. The effect of nitrogen levels (50, 100 and 200 kg N/ha) on NR activity was also studied on plants raised in the same soil.

The *in vivo* method of Klepper, Flesher and Hageman (1971) was used for enzyme assay. The leaves of sorghum contain cyanogenic glucosides which release HCN, and this, in turn, adversely affects the nitrate reductase activity. Maranville (1970) showed that the inclusion of nickel chloride could restore the activity of NR in the *in vitro* determinations. Similarly, we observed that inclusion of 10^{-4} M nickel chloride helped in achieving the maximum enzyme activity. It was, therefore, routinely added in all assays. There were three determinations for each genotype.

Results and Discussion

Nitrate reductase during growth

In most genotypes the enzyme activity in seedling was slightly above or below 200 n moles NO^-_2/ gm. fresh weight/hr. The only exception was the hybrid CSH–2 where it was 650 n moles NO^-_2/gfw/hr. The maximum activity of 900 n moles NO^-_2/gfw/hr was observed in PD–2–5 at the time of panicle differentiation. On the basis of nitrate reductase activity three distinct groups could be made of the genotypes. The first group showed stimulation in enzyme activity at the time of panicle differentiation followed by a clear fall in the activity at anthesis (Fig. 1). In most genotypes in this group the NR activity was stimulated once again in the post anthesis period. The second group, consisting of CSH–1, CSH–2 and 302, had its peak enzyme activity at anthesis (Fig. 2). The third group including CS 3541 and 651 was characterized by a gradual rise in enzyme activity throughout the growth period, reaching maximum at 25 days after anthesis (Fig. 3).

Effect of nitrogen application on NR activity

Since NR activity is closely associated with nitrate uptake and reduced nitrogen build-up in the plant (Beevers and Hageman, 1969), the effect of different levels of nitrogen on NR activity was studied using 15 day old seedlings. Nineteen genotypes were grown at 50, 100 and 200 kg N/ha levels under field conditions. No single and common response to nitrogen was observed in NR activity. The lowest and the highest NR activity obtained at 50 kg N/ha were 180 and 1220 n moles NO^-_2/gfw/hr in the genotypes 604 and 648 A. The maximum NR activity of 2050 n moles NO^-_2/gfw/hr was reached in CSH–3 at 100 kg N/ha.

The following groups could be distinguished on the basis of NR activity in relation to nitrogen supply: (i) Showing an increase in enzyme activity with increasing nitrogen level from 50 kg N/ha to 200 kg N/ha (Fig. 4). (ii) Showing a decrease in enzyme activity with increasing nitrogen level from 50 kg N/ha to 200 kg N/ha (Fig. 5). (iii) Showing an increase in enzyme activity upto 100 kg N/ha but followed by a decline in enzyme activity at 200 kg N/ha (Fig. 6). (iv) Showing an inconsistent behaviour (Fig. 7).

These are only broad categories and may not be watertight compartments; some genotypes could be placed in another group. However, the important point is the occurrence of various kinds of responses. An interesting feature of this study was that the genotypes having a relatively low NR activity at 50 kg N/ha showed enhancement in enzyme activity with increasing levels of nitrogen. With the exception of the variety *Swarna*, the lower the enzyme activity at 50 kg N/ha higher was the response in NR activity to higher doses of nitrogen (Fig. 4 and 6). If the enzyme activity was higher at the lowest level of nitrogen, as in CSH–4, 648 AxID 2930–35 and 670, there was a decrease in enzyme activity at 100 and 200 kg N/ha. Irrespective of genotype and nitrogen level, apparently

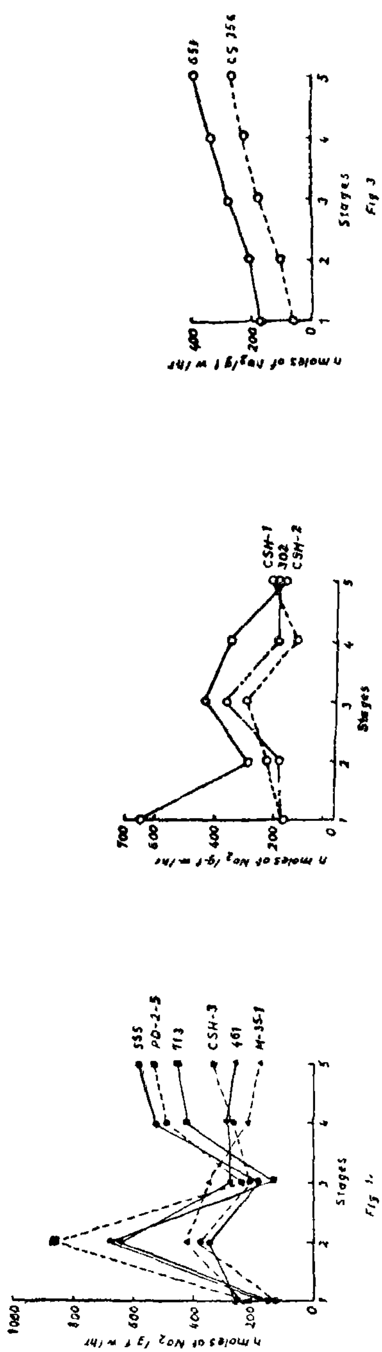

FIG. 1–3. Nitrate reductase activity during growth and development in Sorghum at (1) seedling, (2) panicle differentiation, (3) anthesis, (4) anthesis+10 days and (5) anthesis+25 days stages.

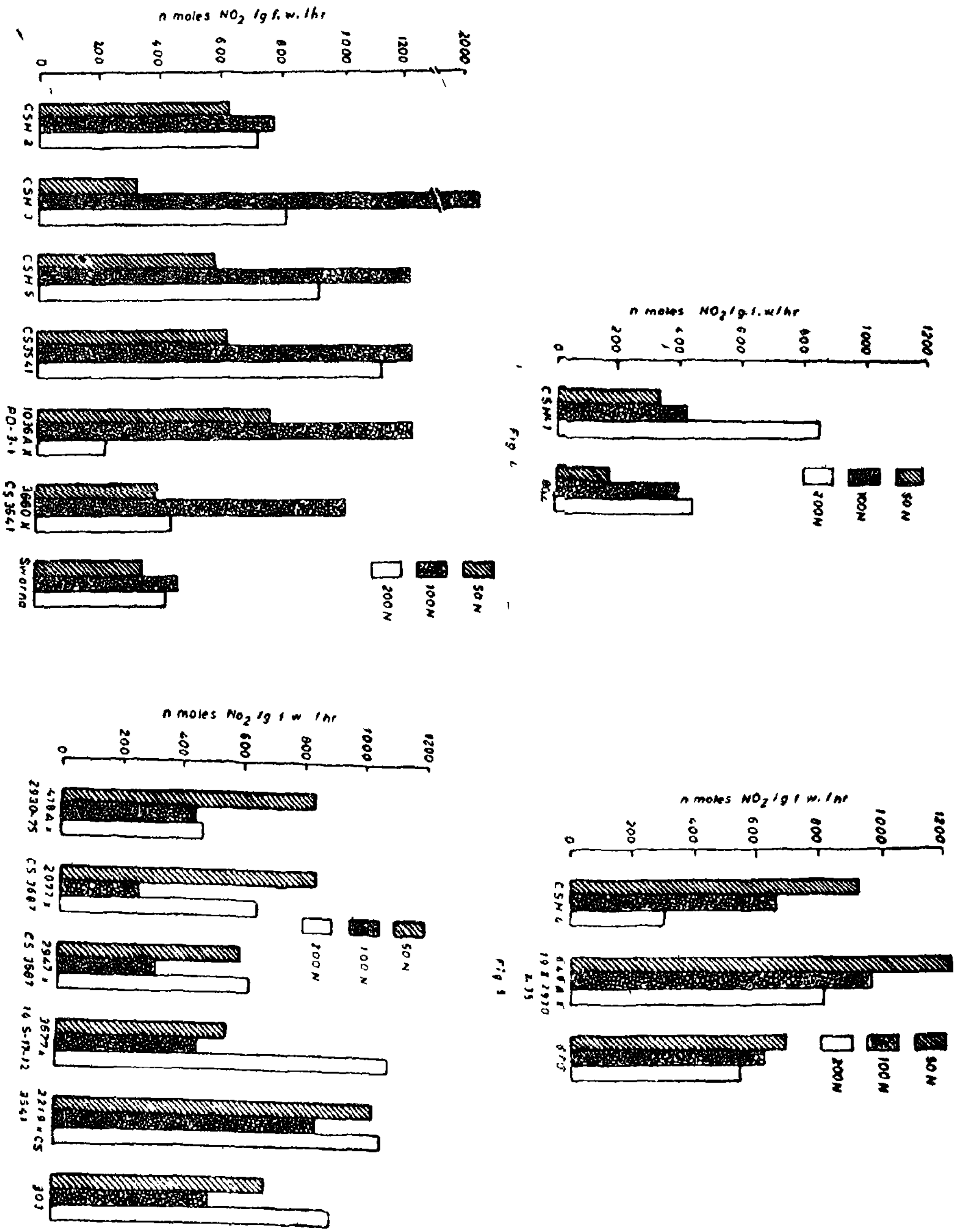

Fig. 4–7. Nitrate reductase activity in sorghum supplied with 50, 100 and 200 kg. N/ha.

1,200 n moles NO^-_2/gfw/hr seemed to be the upper limit of enzyme activity with the sole exception of CSH–3. Once this level of enzyme activity was reached, it was followed by a decline in NR activity. Could it be that beyond 1,200 n moles NO^-_2/gfw/hr level the nitrate reductase becomes limited by some other factor? One of the possibilities is that the reduced nitrogen may not be utilized with equal efficiency resulting in the accumulation of either NH_4^+ or amino-acids. Both NH_4^+ and aminoacids are known to repress the synthesis of nitrate reductase in various plant tissues (see Beevers and Hageman, 1969). This would suggest that the repression limits could vary in different genotypes. Accordingly CSH–3 would appear to have the highest limit in the present study. An investigation involving genotypes belonging to different groups mentioned above should prove rewarding.

The present study thus brings out some important points. There is considerable variation in nitrate reductase activity at the varietal level. It is possible that the higher enzyme activity might be related to nitrate uptake or be independent of that. Nonetheless, the variation can be used possibly in studies on the inheritance of nitrate reductase. The distinct types showing stimulation in enzyme activity at panicle differentiation and anthesis can be examined in detail for determining relationship of this enzyme to panicle development and grain development. An understanding of the response of NR to nitrogen may be used in determining the quantity of nitrogen fertilizer given as split or single doses.

SUMMARY

Nitrate reductase activity (NR) was determined in eleven genotypes of sorghum at five stages of growth, namely seedling stage, panicle differentiation, anthesis, anthesis+10 days and anthesis + 25 days. One group of genotypes showed higher activity of the enzyme at panicle differentiation and at post anthesis. In the second group, the genotypes had higher NR activity at anthesis, while the third group consisted of genotypes which showed a continuous increase in NR activity reaching a maximum at post-anthesis.

The effect of nitrogen application on NR activity was studied in 19 genotypes given 50, 100 and 200 kg of N/ha. There was differential response of the genotypes, some showing increase in enzyme activity with increasing levels of N, others exhibiting the opposite trend. There were also genotypes which showed least enzyme activity at the highest N level.

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GENETIC ANALYSIS OF SOME EXOTIC × INDIAN CROSSES IN SORGHUM XIII. ENVIRONMENTAL AND GENOTYPE-ENVIRONMENTAL COMPONENTS OF VARIABILITY FOR GRAIN YIELD IN HYBRIDS AND THEIR PARENTS[1]

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A KNOWLEDGE of the nature and relative magnitudes of the various types of genotype-environmental interactions is important in making decisions concerning breeding methods, selection programmes and testing procedures in crop plants (Baker, 1969). In recent years attempts to specify, estimate and correct for g × e interactions have taken two directions. The statistical approaches of Yates and Cochran (1938) suitably modified by Finlay and Wilkinson (1963) and Eberhart and Russell (1966) provide for estimates of stability parameters, the mean, the regression of yield on environmental index and the deviation mean square. A second approach (Mather and Jones, 1958; Jinks and Stevens, 1959; Bucio Alanis and Hill, 1966) is based on fitting models which specify genetic, environmental and g×e interactions to generation means and variances. Both types of analyses essentially lead to the same conclusion that the magnitude of g×e interactions are a linear function of the environmental effects. Perkins and Jinks (1968) attempted to bridge the gap between the two approaches and extended the analysis to cover many inbred lines and the crosses among them. The present study is an effort to understand the differential g × e interactions of hybrids and their parents which are of exotic origin or derivatives from exotic × Indian crosses.

MATERIALS AND METHODS

The material for the study comprised five females (CK 60A, 2219A, 3677A, 1587A and 648A) and 21 males, 19 of which are derived from exotic × Indian crosses (586, 674, 724, 743, 780, 781, 810, 846, 851, 892, 990, 1098, 1157, 1302, 1364, 1387, 1452, 1635, 1667) and two (IS 2031 and IS 2954) are exotic dwarfs. The 105 hybrids along with the 21 males and the fertile counterparts of five females were grown in randomised blocks replicated three times at three different locations, Parbhani (Maharashtra), Dharwar (Karnataka) and Yemmiganur (Andhra Pradesh) during *kharif*, 1970. Uniform agronomic practices were followed at all the three locations. Ovservations on five random plants were recorded in each plot in each of the locations. The model given by Perkins and Jinks (1968) was used for analysis of data.

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RESULTS

The joint regression analysis of variance for parents and hybrids respectively is presented in Table 1. It will be seen that all items except remainder M.S. in parents of the regression analysis are significant when tested against error M.S. The linear component (the heterogeneity of regression M.S.) accounts for more of the g × e-interactions than the remainder M.S. in case of parents. On the other hand in case of the hybrids, the remainder M.S. is several times larger than the linear component.

TABLE 1

Joint regression analysis for parents and hybrids

Source of variation	D.F.	Mean squares
Parents		
Lines	25	136·01**
Environments	2	2955·42**
G × E interaction		
Heterogeneity between regressions	25	175·34**
Remainder	25	33·37
Hybrids		
h(il)'s	104	1239·02**
Joint regression	2	7055·97**
G × E interaction		
Heterogeneity between regressions	104	145·12**
Remainder	104	1093·90**
Error	780	36·4

**Significant at 1% level.

The estimates of d_i and β_i for male and female parents are presented in Table 2. The females and two exotic male parents IS 2031 and IS 2954 show negatively significant β_i. This reveals the limited response of exotic male parents and all the female parents to the improved environment. The positively significant β_i's are only observed in case of derivatives of exotic × Indian crosses. Derived males, therefore, show positive response under improved environment and are superior to the exotic males and females. Further, the remainder mean squares are not significant for all these parents. Hence, all the significant genotype environment interactions between these parents, where β_i values are significant and the three environments can be accounted for as a linear regression on the additive environmental values. The parents 892, 990, 1098 and 1302 which show positive β_i values larger than 1·0 may be useful for better environments.

TABLE 2

Estimates of the various parameters for the parents

Parents	d_i	β_i
Females		
2219B	–8·2	–1·163**
648B	–11·7	–0·727**
CK60B	–5·4	–0·853**
1587B	–3·8	–1·447**
3677B	–5·4	–1·000**
Males		
586	0·7	–0·009
674	3·7	0·037
724	–4·2	0·223**
743	1·2	–0·079
780	–6·5	0·035
781	6·9	0·631**
810	–0·8	–0·233**
846	–3·4	0·038
851	–2·8	–0·034
892	5·5	1·098**
990	10·1	1·898**
1098	13·1	1·840**
1157	3·5	–0·130
1302	17·6	1·123**
1364	–2·7	0·304**
1387	–3·9	0·038
1452	0·2	0·425**
1635	–1·0	–0·071
1667	5·2	0·442**
IS 2031	–3·3	–1·007**
IS 2954	–5·1	–1·451**
S.E.		0·075

**Significant at 1% level.

Estimates $B_{(ij)}$ and $h_{(ij)}$ for the various hybrid combinations are given in Table 3, which shows that the distribution of the significant $B_{(ij)}$ values is not entirely at random. The crosses with male parents 586, 743, 781, 892, 1157, 1387, 1452 and 1635 are having significant $B_{(ij)}$ values.

From these studies, it will be seen that both parents and hybrids shows g × e interactions. The g × e interaction in the case of parents are largely linear function of the environmental values with regression slopes (β_i's) differing from parent to parent.

TABLE 3

Genetic and regression statistics for the F_1 hybrids

Male parent	ms 2219		ms 648		ms CK60		ms 1587		ms 3677	
	h(ii)	β(ii)	h(ii)	β(ii)	h(ii)	β(ii)	h(ii)	β(ii)	h(ii)	β(ii)
586	13·8	0·757**	22·3	1·726**	8·4	0·640*	8·5	−0·447	18·1	2·275**
674	11·4	0·226	17·9	1·117**	7·5	−0·007	16·2	−0·652*	11·5	0·302
724	12·1	−0·677*	22·5	1·044**	17·7	−0·683*	11·8	−0·947**	12·7	1·262**
743	24·7	0·734*	18·8	1·655**	14·7	−0·971**	18·9	0·268	30·0	1·223**
780	11·7	−1·044**	14·5	0·010	13·4	−0·458	13·4	−0·508	15·1	0·632*
781	20·6	0·182	24·0	1·552**	21·6	−0·307	25·7	0·561*	24·2	0·561*
810	7·1	−0·344	20·0	0·010	9·4	−0·006	3·8	0·231	7·6	−1·106**
846	13·8	−1·085**	26·1	1·045**	21·8	0·071	11·9	0·102	17·9	0·311
851	15·4	−0·831**	14·2	−0·197	3·4	−0·093	5·5	−0·089	9·4	−1·710**
892	25·0	0·320	25·8	1·422**	15·2	0·226	20·6	1·525**	25·6	0·816**
990	24·1	−0·370	18·4	0·492	14·6	−0·047	12·5	0·813**	19·1	0·532
1098	28·2	−0·061	24·0	0·116	12·6	−0·183	14·0	0·178	25·6	0·475
1157	23·1	0·961**	21·3	1·852**	13·8	2·731**	7·4	−0·351	15·3	1·998**
1302	19·2	0·270	25·6	0·108	11·4	0·046	13·1	−0·907**	20·1	−0·878**
1364	9·7	−0·120	14·8	−0·207	20·1	−1·006**	7·3	−0·860**	12·9	−0·200
1387	19·8	1·798**	20·3	1·845**	15·3	0·498	40·1	4·507**	20·9	1·139**
1452	48·3	3·337**	29·7	2·786**	37·8	4·385**	36·6	3·338**	38·8	2·922**
1635	38·3	4·647**	26·4	2·510**	40·1	2·357**	36·2	7·640**	35·8	1·703**
1667	16·4	−0·741**	17·5	−0·313	14·6	0·216	10·7	−0·497	10·6	−0·235
IS 2031	7·2	0·055	25·3	−0·237	8·8	−2·174**	9·7	0·641*	7·8	−0·790**
IS 2954	10·9	0·535	23·4	−1·125**	10·1	−1·259**	11·1	−0·816**	4·2	0·298

(Column group heading: Female parent.)

S.E. (β_{il}) ±0·279 *Significant at 5% level. **Significant at 1% level.

TABLE 4

Correlations between the genetic and regression statistics

Genotypes	Statistic	Correlation coefficient	D.F.
Parents	d_i & β_i	0·7958**	24
F_1 hybrids	$h_{(i1)}$ & $\beta_{(i1)}$	0·6900**	103

**Significant at 1% level.

On the other hand, the hybrids also exhibit significant g × e interactions, but these interactions differ from those of the parents; they appear largely due to non-linear function of the environmental values. Here also the regression values widely differ from hybrid to hybrid. The overall mean values of the $\beta_{(i1)}$'s for the F_1 hybrids is positive and significant.

The correlations between genetic and regression statistics for parents and hybrids are presented in Table 4. Both the parents and the F_1 hybrids show a positive correlation between the genetic control of performance and the value of the regression slope, indicating that the genetic control of the performance and the value of the regression slope are closely related. The F_1 hybrids have higher mean performances and generally higher slopes than the mean of their respective parents. Heterosis is mean performance is, therefore, generally associated with a greater sensitivity to the environment.

DISCUSSION

Perkins and Jinks (1968) observed that the linear and non-linear components of the g × e interactions are independent and are presumably subject to the control of different genetic systems. Where β_i amounts for all or most of the g × e interaction, it is a convenient measure of the relative sensitivity of the genotype to the environment. In determining the best genotypes, both the genetic component of performance d_i and β_i which represents the sensitivity to environmental variation should be considered. These two aspects of the phenotype are positively correlated both in the inbred varieties and F_1 hybrids derived from them. A higher d_i or $h_{(i1)}$ is generally accompanied by greater sensitivity to environment. Inspite of these correlations, varieties which have an above average mean and average regression slope could be identified. Both parents and hybrids showed g × e interactions that are largely linear functions of the environmental values with regression slopes that differ from one inbred line to another and from one cross to another.

Present studies based on the model of Perkins and Jinks (1968) indicate that g × e interactions are operative in both parents as well as F_1 generation hybrids and that a significant portion of these interactions are accounted for by the linear function of the environmental means. Some of the interactions were, however, independent of this linear component. Both the linear and non-linear components of the g $\times$ e interaction were under the control of different gene systems. Different parents showed dominance for the linear and for the non-linear components. Interaction between the additive component and the environments was greater than that of the dominance component in different environments.

The linear component of the g $\times$ e interaction was greater in the parents than in the F_1 hybrids, but both are significant. A major portion of the additive $\times$ environment interaction is accounted for by a linear relationship and a large portion of the dominance $\times$ environment interaction is non-linear. A number of workers including Jinks and Mather (1955), Jinks and Stevens (1959), Bucio Alanis and Hill (1966), Bucio Alanis, Perkins and Jinks (1969), Jinks and Perkins (1970) and Breese (1969) have investigated the relative sensitivity of additive, dominance and epistatic components and they found situations in which the dominance component has been more sensitive, equally sensitive and less sensitive than the additive component.

In the case of parents, the heterogeneity m.s. alone is significant against error m.s. and against remainder m.s. Thus it is possible to predict, within the limits of the sampling error, all the genotype-environmental interactions for each line from the linear regressions on the environmental values and the predictions of the g $\times$ e interactions based on the linear regression will still have considerable practical value.

In hybrids both regression m.s. and the remainder m.s. are significant against error m.s. and thus show g $\times$ e interaction. The regression m.s. is not significant when tested against the remainder m.s. but this does not rule out the possibility that the regression of $(h_{il} + g_{il})$ on E_j for some of the hybrids taken individually may be highly significant when tested against their remainder m.s. For these particular hybrids, reliable predictions can still be made in this study. In joint regression analysis all of the items except remainder m.s. in parents are significant against error m.s. There are, therefore, differences between the lines and between the environments and there are significant genotype $\times$ environment interactions. This analysis also showed that the $b_{(il)}$ values differ among the crosses. It has frequently been observed that the environmental variability of genetically homogeneous genotypes are related to their mean performance. The parents showed high correlation between mean performance and environmental variability.

In general, it is the expression of the additive effects of genes which is least consistent in both their linear and non-linear response to environment. Furthermore, such non-additive effects as are present appear to be due solely to dominance. The F_1 hybrids are generally characterised by higher mean performance and higher slopes than the mean of their respective parents and heterosis is generally associated with a greater sensitivity to environment.

Summary

Studies on the g × e interaction of varieties and hybrids using the model of Perkins and Jinks (1968) indicated that the linear component of the g × e interaction was greater in the parents than in the F_1 hybrids. The F_1 hybrids were generally characterized by higher mean performance and higher slopes than the mean of their respective parents indicating that heterosis is generally associated with greater sensitivity to the environment.

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GENETIC ANALYSIS OF SOME EXOTIC × INDIAN CROSSES IN SORGHUM. XIV. STABILITY OF HYBRIDS AND PARENTS[1]

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(Accepted: 25–x–75)

A POPULATION of organisms has immediate fitness when its individuals are morphologically and physiologically equipped for growth and reproduction in a constant environment. Since no environment is constant, all organisms attempt to cope with environmental heterogeneity through individual and population adaptability (Cook and Johnson, 1968). In outbreeding species, high degree of stability is generally a property of heterozygotes while in self fertilizers the situation is not as clear. Individual races highly resistant to one or more classes of environmental stress may exist in both autogamous and allogamous species (Pederson, 1968).

Sorghums which have been treated as complete self fertilizers for varietal development and complete outbreeders for purposes of developing commercial hybrids, offer unique possibilities for capitalising the advantages of both self and cross breeding systems. The present study is an effort to analyse the relative performance and stability of lines derived from exotic × Indian crosses and the hybrids derived using them as male parents.

MATERIALS AND METHODS

The material and the lay out for the present study were earlier described by Singhania and Rao (1976).

The conventional pooled analysis of variance and the regression analysis of Eberhart and Russell (1966) were used for analysis and interpretation of data.

RESULTS

Analysis of variance: The analysis of variance for genotype × environment interaction when stability parameters are estimated is presented in Table 1. The three locations used in the study provided a suffcient range of environments, the mean yield ranging from 37·9 gm. per panicle at Dharwar to 57·5 gm. at Parbhani. Significant differences among variety means for all characters are

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TABLE 1

Analysis of variance when stability parameters are estimated

Source of variation	D.F.	Mean squares					
		Mature plant height	Days to 50% bloom	Panicle length	Grain yield/ panicle	Hundred grain weight	Number of grains/ panicle
Varieties (M1)	134	2660·7**	46·5**	32·3**	381·0**	0·446**	563130·6**
Environments	2	17562·0	925·3	677·7	16301·7	5·649	20910850·0
Varieties × Environments	268	154·6	3·4	4·0	132·9	0·074	144078·0
Environment (Linear)	1	35152·2	1852·1	1356·0	32604·4	11·301	41825065·0
Varieties × Environments—Linear (M2)	134	206·1**	3·2	4·2	223·8**	0·033	214739·8**
Pooled deviations (M3)	135	102·4*	3·5	3·7	41·7	0·113*	72915·0
Pooled error	804	72·9	3·5	2·5	36·6	0·011	70673·4

*Significant at 5% level.
**Significant at 1% level.

revealed by the large variance ratio M_1/M_3. The table shows that there are genetic differences among varieties for their regression on environmental index for plant height, grain yield and number of grains per panicle but no genetic differences for panicle length, days to 50% bloom and hundred grain weight (M_2/M_3 variance ratio). Mean squares for pooled deviations from regression are significant for only panicle length, plant height and hundred grain weight.

The results also show that all characters displayed considerable g × e interaction except the days to 50% bloom. Relationship between the performance of lines and the environmental value is essentially linear with respect to plant height, grain yield and number of grains per panicle.

Stability parameters: The stability parameters for individual entries have been estimated. The distribution of the entries in the different quadrants is summarised in Table 2. It will be seen that for grain yield and several other characters except days to 50% bloom and seed weight, most of the genotypes tend to concentrate in Q_1 with $b_i > 1 \cdot 0$ and high mean value and in Q_3 with $b_i < 1 \cdot 0$ and the mean value below the general mean.

TABLE 2

Distribution of different genotypes in the four quadrants

Character	Genotype in quadrant				Percent of genotypes in each quadrant			
	1	2	3	4	1	2	3	4
1. Mature plant height	46	10	70	9	34·07	7·41	51·85	6·67
2. Days to 50% bloom	21	50	32	32	15·56	37·04	23·70	23·70
3. Panicle length	35	24	44	32	25·93	17·78	32·59	23·70
4. Grain yield per panicle	51	12	57	15	37·78	8·89	42·22	11·11
5. Hundred grain weight	40	33	36	26	29·63	24·44	26·67	19·26
6. Grain per panicle	42	26	43	24	31·11	19·26	31·85	17·78

It is interesting to note that the hybrids involving the males, 990, 1098, 1302, 851, 1364 and 1667, exhibited superiority over their respective male parents in less favourable environments, but as the environment became more and more favourable, the male parents exceeded the corresponding hybrids in yield levels (Fig. 1). But this is not universal with all the combinations and certain of the hybrids did exhibit continued superiority over their male parents irrespective of the environmental changes (Fig. 2). The most superior hybrids, particularly those involving 1452 and 1635, are characterised by b values greater than 1·0 and their expression is maximum under more favourable conditions. But an overall examination of the response of parents and hybrids (Fig. 3) indicates that suitable homozygous lines capable of outyielding their respective males could be

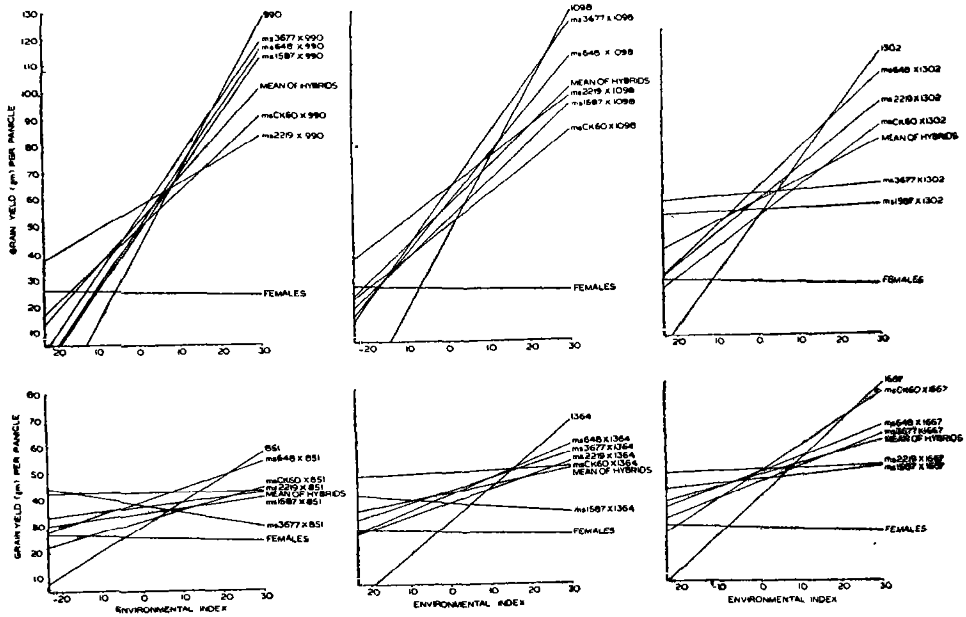

Fig. 1. Stability of performance of parents and hybrids

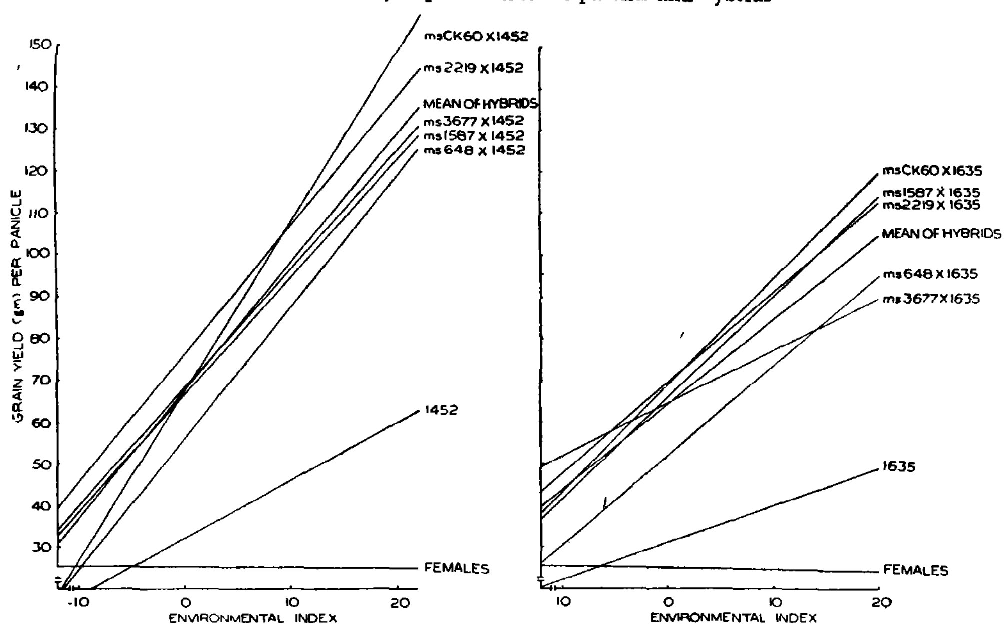

Fig. 2. Stability of performance of parents and hybrids.

developed through proper choice of parental material and selection procedures, but the superiority of such homozygous lines is best expressed under more

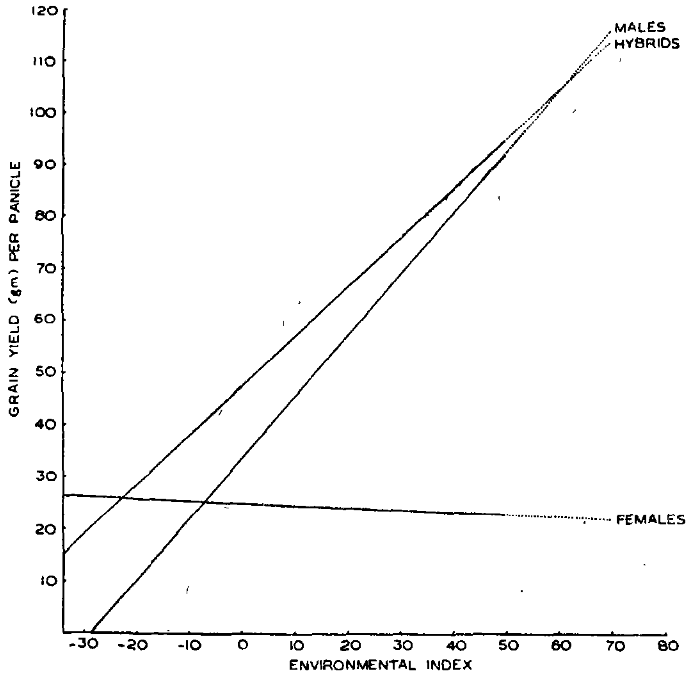

FIG. 3. Stability of females, males and hybrids.

favourable environments. Some of the male parents tended to out yield the corresponding hybrids indicating that homozygous lines could be superior to commercial hybrids provided the growing conditions are satisfactory.

DISCUSSION

Populations of most species differ in their ability to exploit current environments and adjust to environmental change and correlatively vary in their probability of survival and reproduction. Those which maximise this probablity may be regarded as most adapted. The genome may be viewed as a harmoniously co-adapted and integrated gene ensemble which mediates a broad and complex array of developmental processes where successful completion is essential for viability, vigour and fertility. The capacity to buffer under external and internal environmental changes is conferred by regulatory interactions during morphogenesis which are mediated by complex feed back mechanism (Levin, 1970).

In contrast to the consistency of evidence for heterozygote superiority in outbreeding species, the evidence for inbreeding species has been conflicting. Lerner (1954) hypothesized that departure from the breeding system normal for the species leads to loss of buffering powers. Smith and Foote (1970) reported evidence which indicated that in the self fertilized species of barley, heterozygosity reduced phenotypic stability of particular characters at some locations. Experiments with lima bean and *Arabidopsis* suggest that self and cross fertilized species are essentially similar in their heterotic response and that the use of heterosis should carefully be considered irrespective of their breeding system.

There are indications to show that even in self fertilised species, stability is a function of heterozygosity for most classes of environmental stress (Lewis, 1955; Griffing and Langridge, 1963; Pederson, 1968; Rao and Harinarayana, 1969). Both production and consistency of performance over a number of environments should, therefore, be used to compare and evaluate populations. It should also be borne in mind that the distribution of the mean yield of the varieties depends on the particular sample of seasons and stations used for the estimation. If the combinations of seasons and sites result in predominantly high yielding environment, the varieties with high regression coefficients would produce the highest yield means showing that varieties specially adapted to high yielding environments have been favoured (Kaltsikes, 1969).

Results of the present experiment involving parents and their hybrids developed from a line × tester mating system reveal that the advantage of F_1 populations may not only be in the area of increased production, but also in terms of greater stability in production over a number of environments. The hybrids as a group displayed smaller deviations except for grain yield and the regression coefficient is close to 1·0. Thus, a collective consideration of the parameters for stability of yield leads to the interpretation of greater productivity and stability for hybrids.

Regarding the behaviour of the parents, the males and females reacted differently to environmental variations. For the females as a group, the b_i was close to 1·0 for several characters. The male group on the other hand exhibited below average stability for all characters except hundred grain weight and appeared better adapted to favourable environments. All the parents put together, the parental population exhibited b values close to 1·0 and hence greater stability. Thus a heterogeneous population of homozygous individuals (mixture) behaved somewhat similar to the heterogeneous population of heterozygous individuals. There seems to be no doubt about the superiority of hybrids under less favourable conditions because of the developmental flexibility that heterozygosity affords.

Summary

An analysis of stability of hybrids and parents revealed that the F_1 populations were not only better in the area of increased production but were also marked by greater stability in production over environments. Amongst the parents studied, the females were more stable, but they were characterited by low mean yields. The males on the other hand exhibited below average stability but appear better adapted to favourable environments.

The hybrids with male parents 851, 990, 1098, 1302 (IS 2031 × Karad local), 1364 (R-78 × M. 35-1) and 1667 (IS 3922 × Karad local) exhibited superiority over the respective male parents in less favourable environments, but as the environment became more and more favourable, the male parents tended to outyield the corresponding hybrids. The overall performance of males and their hybrids is indicative that homozygotes (lines) could perform better than their hybrids in better environments while the hybrid superiority under less favourable conditions tended to be universal.

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GENETIC ANALYSIS OF SOME EXOTIC×INDIAN CROSSES IN SORGHUM

XV. INHERITANCE OF RESISTANCE TO SORGHUM RUST

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Efforts have been in progress to breed superior genotypes through exotic× Indian crosses in sorghum and to understand the genetic basis of the various economic traits (Rao, 1972 and Rana *et al.* 1975). The present paper is a study of the inheritance of resistance to sorghum rust (*Puccinia purpurea* Cke.) and its implications in breeding resistant genotypes.

Materials and Methods

Three improved varieties, CSV–3 (370), CSV–5 (148) and CSV–7R (R–16) and two bold seeded cultivars BP–53 and IS 9985 (Sudan) were crossed in all possible combinations. The five parents, ten F_1 hybrids and 10 F_2's were planted in a randomized complete block design with three replications during *kharif*, 1975 at IARI Regional Research Station, Hyderabad. Of the parents, CSV–5 (148/168) remained almost free from rust at Hyderabad; CSV–3 (370) was less susceptible and CSV–7R (R–16), BP–53 and IS 9985 were highly susceptible. CSV–5 is popularly classified as a tan plant type, CSV–3 is less tan and the rest are non-tan. The 'tan' and 'non-tan' or 'pigmented' classification of plant types in sorghum is common terminology familiar to sorghum breeders but the types of pigments involved do not seem to have been characterized as yet. The tan types are characterized by straw colour on leaf sheaths and leaf margins. The non-tan or pigmented types developed purple pigment on leaf sheath, the pigment being conspicuous on lower sheaths.

The parents and F_1 hybrids were planted in single rows of 4·5 metres, 60 cm apart having 30 plants per row. The plot size for each F_2 consisted of five such rows. Rust appeared in an epidemic form. Individual plants were graded on the basis of pustule size and intensity on lamina. The following system was followed for grading.

Grade	Infection type
0 —	No pustules—almost free from rust.
1 —	Traces, isolated, very small pustules on few lower leaves, six pustules/4 sq. cm., pustules covering 5–10% leaf area.
2 —	Pustules isolated, small to medium, slightly chlorotic, some times surrounded by hypersensitive necrotic areas, 15 pustules/4 sq. cm., 10–25% leaf area covered by pustules.
3 —	Pustules slightly bigger in size, 30 pustules/4 sq. cm., few start rupturing and coalescing, chlorotic areas occasionally present, 25–40% leaf area covered by pustules.
4 —	Pustules larger, ruptured and generally coalescing, 45 pustules/4 sq. cm., pustules present on most of the leaves covering 40–75% leaf area.
5 —	Pustules largest, ruptured and coalescing, 60 pustules/4 sq. cm., covering 75–95% leaf area.

In coding the rust grades, the basis suggested by Browder (1971) has been kept in view.

All the individual F_2 plants were scored for rust as well as plant type, tan or pigmented (non-tan).

Results

The average scores over replications for parents and F_1 are given in Table 1. CSV-5 (148) was resistant and no pustules were present. CSV-3 (370) showed moderate susceptibility while rest of the parents were highly susceptible. The F_1's were almost as susceptible as susceptible parent. Susceptibility thus showed dominance over resistance. Even moderate susceptibility in CSV-5×CSV-3 cross was dominant over resistance. Similarly, high susceptibility showed dominance over moderate susceptibility. The genotypic differences and interaction between resistance, moderate susceptibility and high susceptibility classes revealed existence of different genes causing these differential reactions. However, IS 9985 behaved differently than the other two susceptible genotypes.

The F_2 distribution for susceptibility and plant type showed that resistant and tan plant types were occurring only in crosses involving CSV-5 (Table 1). Rest of the crosses showed moderate to high susceptibility and purple pigmentation.

The χ^2 tests using cumulative frequencies are presented in Table 2. In resistant (score-0) *vs* rest of the classes (scores 1–5) of CSV-5×highly susceptible crosses, goodness of fit for 63 : 1 ratio was satisfied. When scores 0–1 *vs* 2–5 were compared, 3 : 1 ratio in CSV-5×CSV-3 and 15 : 1 ratio in CSV-5×CSV-7R were fitting closely. Among CSV-5 crosses, subsequent cumulative frequencies *e.g.*, 0–2 *vs* 3–5 and 0–3 *vs* 4–5 were fitting to 1 : 1, 3 : 1 and 15 : 1 genetic ratios except in CSV-5×IS 9985 cross.

Moderately susceptible plants were absent in the F_2 generation of CSV-3 ×CSV-7R inspite of CSV-3 being moderately susceptible. But both moderately susceptible and susceptible plants were present in other two crosses of CSV-3 showing a good fit to 3 : 1 ratio. Among highly susceptible × highly susceptible crosses, a low frequency of moderately susceptible plants was observed. It was 15 : 1 in CSV-7R×BP-53 cross while no genetic ratio could be fitted in other two crosses (CSV-7R×IS 9985 and BP-53×IS 9985).

The segregation for plant types (pigment) was studied in four tan×purple pigmented crosses. CSV-5 was a tan parent while other parents had purple pigment. There was 3 : 1 segregation for purple and tan types in all these crosses.

The distribution of disease scores showed a distinct pattern with plant pigment (Table 3). Absolute resistance (Score-0) was occurring only in tan pigmented plants. Not a single purple pigmented plant was immune to rust. Thus, recombination of resistance with purple pigment was absent and was confined only to tan types. Greater frequency of parental types and lack of recombination indicated existence of linkage. The χ^2 test revealed strong linkage between disease score and plant pigments.

Discussion

Rust of sorghum caused by *Puccinia purpurea* Cke., is a wide spread disease of sorghum. It usually occures late when the sorghum crop is about to

TABLE 1

Rust reaction of parents, F_1 and F_2 generations and its relation with plant type (pigment)

Cross	Rust grade			Rust grade F_2 frequency						Plant pigment	
	P_1	P_2	F_1	0	1	2	3	4	5	Tan	Purple
CSV-5 × CSV-3	0	2	2·5	28	45	89	121	24	0	85	222
CSV-5 × CSV-7R	0	4	4·0	5	13	45	62	101	18	54	190
CSV-5 × BP 53	0	4	3·5	5	15	42	63	99	2	56	170
CSV-5 × IS 9985	0	4	3·0	4	29	61	98	96	4	75	217
CSV-3 × CSV-7R	2	4	3·5	0	0	0	14	251	7	0	272
CSV-3 × BP 53	2	4	3·5	0	0	66	89	113	4	0	272
CSV-3 × IS 9985	2	4	3·0	0	0	51	87	108	3	0	249
CSV-7R × BP 53	4	4	4·5	0	0	0	13	187	5	0	205
CSV-7R × IS 9985	4	4	4·0	0	0	0	17	96	3	0	116
IS 9985 × BP 53	4	4	3·5	0	0	0	14	101	4	0	119

TABLE 2

Cumulative F_2 frequencies for different disease grades and estimates of χ^2 for rust susceptibility in sorghum

Cross	A				B				C				D			
	0	1–5	Ratio	χ^2	0–1	2–5	Ratio	χ^2	0–2	3–5	Ratio	χ^2	0–3	4–5	Ratio	χ^2
CSV-5 × CSV-3	28	279	1 : 15	4·317*	73	234	1 : 3	0·244	162	145	1 : 1	0·941	283	24	15 : 1	1·287
CSV-5 × CSV-7R	5	239	1 : 63	0·375	18	226	1 : 15	0·528	63	181	1 : 3	0·087	125	119	1 : 1	0·147
CSV-5 × BP 53	5	221	1 : 63	0·620	20	206	1 : 15	4·682*	62	164	1 : 3	0·713	125	101	1 : 1	2·548
CSV-5 × IS 9985	4	292	1 : 63	0·085	33	259	1 : 15	12·715**	94	198	1 : 3	8·054*	193	100	1 : 1	9·518**
CSV-3 × CSV-7R									0	272			14	258	1 : 15	0·422
CSV-3 × BP 53									66	206	1 : 3	0·078	155	117	1 : 1	5·311*
CSV-3 × IS 9985									51	198	1 : 3	2·710	138	111	1 : 1	2·927
CSV-7R × BP 53									0	205			13	192	1 : 15	0·021
CSV-7R × IS 9985									0	116			17	99	1 : 3	4·260*
IS 9985 × BP 53									0	119			14	105	1 : 3	4·682*

*Significant at 5% **Significant at 1%.

TABLE 3

Joint segregation and χ^2 test for rust susceptibility and plant type (pigment)

	Rust susceptibility (Grades 0–5)							
	1		2		3		4	
Plant Pigments	0	1–5	0	1–5	0	1·5	0	1–5
Tan	28	57	5	49	5	51	4	71
Purple	0	222	0	190	0	170	0	217
Total	28	279	5	239	5	221	4	288

Source	DF	χ^2 Values			
Plant pigment (3:1)	1	1·1747	1·0710	0·0058	0·0730
Susceptibility (63:1)	1	4·3172*	0·3756	0·6206	0·0857
Linkage	1	601·7237**	23·2754**	21·6663**	10·4759**
Total	3	607·2156**	24·7220**	22·2927**	10·6346*

*Significant at 5% **Significant at 1%. 1=CSV–5×CSV–3; 2=CSV–5×CSV–7R; 3=CSV–5×BP 53; 4=CSV–5×IS 9985

mature affecting the quality of forage, but could be disastrous if occurs during early stages of growth.

While Coleman and Dean (1961) observed rust resistance to be controlled by a simple dominant gene, Patil, Kulkarni *et al.* (1972) reported susceptibility to be dominant and that there were more than two pairs of genes with a few modifiers governing inheritance of resistance to rust. They also inferred possible physiologic specialization of the rust fungus.

The present study involving diverse parents indicates that at least three major genes are involved and that susceptibility is dominant. It is, therefore, necessary that both parents should be resistant if commercial hybrids are to be resistant to rust. Presence of 1–2 resistant genes confers different degrees of susceptibility as indicated by duplicate factor and monogenic types of inheritance in comparison involving different grades (Table 3).

The study also reveals that rust resistance is associated with the 'Tan Plant' type and a bio-chemical characterization of the pigments involving 'tan' and 'purple' plant types is a worthwhile study. The tan plant provides phenotypic criteria for selecting resistant genotypes.

It is interesting to note that the cultivar CSV-5 (148/168) a dwarf derivative of the exotic×Indian cross IS 3687×*Aispuri* exhibited resistance to most leaf spots, downy mildew and also tolerance to *striga* parasite. It also combined some tolerance to the insect pests, shootfly and stem borer and is a useful genotype for resistance breeding. However, CSV-5 had shown traces of rust in northern India and this may indicate physiologic specialization of the rust fungus.

SUMMARY

Resistance to sorghum rust (*Puccinia purpurea* Cke.,) is governed by three major genes, susceptibility being dominant. The 'tan' plant type and resistance are strongly linked. There is reason to believe that there may be physiological races of the rust fungus. The cultivar CSV-5 (148/168) a dwarf derivative of the exotic × Indian cross IS 3687 × *Aispuri*, combines satisfactory yields with resistance to most leaf spots, downy mildew and tolerance to *Striga*, shootfly and stem borer and is therefore a useful parent for combining yield and resistance attributes.

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GENETIC ANALYSIS OF SOME EXOTIC×INDIAN CROSSES IN SORGHUM

XVI. EFFECTS OF DIRECTIONAL SELECTION ON YIELD AND COMPONENT CHARACTERS

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There is growing interest in evaluating the effectiveness of various selection schemes and also the role of intermating before selection in self-fertilizing species. That in most genetic situations, between family selection is more effective than within family selection, was brought out by Pederson (1969 a, b). Significant rank correlations between F_3 lines and means of F_5 derived lines of spring wheat were reported by Briggs and Shebeski (1971). More recently, Boerma and Cooper (1975) and Knot and Kumar (1975) compared the effectiveness of various selection schemes and their analyses indicated some merit in single-seed-descent (SSD) procedure. Tee and Qualset (1975) felt that unless competition effects are important, random bulk method is preferable to SSD method. Pederson (1974) felt that truncation selection is usually preferable to intermating as a procedure for increasing the proportion of desirable homozygotes in a population.

In sorghum, height and maturity genes have considerable effects on yields. Continued selection for relatively dwarf stature, earlier maturity and high yields resulted in the dissipation of indirect effects of height and maturing genes on yield, but their influence on yields was still perceptible in advanced generation progenies of exotic×Indian crosses (Subba Reddy and Rao, 1971; Rao *et al.*, 1973). The present paper examines the effects of selection on yield and component characters in advanced generation progenies of some exotic×Indian crosses of sorghum obtained through continued pedigree selection.

Materials and Methods

Thirty advanced generation derivatives from eight exotic × Indian crosses observed to be promising in yield trials and representing a range of height and maturity, the six exotic and four Indian parents, entered into the crosses, eight corresponding F_1's of these derivatives and six checks, 'Swarna' a high yielding variety and five commercial hybrids, CSH–1, CSH–2, CSH–3, CSH–4 and CSH–5, were chosen for the study. The pedigrees of the derivatives are presented below.

Pedigrees of the selected derivatives

Progeny	Pedigree
148, 168, 500, 550, 900	IS 3687 × Aispuri
173, 564, 565, 604	IS 3922 × Aispuri
8, 370, 461, 475, 734, 815	IS 2954 × BP 53
882	IS 508 × BP 53
221, 227, 252, 612, 651,655	IS 2031 × Karad Local
285, 296, 302, 303, 667, 670	IS 3922 × Karad Local
730	IS 508 × Karad Local
713	M. 35–1 × IS 84

The parents, F_1's, derivatives and checks were grown in a randomized complete block design with three replications during *Kharif* season at IARI Regional Research Station, Hyderabad. The entries were randomized according to their height to minimise competition effects. Each plot comprised of four rows of 3·6 metres spaced 60 cm apart. A fertilizer dose of 100 kg N, 60 kg P_2O_5 and 60 kg K_2O per hectare was given. Nitrogen was applied in two split doses, half as basal and the other half as top dressing. Recommended plant protection measures were adopted for the control of shootfly and stem borer.

Observations were recorded from middle two rows leaving border plants on either side. The characters, plant height, number of leaves, panicle length, panicle branches, 100-seed weight were recorded on five random plants; days to 50% flowering, panicle weight, grain yield and dry fodder weight were recorded on plot basis represented by 25 contiguous normal plants selected from the two middle rows of the plot. Panicle, grain and fodder weights were subsequently converted to single plant basis. The analyses of variance and regression were based on standard statistical procedures.

Results

The means and ranges of parents, F_1's, derivatives and checks for the various characters under study and the analysis of variance are presented in Tables 1 and 2.

Significant differences were observed both among parents and derivatives for all the characters except for panicle branches in parents. Although variability within exotic and within Indian parents was observed for most of the characters, differences between exotic and Indian parents were much more pronounced for flowering time, height, number of leaves, panicle length and dry fodder weight. Indian parents were 23 days late in maturity, more than twice in height and five times more in fodder weight as compared to exotic parents.

F_1 hybrids were significantly superior to mid-parent values for all the characters except 100-seed weight. Hybrids were also better than superior parent for panicle weight, panicle branches, plot yield and 100-seed weight.

Derivatives were significantly different from mid-parental values for flowering time, panicle length, panicle branches, fodder weight and 100-seed weight and intermediate between exotic and Indian parents for other characters. Comparisons of derivatives with exotic and Indian parents indicated that derivatives were significantly different from both the parents for all those characters

TABLE 1

Means (M) and Ranges (R) for yield and component characters in exotic and Indian parents, their F_1's and advanced generation derivatives

Entry		Flowering time (days)	Height (cm)	No. of leaves	Panicle			Yield (gm/plant)	Fodder dry weight (gm/plant)	100-seed weight (gm)
					Weight (gm)	Length (cm)	Branches			
Parents	M	75·27	197·67	15·63	74·07	26·27	68·50	50·23	284·86	2·74
	R	62·0–99·0	106·7–322·0	12·0–20·3	55·0–131·0	13·7–37·0	58·7–74·3	30·3–89·7	52·0–760·0	2·14–3·25
Exotic	M	66·00	124·06	14·06	77·39	31·05	66·55	48·05	96·99	2·71
	R	62·0–70·3	106·7–143·7	12·0–15·3	57·0–90·7	20·0–37·0	58·7–74·0	36·0–57·0	52·0–152·0	2·14–3·25
Indian	M	88·75	292·60	18·00	79·00	19·00	71·41	53·49	566·66	2·78
	R	73·0–99·0	267·0–322·0	15·7–20·3	55·0–131·0	13·7–23·7	67·3–74·3	30·3–89·7	309·3–760·0	2·42–3·24
F_1	M	78·17	300·38	17·92	87·83	27·63	73·92	66·11	436·79	2·97
	R	75·0–85·7	255·3–332·3	17·0–19·0	79·3–105·7	21·0–34·7	66·7–85·0	47·7–103·8	324·0–558·7	2·65–3·48
Derivatives	M	78·62	189·82	15·77	79·43	29·70	77·18	53·42	192·58	2·60
	R	62·7–89·3	114·6–303·3	12·0–19·0	53·0–124·3	19·3–37·6	54·3–94·6	30·3–78·0	88·0–470·3	1·83–3·39
Aispuri	M	81·70	185·03	16·82	77·44	25·00	75·93	53·74	189·40	2·84
	R	74·0–87·7	118·3–244·0	15·0–19·0	66·0–94·0	19·3–29·0	54·3–84·6	42·0–66·0	88·6–248·0	2·18–3·39
BP 53	M	83·23	277·20	15·86	74·29	32·00	69·32	43·85	225·15	2·36
	R	62·6–89·3	114·6–303·3	12·0–19·0	53·3–124·3	19·3–36·3	60·3–84·0	30·3–68·6	98·6–470·3	1·76–3·42
Karad Local	M	74·43	122·33	15·06	83·95	31·90	83·08	58·00	180·89	2·55
	R	66·3–85·3	131·0–242·0	12·0–17·0	66·3–126·6	22·0–37·6	68·3–94·6	41·0–78·0	133·0–258·0	1·83–3·66
M35–1*	M	73·00	167·67	14·67	74·67	29·67	66·67	58·00	144·67	2·63
Checks	M	69·66	173·44	14·95	98·94	30·77	67·05	66·15	173·11	2·85
	R	62·3–80·7	147·0–200·0	13·0–17·7	93·3–111·0	27·0–33·0	52·7–87·7	59·6–74·0	110·0–249·0	2·21–3·49

*One derivative.

TABLE 2

Analysis of variance

Source	DF	Flowering time (days)	Height (cm)	No. of leaves	Panicle Weight (gm)	Panicle Length (cm)	Panicle Branches	Yield (gm/plant)	Fedder dry wt. (gm/plant)	100 seed weight- (gm)
Replications	2	9·5	4638**	5·0**	163·7	0·0	22·2	132·6	35349**	0·09
Entries	53	233·8**	13226**	11·8**	1067·5**	94·9**	336·1**	596·9**	74284**	0·79**
Parents	9	544·0**	22845**	18·7**	1451·3**	191·2**	89·1	801·0**	224501**	0·41**
Exotic parents	3	184·1**	3639**	4·5**	410·6	106·5**	110·8	240·4	3419	0·51**
Indian parents	5	377·8**	2782**	11·1**	3662·8**	52·0**	26·0	1930·0**	138415**	0·37**
Indian vs Exotic	1	2842·1**	179066**	111·9**	20·6	1032·0**	169·9	214·4	1588171**	0·01
F_1's	7	84·6**	3079**	1·1	304·4	48·8**	122·9	1279·0**	20686**	0·54**
Derivatives	29	166·9**	7154**	9·6**	835·7**	87·0**	336·1**	443·9**	15529**	0·92**
Between groups	3	473·6**	16315**	17·3**	512·1	319·0**	1002·8**	931·6**	11634	0·95**
Within groups	26	171·1**	6097**	8·8**	873·1**	60·2**	259·3**	387·6**	15979**	1·26**
Within Aispuri Derivatives	8	50·0**	8118**	4·7**	293·6	33·8**	308·5**	202·8	9790	0·55**
Within BP. 53 Derivatives	6	281·5**	7110**	13·2**	1561·9**	107·2**	238·1**	477·6**	48564**	0·98**
Within K. Local Derivatives	12	196·5**	4242**	9·2**	914·9**	54·3**	236·9**	465·8**	3812	1·13**
Checks	5	146·6**	1113**	11·2**	262·1	15·8**	744·0**	121·4	10162	0·74*
Derivatives *Vs* Parents	1	284·1**	60	0·3	41·8	245·8**	1696·7**	228·6	191617**	0·48**
Derivatives *Vs* Indian Parents	1	1090·2**	1118**	52·4**	1·3	1194·7**	352·2*	0·1	1481693**	0·39*
Derivatives *Vs* Exotic Parents	1	2407·8**	2915543**	45·1**	62·4	27·4**	1694·4**	431·7	136987**	0·15
Derivatives *Vs* F_1	1	3·8	231219**	87·5**	1336·0**	81·1**	201·3	3051·2**	1129993**	2·61**
Derivatives *Vs* Check	1	1203·3**	4123**	10·2**	5710·5**	17·3**	1538·7**	2627·4**	65686**	0·99
Parents *Vs* F_1	1	128·4**	158163**	69·7**	1518·3**	24·9**	392·2**	3361·4**	307153**	0·72
Error	106	8·1	240	0·8	213·8	3·8	61·7	142·5	5684	0·06

*Significant at 5% **Significant at 1%.

TABLE 3

Regression analysis of derivatives (D) on Indian Parents (I), Exotic Parents (E) and F_1

Source	DF	Flowering time (days)	Height (cm)	No. of leaves	Panicle Weight (gm)	Panicle Length (cm)	Panicle Branches	Yield (gm/plant)	Fodder dry wt. (gm/plant)	100-seed weight (gm)
Derivatives	29	166·9**	7154·0**	9·6**	835·7**	87·0**	336·1**	443·9**	15529·9**	0·92**
Regression on Indian	1	104·4	2291·5	114·3**	4052·3*	23·0	542·8	7·3	6639·7	15·25**
Residual	28	169·2**	7327·7**	5·9**	720·8**	89·3**	328·7**	459·5**	15847·4**	0·75
Regression on Exotic	1	36·2	194·4	0·4	723·4	1207·5**	4655·7**	27·7	19202·8	0·33
Residual	28	171·6**	7402·6**	10·0**	839·7**	47·0**	181·9**	458·7**	15398·7**	0·94
Regression on F_1	1	471·1	24877·6	22·8	1117·3	1499·9**	333·7	7671·2**	58765·9	4·97*
Residual	28	156·1**	6521·1**	9·2**	825·6**	36·5**	336·2**	185·8	13985·7**	0·78
Error	106	8·1	240·6	0·8	213·8	3·8	61·7	142·5	5684·7	0·06
b_{DI}		0·21	−0·29	−0·84**	−0·22*	0·12	0·96	0·01	0·06	−2·21**
		±0·46	±0·89	±0·33	±0·06	±0·43	±1·29	±0·19	±0·16	±0·48
b_{DE}		−0·27	−0·12	−0·08	0·23	0·64**	1·22**	0·07	−0·51	0·17
		±1·03	±1·33	±0·72	±0·44	±0·21	±0·41	±0·52	±0·80	±0·50
b_{DF_1}		−0·57	0·72	−0·89	−0·39	0·96**	−0·31	−0·67**	0·46	0·69*
		±0·52	±0·64	±0·97	±0·58	±0·26	±0·50	±0·18	±0·38	±0·26

*Significant at 5% **Significant at 1%.

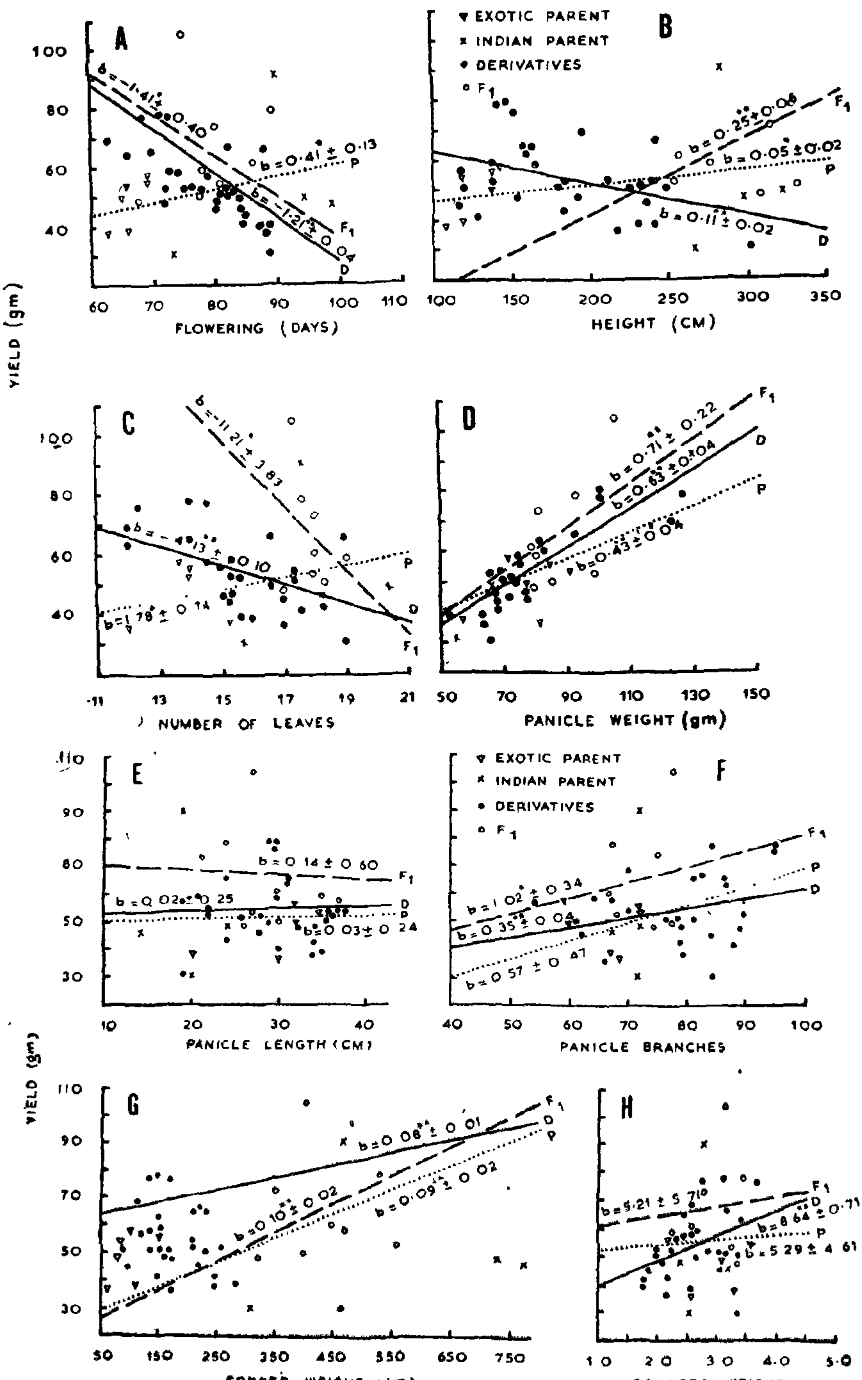

Fig. A-H Relationship between grain yield and component characters in exotic and Indian parents, F_1's and derivatives.

where parental differences were marked. Significant reduction in flowering, height, number of leaves and fodder weight of derivatives evidenced substantial change in plant type of derivatives as compared to Indian parents. Comparison of derivatives of different crosses revealed significant group differences for all characters except panicle and fodder weight. In addition to the between group differences, highly significant differences within each group of derivatives provided further opportunity for selecting superior genotypes from each of the groups. Some of the derivatives of *Karad Local* were early, possessed large panicles, more number of panicle branches, higher yields and better 100-grain weight. With respect to yield, three early derivatives of *Karad Local* (285, 296 and 302) were even better than the highest yielding hybrid while three other early maturing derivatives 370 (IS 2954×BP 53), 227 (IS 2031×Karad Local) and 303 (IS 3922×Karad Local) and two mid-late derivatives, 173 (IS 3922×Aispuri) and 550 (IS 3687×Aispuri) were on par when compared to released hybrids.

Maximum number of transgressive segregates were observed for panicle length, panicle branches and 100-seed weight. Seven derivatives 370 (IS 2954×BP 53), 227 (IS 2031×Karad Local), 713 (M. 35-1×IS 84) and 285, 296, 302 and 303 (IS 3922×Karad Local) were transgressive segregates for yield.

Regression analysis revealed the degree of resemblance of derivatives with parents and their corresponding F_1 (Table 3). The regression coefficient of derivatives on Indian parents was negative and significant for number of leaves, panicle weight and 100-seed weight. However, panicle length and panicle branches of derivatives were determined by exotic parents. Similarly, there was good resemblance between derivatives and F_1's for panicle length, fodder yield and 100-seed weight. Deviation from regression was significant for all characters except 100-seed weight indicating that derivatives were quite dissimilar to either of the parents or the corresponding F_1 due to recombination and selection.

The relationship of yield with other characters substantially changed in derivatives as compared to parents (Figs. 1–8). Flowering time, height and number of leaves showed negative relationship with yield in derivatives unlike parents while panicle weight, panicle branches and seed weight contributed positively to yield. Selection for intermediate maturity and height; increased panicle weight, panicle branches and seed weight resulted in higher yielding derivatives.

Discussion

The parents used in exotic×Indian crosses in sorghum being investigated by us represent tropical and temperate types with extreme differences for plant height, maturity, panicle type and grain yield. Based on quantitative genetic studies, Rao (1970) suggested selection of parents based on performance of line *per se* together with the nature of combining ability and emphasis on between family selection. Experience has also revealed that only a few out of several crosses handled yielded superior progeny of commercial worth.

Strong association of height and maturity genes with yield and possibly pleiotropic effects imposed restrictions on recovering recombinants combining relatively dwarf stature, early maturity and high yields (Subba Reddy and Rao, 1971). Yet, continued selection in promising families resulted in isolation of progenies of commercial value such as CSV-2 (302), CSV-3 (370), CSV-5 (168), CSV-6 (604), and CSV-7R (R-16) released for general cultivation. Present analysis of selection effects on such progenies when compared to their parents and corresponding F_1's revealed that there has been considerable amount of recombination between traits such as height, maturity, yield etc., which in earlier studies exhibited strong associations thus indicating the value of directional selection inspite of established character associations.

While there is some evidence that intermating provides better source material for selection (Miller and Rawlings, 1967), the observations of Pederson (1974) that the 'parent state of our knowledge makes it difficult to generalise on the possible merits of intermating, even for a particular character in a particular species, but the odds are against it being a useful procedure' are worth noting. Reanalysis of the results obtained by Boerma and Cooper (1975) and Knot and Kumar (1975) (Subba Reddy, unpublished) indicates that even the SSD method may not be superior to the pedigree method provided certain precautions are taken. Present studies indicate that with the choice of suitable parents and emphasis on between family selection, directional selection using pedigree method could still increase frequency of desirable homozygotes inspite of strong character associations as furnished by the exotic × Indian crosses in sorghum.

SUMMARY

Effects of directional selection on yield and component attributes in promising advanced generation progenies of selected exotic × Indian crosses of sorghum as compared to their parents and the corresponding F_1 hybirds were studied. Some of the derived lines combined high yields with simultaneous reduction in plant height and days to maturity as compared with the Indian parents. Some derivatives such as 302 (CSV-2), 370 (CSV-3), 168 (CSV-5), 604 (CSV-6) and R-16 (CSV-7R) have also been released for commercial cultivation. It is indicated that with proper choice of parents and emphasis on between family selection, pedigree selection could yield desired results even when character associations tend to restrict progress from selection.

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GENETIC ANALYSIS OF EXOTIC × INDIAN CROSSES IN SORGHUM XVII : RESISTANCE TO GRAIN DETERIORATION

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COMPARED to several improved local varieties of *kharif* sorghums maturing in 150 days, recently developed hybrids and varieties are earlier and mature in 95–110 days. Besides their higher order yields, the early maturity itself confers greater stability in production during normal as well as subnormal years of rainfall (Rao, 1976). While the advantages of early maturing hybrids and varieties during years of drought are very well recognised, in years when continuous rains are received during late September and October, the grains tend to deteriorate. Such grain deterioration is primarily due to soaking during grain drying stage, the development of moulds and the consequent loss of lustre resulting in low market prices. The *kharif* season of 1975–76, characterized by heavy and prolonged rains, provided an opportunity to study the problem of grain deterioration at some depth and develop criteria to select varieties which could withstand deterioration inspite of being caught in rains at harvest. The results of these studies are presented in this paper.

MATERIALS AND METHODS

The *kharif* season of 1975–76 at Hyderabad and the country was characterised by heavy and continuous rains. Hybrids and varieties of sorghum were caught in rains during maturity resulting in grain deterioration.

A large number of breeding lines exposed to intermittent rains for several days after grain maturity were examined for mould development. Based on the extent of mould loading, the entries were classified into six grades, grade-I being most deteriorated and grade-VI least deteriorated (Fig. 1). These grades were represented by released or experimental hybrids/varieties: grade-I by FR-493, grade-II by CSH-1 grade-III by CSV-3, grade-IV by CSH-5, grade-V by 3660A × CS 3541 and grade-VI by CSV-4 and, CSV-5. All the hybrids and varieties were of approximately comparable maturity and the rainfall distribution brought about maximum deterioration in all cases. Since all the seeds of a panicle in each variety were not deteriorated to the same extent, the seeds in each grade were further classified into relatively clean (A), slightly deteriorated (B) and completely deteriorated (C) fractions. Seeds free from fungus in grade-I and completely deteriorated seeds in grade-VI were absent. This resulted in a total of 16 classes.

All the 16 individual classes were examined for water absorption capacity, grain hardness (breaking strength), 100-seed weight and germination percentage. Two samples of 200 grains were selected from all the 16 classes for water absorption study. The water absorbed by 200 grains after each half-an-hour was determined upto six hours and finally at 24 hours. The soaked seeds were subsequently transferred to a soil bench for germination test. The breaking strength of uniform sample of seeds in each class was measured by automatic hardness tester.

Rate of water absorption was calculated on transformed time scale ($Hour^{0.5}$) to induce linearity. Multiple regression and multiple correlation coefficients were computed to ascertain the relationship of grain deterioration and germination with other characters.

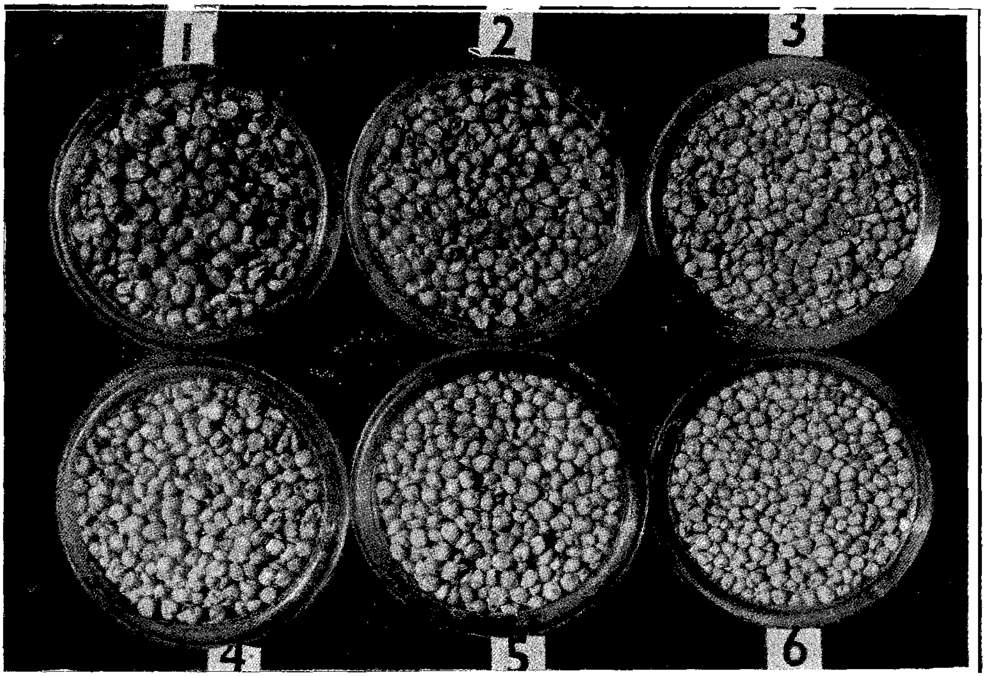

Fig. 1. Different grades of grain deterioration in sorghum

RESULTS

1. *Absorption of water:* The six different grades exhibited variation for water absorption over different periods of time (Fig. 2). Analysis of variance (Table 1) reveals these differences to be significant. The differences, particularly, between highly deteriorated fraction (C) and rest of the fractions became significant even in first half-an-hour while the variation within (C) fractions showed significant differences only after an hour. The rest of the within and between fraction differences also became significant as the time of soaking increased. After 1·5 hours of soaking, the differences within B fractions and between (A) and (B) fractions became perceptible. However, differences between fractions (A) and (B) were highly significant only after 2 hours. Therefore, highly deteriorated seeds can be differentiated after half-an-hour soaking while two hours soaking was essential to differentiate slightly deteriorated (B) and clean fractions (A).

2. *Characters related to grain deterioration and their interrelationships:* In addition to water absorption, grain hardness, germination capacity and seedling vigour of different grades were studied and their relationships to grain deterioration estimated. Data on different grades are presented in Table 2 and 3. It is evident that deteriorated seeds absorbed water more rapidly, they were

TABLE 1

Analysis of variance (M.S.) for water absorption at half-an-hour intervals

Source	DF	0·5 hr	1·0 hr	1·5 hr	2·0 hr	2·5 hr	3·0 hr	3·5 hr	4·0 hr	4·5 hr	5·0 hr	5·5 hr	6·0 hr	24 hr
Replication	1	0·02	0·01	0·00	0·00	0·01	0·02	0·02	0·00	0·00	0·00	0·00	0·01	0·13
Treatments	15	0·06**	0·10**	0·13**	0·15**	0·16**	0·17**	0·17**	0·16**	0·16**	0·16**	0·16**	0·15**	0·16**
A Fractions+	4	0·01	0·01	0·01	0·02	0·02	0·02	0·02	0·02	0·03	0·02	0·02	0·02	0·09
B Fractions+	5	0·02	0·03	0·05*	0·06*	0·07*	0·08*	0·09**	0·10**	0·10**	0·11**	0·11**	0·13**	0·22**
C Fractions+	4	0·06	0·10**	0·11**	0·12**	0·13**	0·12**	0·13**	0·12**	0·13**	0·13**	0·11**	0·13**	0·21**
AB vs C	1	0·49**	0·94**	1·18**	1·30**	1·45**	1·42**	1·35**	1·26**	1·14**	1·10**	0·97**	0·85**	0·08
A vs B	1	0·02	0·03	0·07*	0·10**	0·12**	0·18**	0·16**	0·13**	0·17**	0·18**	0·15**	0·16**	0·02
A vs C	1	0·44**	0·85**	1·13**	1·30**	1·46**	1·54**	1·44**	1·32**	1·27**	1·25**	1·09**	0·98**	0·09
B vs C	1	0·32**	0·60**	0·72**	0·77**	0·83**	0·76**	0·73**	0·70**	0·58**	0·55**	0·49**	0·41**	0·04
Error	15	0·02	0·01	0·01	0·01	0·01	0·01	0·01	0·01	0·01	0·01	0·01	0·01	0·02

*Significant at 5%; **Significant at 1%; + A = relatively clean; B = Slightly deteriorated and C = Deteriorated.

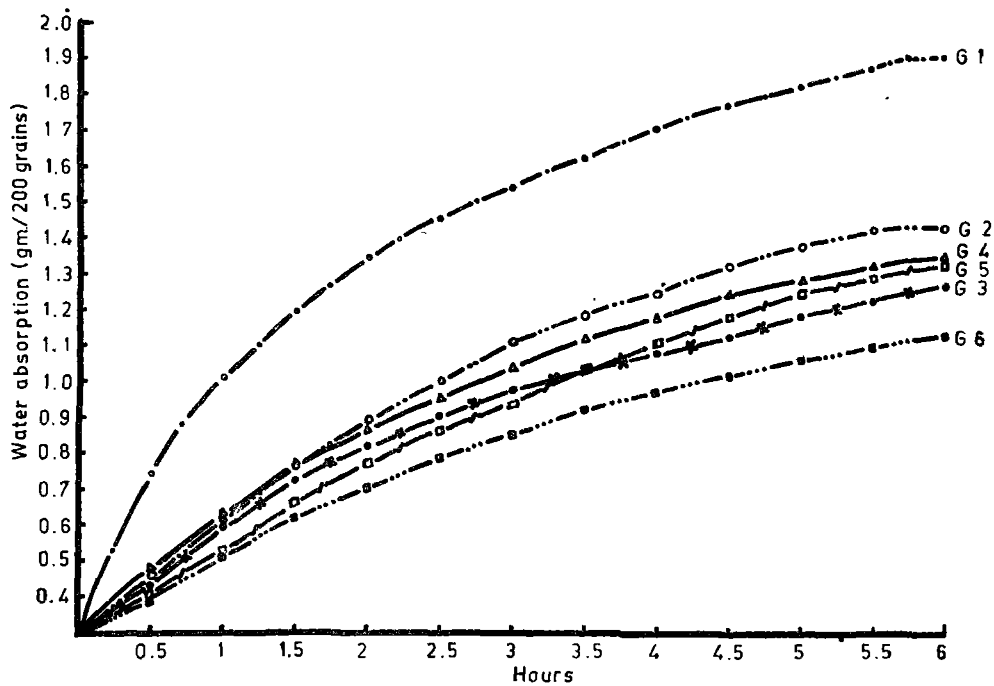

Fig. 2. Absorption of water by different grades (G) of deteriorated sorghums

TABLE 2

Regression analysis of rate of water absorption (gm) by 200 grains $\hat{Y}$=Estimated water absorbed

Grade	on 2 hr basis				on 6 hr basis			
	Mean	b	$\hat{Y}(\sqrt{1\ hr})$	$\hat{Y}(\sqrt{2hr})$	Mean	b	$\hat{Y}(\sqrt{1hr})$	$\hat{Y}(\sqrt{2hr})$
I	1·08	0·81	1·01	1·34	1·50	0·71	0·99	1·27
II	0·69	0·62	0·64	0·90	1·07	0·22	0·91	1·00
III	0·65	0·54	0·61	0·82	0·96	0·18	0·82	0·90
IV	0·68	0·56	0·63	0·87	1·01	0·19	0·87	0·95
V	0·57	0·57	0·52	0·76	0·94	0·22	0·78	0·87
VI	0·55	0·44	0·52	0·70	0·86	0·18	0·73	0·80

soft (low breaking strength) and their germination percentage was also low. The differences between fractions were significant for grain hardness, water absorption capacity, 100-grain weight and germination percentage (Table 4). Comparison of means revealed that relatively clean fraction was characterized

TABLE 3

Grain deterioration and related characters

Grade*	Deteriora-tion %**	Grain hardness+	Water absorbed (gm) at 2 hr by		Germina-tion %**
			200 seeds	100 gm of seed	
I	88	2·7	1·3	15	24
II	88	4·1	0·9	15	56
III	45	4·8	0·8	17	54
IV	37	5·1	0·8	18	59
V	24	8·7	0·7	12	67
VI	4	5·5	0·7	16	65
S.E.	1·7	1·3	0·2	1·5	4·1

*Grade I highly deteriorated, Grade VI least deteriorated. **Transformed value +breaking strength (kg).

TABLE 4

Analysis of variance for characters related to grain deterioration and mean values for different deteriorated fractions

Source	DF	Grain hardness (kg)	Water absorbed (gm.) at 2 hr by		100 grain weight (gm)	Germina-tion (0o)
			200 seeds	100 gm of seed		
			Mean squares			
Fractions	2	11·7*	0·35*	228**	0·36*	973**
Grades	5	10·5	0·19*	32	0·43*	155**
Residual	8	2·1	0·04	3	0·07	19
			Fraction means			
A		6·9	0·67	11	3·01	70
B		5·6	0·81	14	2·81	61
C		3·5	1·18	24	2·47	40
S.E. ±		0·9	0·12	1	0·16	2·7

*Significant at 5%, **Significant at 1%.

by increased grain hardness, low water absorption capacity, higher 100-grain weight and germination. On the other hand, the deteriorated fraction (C) absorbed more water and was soft, light and poor in germination.

Multiple correlation coefficient (R^2=0·90**) indicated that water absorption capacity and grain hardness are highly related with grain deterioration and contributed to most of the variation. The multiple regression coefficients (b_i) revealed that water absorption capacity (31·27±5·92; t=5·28,) was the most important character which contributes to grain deterioration while grain hardness had a bi=(1·69±0·96; t=1·77).

The germinability of seed was affected by grain deterioration and its component characters (Table 5). Among these, grain hardness and deterioration (%) were the most potent characters influencing germination.

TABLE 5

Relation between germination (%) vs. *grain deterioration* (%), *grain hardness and water absorption capacity* (*WA*)

Variables	b	SE	T
1. Deterioration (%)	0·30	0·22	1·34
2. Grain hardness	7·60	0·88	8·63
3. WA/200 grains	5·18	8·55	0·60
	R^2=0·97**		
1. Deterioration (%)	1·12	0·50	2·22
2. WA/200 grains	10·49	21·30	0·45
	R^2=0·81**		
1. Grain hardness	8·11	0·82	9·89
2. WA/200 grains	14·57	5·08	2·86
	R^2=0·97**		
1. Deterioration (%)	0·41	0·12	3·26
2. Grain hardness	7·64	0·86	8·89
	R^2=0·97**		

**Significant at 1%.

DISCUSSION

A solution to the problem of grain deterioration of early maturing hybrids and varieties of sorghum would eliminate a major constraint limiting their wide scale adoption during *kharif* season and could bring about greater stability to sorghum production during normal, subnormal and excessive rainfall years. While hybrid CSH-1 is stable in yield levels in all years, its acceptance is greater in dry years than during wet years when grain deterioration reduces market price.

The problem of grain deterioration due to mould incidence has been investigated by various workers (Narasimhan and Rangaswamy, 1969a, b; Koteswara Rao and Poornachandrudu, 1971 and Ravindranath, 1976). Several genera of fungi were isolated from different varieties with quantitative and qualitative differences. Both saprophytic and pathogenic genera are known to infect the grains and cause deterioration, the more commonly reported fungi being, *Curvularia*, *Fusarium*, *Helminthosporium*, *Phoma* and *Alternaria*. In addition to the role of fungi in deterioration, the glume and plant pigments and process of soaking and drying itself during maturity of grain add to grain deterioration.

Sorghum grains of different varieties differ in their endosperm structure and texture and consequently their capacity to absorb water when caught in rains. Differences in diffusion rates of water in kernels of corn and sorghum were studied by Fan, Chu and Shellenberger (1963) and they found that the diffusion equation derived for particles with arbitrary shape was valid upto 2 hours. The present study, involving water absorption rates of different classes of deterioration, indicated that a two-hour soaking period could distinguish the most deteriorated from the least deteriorated classes and could provide a useful laboratory technique to screen for grain deterioration.

The physical characters, water absorption and grain hardness as determined by breaking strength, are interrelated, the harder seeds absorbing less water. Among the biological factors tan plant types, which are generally resistant to most leaf spots, also show somewhat less development of moulds compared to pigmented (purple) types. Thus, the three factors, a tan plant type, low water absorbing capacity when soaked in water for two-hours and harder seeds (breaking strength $>$ 7 kg) together provide criteria for selection of types with a capacity to stand grain deterioration.

While these three criteria, namely tan plant type, low water absorption rate and hardness of seed may furnish general criteria for breeding mould resistant types, individual fungi may still cause deterioration problems. Hence the precise biochemical basis for mould resistance needs to be worked out. There is evidence that there is a positive relation between the uric acid content of sorghum seed and fungal deterioration and moisture could be correlated with free fatty acids, fungi and apparent uric acid (Parvathappa, Poornima, Raghunathan and Majumdar, 1970). Further studies could enable the determination of criteria needed to breed for total resistance to grain deterioration. Already some success has been achieved in breeding hybrids and varieties like CSH-5, CSH-6, CSV-4, CSV-5 etc., which, compared to CSH-1, withstand grain deterioration. A vast portion of the *kharif* sorghum tract from Malwa plateau to the Deccan receives adequate rainfall. Development of short duration genotypes with capacity to withstand grain deterioration provides for an assured single crop even in subnormal years and a two crop system in years of adequate rainfall. The genetic basis of grain deterioration and development of further resistant types are in progress.

Summary

The problem of grain deterioration in *kharif* sorghums resulting from continuous rains received during maturity has been investigated. The three characters tan plant type, low water absorption capacity when soaked for a 2-hour period and harder seed as determined by breaking strength furnish criteria for selecting types resistant to grain deterioration under wet conditions prevailing during harvest time. Breeding short duration hybrids and varieties with a capacity to withstand grain deterioration can provide for stability of production in dry as well as wet years and also furnish scope for double cropping in years of adequate rainfall.

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Resistance to the sorghum shoot-fly, *Atherigona soccata* (Rondani) and its genetic analysis*

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ABSTRACT : Diallel analysis involving four agronomically superior dwarfs and four resistant varieties of sorghum was undertaken to study the mechanism and inheritance of resistance to the sorghum shoot-fly, *Atherigona soccata* (Rondani). Group differences for egg laying between susceptible and resistant parents, and between susceptible × susceptible and resistant × resistant crosses revealed that resistance to the shoot-fly involved ovipositional non-preference. Tiller development consequent to dead-heart formation of the main shoot and subsequent survival and recovery depended on primary resistance. Resistance was quantitative in inheritance and mainly governed by additive genes. It is suggested that selection from resistant families of agronomicallysuperior × resistant lines would be effective in developing resistant varieties combining dwarf to semi-dwarf stature, earliness and high yield.

A systematic programme of screening for resistance to the sorghum shoot-fly under diverse environmental conditions has been in progress for over a decade in India. None of the varieties screened so far proved to be immune. However, some of the Indian varieties are reported to possess fairly high degree of resistance (Jotwani *et al.*, 1971; Soto, 1972). Investigations on the mechanism of resistance indicated ovipositional non-preference to be the major factor responsible for shoot-fly resistance in sorghum (Blum, 1967; Jotwani *et al.*, 1971). Evidence of some degree of antibiosis (Jotwani and Srivastava, 1970) and recovery resistance (Doggett, 1972) is also available.

While non-preference for oviposition as the predominant mechanism of resistance has been fairly well established, the genetic basis of non-preference itself is not fully understood. Recent studies have revealed that the distribution of resistant and susceptible types in segregating populations fits the normal curve and the inheritance is predominantly additive (Rao *et al.*, 1974; Balakotaiah *et al.*, 1975; Rana *et al.*, 1975). The examination of resistance mechanism and its inheritance would help in the transfer of resistance from the available resistant stocks to agronomically desirable lines of sorghum. The present study is an effort to understand the relationship between different parameters of shoot-fly resistance and inheritance.

MATERIALS AND METHODS

Four Indian cultivars, *viz.*, IS 2146, 4664, 5469 and 5490, selected primarily on the basis of ovipositional non-preference and low shoot-fly damage from the screening trials, and four high yielding agronomically superior but shoot-fly susceptible varieties, *viz.*, CSV–4 (cs 3541), CSV–5 (148), CSV–6 (604) and R–147 were utilized in 8×8 diallel crosses excluding reciprocals. CSV–5 and 6 and R–147 were derived from exotic × Indian crosses while CSV–4 was developed from an exotic × exotic cross. The resulting 28 F_1 hybrids and their F_2 progenies, along with eight parents were sown in a randomized complete block design during the last week of July, 1973 under high shoot-fly infestation conditions at the Indian Agricultural Research Institute, New

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Delhi. There were four replications. The parent and F_1's were sown in single row plots, whereas F_2 progenies were sown in plots of four rows of three metres. The distances between and within the rows were kept at 75 cm and 15 cm, respectively. A basal dose of fertilizers at the rate of 60 kg N, 60 kg P_2O_5 and 40 kg K per hectare, was applied before sowing. Two top dressings of N, each at the rate of 30 kg per hectare, were applied at one month and at boot leaf stage. No chemical control of the shoot-fly was attempted and the material was exposed to natural infestation.

The data were recorded for seven characters, *viz.*, dead-hearts, eggs per infested plant, seedling height, tillers per 100 plants, effective tillers, plant recovery, yield per plant, and yield per productive plant. Eggs were counted at weekly intervals up to three weeks on all the plants, but it was discontinued on the plants showing dead-hearts. The average number of eggs per plant (x) were transformed to square roots after adding 0.5 $\sqrt{(x + 0.5)}$. Dead-hearts were recorded at weekly intervals up to four weeks after germination and were calculated as per cent of total plants in the plot. These percentages were transformed into angles as 0° = Arcsin $\sqrt{\text{percentage}}$.

Some of the infested plants were completely killed but others gave some yield through tillers. The infested plants which gave productive (effective) tillers were termed as 'recovered plants'. The recovery of infested plants was calculated plot-wise as per cent of recovered plants to total infested plants. Tillers per 100 plants were also counted. Effective tillers were calculated as per cent of productive tillers to total tillers produced in a plot. The percentage of effective tillers provided an index of 'recovery resistance'.

Grain yield per plant was calculated on the basis of total and the productive plants per plot. Yield per plant on total plant population basis indicates the yielding ability per unit area, whereas yield per productive plant reveals the maximum yield potential of a variety under unprotected conditions.

Statistical analysis of diallel crosses was done according to Griffing (1956). Correlations and regressions were calculated by following the standard statistical procedures.

RESULTS AND DISCUSSION

Evaluation of parents, F_1 and F_2 progenies

Parents : Significant differences were observed among parents for all the characters except for tillers per 100 plants (Table 1). No variety was found to be immune. On the basis of relative shoot-fly damage, the Indian parents (showing less than 20 per cent dead-hearts) have been designated as resistant parents (R) and derivatives as susceptible (S). Significant variation was observed among susceptible parents for effective tillers and yield per productive plant, while resistant parents showed significant variation for percentage dead-hearts and yield per plant. The comparison between susceptible and resistant parents showed that the two groups of parents were distinct from each other for eggs per infested plant, percentage dead-hearts, seedling height, plant recovery and yield per plant. Resistant parents showed less egg laying and higher plant recovery as compared to the susceptible parents.

The newly released variety CSV-5 (148) gave maximum effective tillers and highest yield per productive plant. Among the resistant parents, IS 5469 and IS 5490 were relatively high yielding and more resistant.

F_1 hybrids : The variation among F_1 hybrids was significant for all the characters except yield per productive plant (Table 1). R × R hybrids were superior to S × S

Table I Analysis of variance of parents F_1 hybrids and F_2 progenies of 8 × 8 diallel crosses between susceptible and resistant parents for eight characters in sorghum

Source	d f	Mean squares							
		Dead-heart (%)	Eggs/infested plant	Seedling height (cm)	Tillers/100 plants	Effective tillers (%)	Plant recovery (%)	Yield per plant (gm)	Yield/productive plant (gm)
Replications	3	1600 00**	0 872**	384 67**	747 33	1020 00**	293 00	745 33**	2294 33**
Treatments	63	584 10**	0 098**	106 03	756 81**	229 58**	561 22**	572 38**	720 30**
Parents	7	1255 57**	0 226**	125 78**	212 00	351 80**	655 59**	583 18**	466 82*
Susceptible (S) parents	3	163 80	0 013	67 63	99 29	667 20**	124 41	46 01	600 93*
Resistant (R) parents	3	278 04*	0 000	18 51	101 03	95 72	40 07	325 49**	274 76
Susc *vs* Resist parents	1	7463 46**	1 540**	622 06**	883 06	173 83	4096 71**	2967 73**	640 66
Hybrid progenies (F_1 + F_2)	55	490 62**	0 084**	105 31**	787 31**	217 98**	552 96**	581 33**	756 32**
Parents *vs* Hybrid progenies	1	1025 11**	0 020	7 16	2892 92**	11 98	353 77	4 73	513 56
F_1 hybrids	27	677 74**	0 134**	124 77**	913 31**	245 38**	612.99**	787 68**	126 15
S × S	5	349 80**	0 096*	66 18*	725 70*	233 06	75 18	264 30**	2235 30**
R × R	5	90 45	0 088*	36 39	428 78	157 13	228 51	273 73**	227 39
S × R	15	172 33*	0 067*	100 96**	837 23**	184 41*	415 09**	966 99**	1440 19**
(S × S) *vs* (R × R)	1	10860 44**	1 280**	1333 64**	3778 12**	1544 44**	8804 12**	4018 84**	79 88
(S × S + R × R) *vs* S × R	1	2604 92**	0 410**	7 78	2550 52**	363 88	2 11	56 55	65 01
F_2 progenies	27	307 32**	0 035	75 23**	321 61	113 80	354 98**	298 34**	249 78
S × S	5	45 01	0 072	36 64	63 46	27 16	87 92	76 05	561 78**
R × R	5	72 46	0 024	5 80	198 02	55 16	121 10	146 26	234 64
S × R	15	224 23**	0 010	61 42**	275 82	77 26	164 61	147 89*	134 40
(S × S) *vs* (R × R)	1	6337 32**	0 160*	867 88**	3230 96**	1406 48**	5918 96**	4722 68**	527 00
(S × S + R × R) *vs* S × R	1	241 94	0 140*	29 69	7 92	95 63	151 33	2 56	219 07
F_1 hybrids *vs* F_2 progenies	1	378 84*	0 050	392 56**	9959 10**	2291 34**	4277 53**	2650 32**	792 45*
Parents *vs* F_1 hybrids	1	1350 69**	0 001	16 62	7051 88**	161 11	1562 96**	369 07**	945 55*
Parents *vs* F_2 progenies	1	558 03*	0 015	83 25	304 33	327 29	16 54	228 31	143 57
Error	189	83 23	0 036	27 86	278 20	112 01	121 38	79 49	182.59
Means									
Parents		67 12	1 41	26 71	43 31	32 58	42 83	22 62	35 74
S		82 40	1 63	22 30	38 06	40 23	31 55	13 19	31 26
R		51 85	1 19	31 12	48 56	34 92	54 15	32.05	40 22
F_1 hybrids		74 50	1 42	25 89	60 15	35 12	50 75	26 47	41 90
S × S		83 97	1 65	20 96	46 00	31 53	37 10	16 51	39 73
R × R		53 89	1 32	31 50	63 75	42.87	64 09	34 82	42.31
S × R		78 66	1 36	25 63	64 10	33 56	50 87	27 07	42 56
F_2 progenies		71 85	1 39	28 54	46 81	28 72	42 01	19 59	38 14
S × S		81 85	1 49	23 19	38 30	24 17	32 25	9 84	33 21
R × R		58 86	1 38	30 87	54 71	35 00	54 46	29 68	39 84
S × R		73 34	1 35	29 66	47 04	28 07	41 00	19 46	39 35

*Significant at 5 per cent **Significant at 1per cent S = Susceptible R = Resistant crosses for all the characters while S × R crosses were intermediate. The range of variation among S × R crosses was maximum which provides opportunity for selecting high yielding resistant crosses.

F_2 progenies : Significant variation was observed among F_2 progenies for percentage dead-hearts, seedling height, plant recovery and yield per plant (Table 1). Large range of variation was maintained among S × R progenies for percentage dead-hearts, seedling height and yield per plant. These progenies were comparable to R × R progenies for plant height and yield per productive plant and were intermediate between S × S and R × R groups for percentage dead-hearts and other characters. However, seven of these progenies were as resistant as R × R progenies. S × S progenies were significantly different for yield per productive plant. Among these, CSV-5 × CSV-6, and CSV-4 × CSV-5 were the highest yielders.

The frequency distribution of dead-hearts (%) in parents, F_1 and F_2 (Fig. 1) shows the range of variation from 35.0 to 87.5 per cent with a mean of 72.3 per cent. The 14 progenies fall within one standard deviation below the mean (μ — 1 S.D.). It is evident that the groups showing resistance comprise resistant parents, F_1 and F_2 progenies of R × R crosses. The F_2 distribution (Fig. 2) has also followed the similar pattern indicating that R × R progenies are one standard deviation below population means and are distinct from the rest. Therefore, selection for high degree of resistance in parents, F_1 or F_2 progenies is limited to resistant groups. The frequency distribution of eggs per plant (Fig. 3) showed that at least one egg was laid on all the entries and no absolute non-preferred entry was available. However, IS 5469, CSV-6 (604) × IS 4664 F_1, and IS 5490 × IS 5469 F_2 fell one standard deviation below the mean. In F_2 distribution (Fig. 4), three progenies from susceptible × resistant and one progeny from resistant × resistant group had eggs one standard deviation below F_2 means.

Heterosis and inbreeding depression : Significant differences between parents and F_1 hybrids indicated positive heterosis for percentage dead-hearts, tillers per 100 plants, plant recovery and yield. Significant differences between parents and F_2 progenies confirmed the existence of residual heterosis for percentage dead-hearts in F_2 generation. Residual heterosis was absent for rest of the characters. The F_1 hybrids were significantly different from F_2 progenies for all the characters except eggs per infested plant. The reduction in percentage dead-hearts is desirable.

The percentage dead-hearts in susceptible parents, S × S F_1 and F_2 remained almost the same while it slightly increased in the subsequent generations of R × R crosses. The increased level of resistance in S × R crosses from F_1 to F_2 generation revealed the desirability of selecting within these crosses for the improvement of resistance and the other characters.

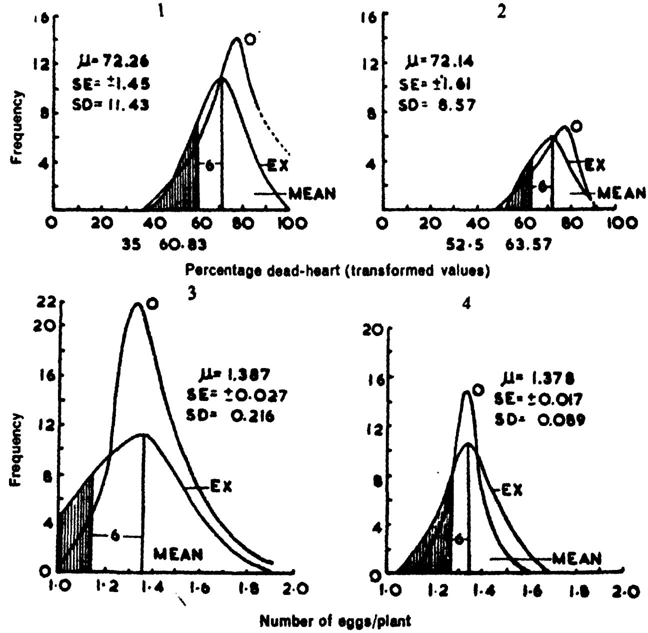
Diallel analysis and nature of gene action

Combining ability analysis : General combining ability effects in F_1 and F_2 generations were significant for all the characters (Table 2). Specific combining ability effects were also significant in F_1 for all the characters but differences diminished in F_2 except for yield per plant.

Estimates of variance and heritability : General combining ability variance ($\hat{\sigma}^2$ gca) was larger than the estimates of specific combining ability variance ($\hat{\sigma}^2$ sca) for percentage dead-hearts and equal for seedling height and plant recovery in F_1 (Table 2). It indicates that additive and additive × additive gene actions are predominant for these characters. The nature of gene action in F_1 for rest of the characters was non-additive as indicated by low proportion of σ^2 gca and heritability estimates. The proportion of σ^2 gca and heritability increased in F_2 for all the characters except number of eggs per infested plant.

Parent off-spring regression : The regression co-efficients of F_1 and F_2 general combining ability effects (gca) on parents were significant for all the characters except for effective tillers in F_1 (Table 3). Therefore, parental performance is reflected in F_1 and F_2 generations. As the regression of average hybrid performance on parents provides the measure of heritability, significant values of regression revealed the high proportion of heritable variance particularly for percentage dead-hearts, plant recovery and yield per plant. Significant regression co-efficients of F_2 gca on F_1 gca and F_2 on F_1 hybrids also revealed the high heritability and determination of F_2 performance by F_1.

Estimates of combining ability effects in F_1 and F_2 : There was uniformity of



Figs. 1—4. 1. Frequency distribution of parents, 28 F_1 and 28 F_2 families in respect of percentage dead-hearts. 2. Frequency distribution of 28 F_2 families in respect of percentage dead-hearts. 3. Frequency distribution of parents, 28 F_1 and 28 F_2 families in respect of number of eggs/plant. 4. Frequency distribution of 28 F_2 families in respect of number of eggs/plant.

Table 2 Combining ability analysis in F_1 and F_2 generations of 8 × 8 diallel crosses for eight characters in sorghum

Source	d f	Dead-heart (%)	Eggs/infested plant	Seedling height (cm)	Tillers/100 plants	Effective tillers (%)	Plant recovery (%)	Yield per plant (gm)	Yield/productive plant (gm)
F_1 hybrids				—					
GCA	7	742.32**	0.100**	93.41	255.88**	114.33**	516.90**	416.78**	324.25**
SCA	28	68.34**	0.021*	14.74*	232.42**	54.00**	73.49**	125.44**	260.67**
F_2 progenies									
GCA	7	543.09**	0.044**	69.18**	202.78**	79.40**	392.40**	298.51**	109.24*
SCA	28	22.75	0.012	9.44	42.79	32.27	28.61	35.78*	63.36
Av error	189	20.81	0.009	6.96	69.55	28.00	30.34	19.87	45.65
				Estimates of variance					
F_1 generation									
$\hat{\sigma}^2$gca		67.40	0.008	7.87	2.35	6.03	44.34	29.13	6.36
$\hat{\sigma}^2$sca		46.53	0.012	7.78	162.87	26.00	43.15	105.57	215.02
$\hat{\sigma}^2$gca/$\hat{\sigma}^2$sca		1.42	0.667	1.01	0.01	0.23	1.03	0.28	0.03
Heritability		49.65	27.590	34.80	1.00	10.05	37.63	18.85	2.38
F_2 generation									
$\hat{\sigma}^2$gca		104.07	0.006	11.95	32.00	9.43	72.76	52.55	9.18
$\hat{\sigma}^2$sca		1.94	0.003	2.84	26.76	4.27	1.73	15.91	17.71
$\hat{\sigma}^2$gca/$\hat{\sigma}^2$sca		53.64	2.000	4.82		2.21		3.30	0.52
Heritability		82.06	30.000	55.86	42.78	22.61	71.78	59.49	12.65
$\hat{\sigma}^2$gca F_2/$\hat{\sigma}^2$gca F_1		1.48	0.750	1.52	13.64	1.56	1.64	1.80	1.44
Heritability F_2/Heritability F_1		1.65	1.090	1.61	42.78	2.25	1.91	3.16	5.32

*Significant at 5 per cent **Significant at 1 per cent

Table 3. Regression coefficients of F_2 and F_1 progenies and general combining ability effects (GCA) of F_1 and F_2 on parents

Regression of	Dead-heart (%)	Eggs/infested plant	Seedling height (cm)	Tillers/100 plants	Effective tillers (%)	Plant recovery (%)	Yield per plant (gm)	Yield/productive plant (gm)
GCA (F_1) on parents	0.463** ±0.061	0.406** ±0.042	0.488* ±0.170	0.504* ±0.195	0.196 ±0.123	0.507** ±0.098	0.463** ±0.109	0.420* ±0.130
GCA (F_2) on parents	0.412** ±0.024	0.270** ±0.026	0.448** ±0.056	0.558** ±0.109	0.230* ±0.079	0.482** ±0.034	0.425* ±0.064	0.268** ±0.059
GCA (F_2) on GCA (F_1)	0.833** ±0.078	0.640** ±0.043	0.763** ±0.163	0.746** ±0.198	0.723** ±0.169	0.818** ±0.122	0.735** ±0.171	0.340 ±0.192
F_2 on F_1	0.565** ±0.071	0.321** ±0.078	0.451** ±0.124	0.206 ±0.109	0.369** ±0.112	0.481** ±0.115	0.364** ±0.097	0.231** ±0.074

*Significant at 5 per cent **Significant at 1 per cent

Table 4 General combining ability effects of eight parents in F_1 and F_2 generations for eight characters in sorghum

Parents	Dead-heart (%)	Eggs/infested plant	Seedling height (cm)	Tillers/100 plants	Effective tillers (%)	Plant recovery (%)	Yield per plant (gm)	Yield/ productive plant (gm)
F_1 generation								
148	7 25**	0 098**	— 1 50	— 9 14**	— 1 18	—10 96**	— 8 99**	— 1 39
604	4 98**	0 094**	— 1 88**	— 5 52	— 2 62	— 5 53**	— 3 35*	— 3 51
R–147	4 56**	0 091**	— 0 79	— 0 10	1 01	— 2.82	1 13	6 06*
cs 3541	13 48**	0 084**	— 5 68**	— 0 10	—55 88**	— 5 93**	— 7 32**	— 6 29**
IS 5490	— 8 86**	— 0 071*	— 1 40	2 93	3 91	5 24**	5 38**	1 92
IS 5469	— 9 36**	— 0 128**	3 09**	4 03	4 55*	8 20**	10 47**	10 33**
IS 4664	— 6 71**	— 0 708*	3 31**	1 81	— 0 20	4 57*	0 20	— 4 09
IS 2146	— 5 34**	— 0 091**	2 04*	6 08*	0 42	7 24**	2 48	— 3 04
SE ($\hat{g}_i$)	1 60	0 033	0 86	3 07	2 01	2 04	1 61	2 40
SE ($\hat{g}_i - \hat{g}_j$)	2 26	0 046	1 22	4 34	2 84	2 88	2.27	3 39
F_2 generation								
148	7 10**	0 048	— 0 29	— 5 58**	0 84	— 6 81**	— 4 82**	2.17
604	6 53**	0 065**	— 0 56	— 4 19*	— 3 18**	— 7 56**	— 5 75**	— 5 47**
R 147	3 19**	0 043	— 2 67**	— 5 82**	— 1 97	— 5 26**	— 3 66**	0 15
cs 3541	9 34**	0 085**	— 4 61**	1 54	— 3 88**	— 2 74*	— 5 22**	— 4 41**
IS 5490	— 9 25**	— 0 057*	1 19	1 68	2 80*	6 37**	5 82**	1 35
IS 5469	— 7 78**	— 0 067**	2 52**	4 75*	3 99**	7 24**	6 97**	3 62**
IS 4664	— 3 60**	— 0 047	1 28	2 64	— 0 06	2 89*	1 40	— 0 13
IS 2146	— 5 53**	— 0 070*	3 23**	4 96*	1 45	5 88**	5 26**	2 72
S E ($\hat{g}_i$)	1 21	0 025	0 74	1 92	1 14	1 13	1 02	1 58
S E ($\hat{g}_i - \hat{g}_j$)	1 58	0 035	1 05	2 71	1 61	1 60	1 44	2 23

*Significant at 5 per cent **Significant at 1 per cent

general combining ability effects in both the generations (Table 4). The susceptible parents were generally poor combiners while resistant parents were better combiners for percentage dead-hearts, egg laying and plant recovery. IS 5469 and IS 5490 were better general combiners for shoot-fly resistance.

Correlation among characters related to resistance

There was positive genotypic association between percentage dead-hearts and egg laying (Table 5). Negative associations of percentage dead-hearts with other characters indicated that tall seedlings, more effective tillers, higher plant recovery and higher yield per plant were phenotypically and genotypically related with low percentage dead-hearts. Similarly, tall seedlings, high plant recovery, high yield per plant and per productive plant were related to low egg laying. High plant recovery was also positively associated with tillers per 100 plants, effective tillers, yield per plant and per productive plant. But some of these associations were liable to be influenced by the environment as indicated by significant environmental correlations. The general trend of correlations of yield per plant and yield per productive plant was similar.

Differential egg laying by the sorghum shoot-fly when groups of heterogeneous varieties were planted side by side resulted in higher mortalities in some of the varieties. Consequently, there were significant group differences between the dwarf derivatives and local Indian varieties for percentage dead-hearts. Significant positive correlation between percentage dead-hearts and egg laying indicated that dead-heart formation depends on the extent of egg laying. The parameter of percentage dead-hearts is thus a good indication of non-preference mechanism. Recently, Rana *et al.* (1975) observed conspicuous group differences for percentage dead-hearts when groups of exotic, Indian, and derivatives of exotic × Indian varieties were planted side by side. The significant group differences established in their study and screening trials under glass house conditions by Soto (1972) add to the evidence that non-preference is the primary mechanism for sorghum shoot-fly resistance.

Doggett (1972) and Blum (1972) have established the existence of 'recovery resistance' as secondary mechanism of resistance. As Indian sorghums were non-tillering, basal tillering was a consequence of failure of the main shoot to grow due to dead-heart formation. However, these tillers did not show any improvement in the level of resistance and were repeatedly killed in both groups of varieties. Shoot-fly still showed preferential egg laying between the tillers of susceptible and resistant varieties. It resulted in higher tiller mortality and low plant recovery in susceptible varieties or crosses while resistant varieties or their crosses still showed high recovery. Tiller survival and plant recovery are, therefore not independent mechanisms in determining shoot-fly resistance. These are the functions of genotypic differences for ovipositional non-preference in parental varieties.

The continuous variation in different generations and intermediate nature of F_1 conforms to the quantitative nature of inheritance. The susceptible parents when crossed with resistant parents resulted in F_1's which were slightly more susceptible than the mid-parental value and thus, susceptibility appeared to be partially dominant. However, Rao *et al.* (1974) have reported partial dominance for resistance in exotic × derivative and derivative × derivative crosses. Such a shift in dominance for ovipositional non-preference appears due to differences in shoot-fly infestation. Blum (1972) also observed that non-preference for oviposition was dominant when evaluated under low shoot-fly population, but susceptibility was dominant with high infestation. indicating complex inheritance.

Table 5. Phenotypic (P), genotypic (G) and environmental (E) correlation coefficients for 64 treatments (8 parents $+$ 28 F_1 $+$ 28 F_2) among eight characters in sorghum

Criterion		Dead-heart (%)	Eggs/infested plant	Seedling height (cm)	Tillers/100 plants	Effective tillers (%)	Plant recovery (%)	Yield/plant (gm)
Eggs/infested plant	P	0.225						
	G	0.695**						
	E	— 0.108						
Seedling height (cm)	P	— 0.559**	— 0.214					
	G	— 0.733**	— 0.650**					
	E	— 0.400**	0.007					
Tillers/100 plants	P	0.093	— 0.007	0.952				
	G	— 0 167	— 0.231	0.243				
	E	0.314**	0 083	0.015				
Effective tillers (%)	P	— 0.216	— 0.007	0.239	0.498**			
	G	— 0.770**	— 0.244	0.623**	0.669**			
	E	0.102	0.067	0.084	0.445**			
Plant recovery (%)	P	— 0.387**	— 0.275*	0.330**	0.677**	0.582**		
	G	— 0 696**	— 0.567**	0.567**	0.856**	0.925**		
	E	— 0.029	— 0.115	0.142*	0.583**	0.453**		
Yield/plant (gm)	P	— 0.439**	— 0.184	0.368**	0.515**	0 521**	0.704**	
	G	— 0.582**	— 0.409**	0.600**	0.702**	0.938**	0.812**	
	E	— 0.218**	— 0.033	0.141*	0.409**	0.337**	0.589**	
Yield/productive plant (gm)	P	— 0.172	— 0.070	0.226	0.178	0.231	0.182	0.715**
	G	— 0.240	— 0.299*	0.403**	0 216	0.497**	0.311*	0.752**
	E	— 0.106	0 048	0.099	0.160*	0 125	0.076	0 700**

*Significant at 5 per cent **Significant at 1 per cent

There is general agreement between parental performance and their general combining ability effects in both the generations for percentage dead-hearts and egg laying. The dose effects in susceptible × susceptible, susceptible × resistant, and resistant × resistant progenies indicated the gradual accumulation of resistant genes and, therefore, showed the additivity of effects. Components of genetic variance provided further evidence for the predominance of additive gene action for percentage dead-hearts and egg laying in both F_1 and F_2.

Among resistant parents, IS 5469 and IS 5490 have emerged as the general combiners for shoot-fly resistance but the crosses between these and similar resistant varieties did not provide further advantage in improving the resistance, plant type or yield *per se*. This is primarily due to excessive height and low yield potential of Indian resistant varieties. However, recently released high yielding varieties are the dwarf version of Indian types and are agronomically superior. Crosses between these two groups of varieties showed significant variation for percentage dead-hearts, seedling height and yield and, therefore, provide sound base for resistant breeding. Some of the crosses such as CSV–5 × IS 5469, CSV–6 × IS 2146, and R 147 crosses with IS 2146, IS 4664, IS 5469 and IS 5490 combine resistance, higher yield and dwarfing genes.

The positive association of resistance with seedling height and performance *per se* of resistant varieties for other characters suggest the necessity for selecting the dwarf and high yielding plants from resistant families of susceptible × resistant crosses. Predominance of fixable genes in F_2 for seedling height, yield and resistance revealed simultaneous effectiveness of such a selection. However, selection may be more effective when between family differences get established for resistance. It also appears that the resistance may be increased gradually due to additive nature of genes as well as absence of major genes. It is reported that shoot-fly resistance is a threshold character (Balakotaiah *et al.*, 1975; Rana *et al.*, 1975). Under such circumstances, where absolute resistance is lacking and threshold depends on shoot-fly population, low intensity of selection pressure should be applied under reasonable levels of infestation (50–80%). Selection for effective tillers or plant recovery *per se* seems to be unnecessary, being a function of dead-heart formation in the main shoot.

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TOWARDS A SORGHUM REVOLUTION

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It is often stated that the impact of the hybrids has not been felt on overall sorghum production in the country. The magnitude of coverage of hybrids, which is of the order of about one million hectares, is not adequate enough to bring about an impact on total production. The coverage has been rather selective and confined mainly to certain kharif tracts in Maharashtra and Karnataka and *maghi* (early rabi) areas in Andhra Pradesh. In other states the programme has been very small.

Research efforts under the All India Co-ordinated Sorghum Improvement Project have resulted in the development of suitable hybrids and high-yielding varieties together with the necessary production technology for the various sorghum states and agroclimatic regions. With concerted efforts, it is now possible to bring about the much-needed change in the productivity levels and impart stability to the production of this great millet, almost a totally rainfed crop.

Production Trends in 1970's

The area, production and productivity in Maharashtra, Karnataka and Andhra Pradesh, the major sorghum-growing states, are given in figure on page 7.

Maharashtra. The coverages under hybrids have been primarily confined to the kharif season which varied between 3-7 lakh hectares during different years. Coverages during rabi have been negligible while in kharif they have touched a maximum of 25 per cent.

Overall kharif production and productivity has steadily gone up during this decade while it is not so during rabi. The upward trend during kharif is obviously due to the hybrid coverages.

Karnataka. Out of the kharif area of 10-11 lakh hectares, 4-5 lakh hectares are under hybrids and this has more than doubled yield levels during 1970's when compared to the productivity during 1960's before the advent of hybrids. Even in Karnataka programme emphasis is during kharif where there is perceptible impact while in rabi there is no worthwhile production programme. Rabi sorghum, therefore, requires special attention to enhance overall production.

Andhra Pradesh. Jowar production in Andhra Pradesh which stood at 9.67 lakh tonnes during 1970-71 steadily rose to 15.71 lakh tonnes during 1974-75. This increase in production primarily came from the rabi (*maghi*) season rather than kharif. While the rabi (*maghi*) production steadily grew from 3.79 to 9.00 lakh tonnes and the productivity from 377 to 618 kg/ha during this period, production and productivity during kharif did not exhibit such a trend. The high-yielding varieties programme in Andhra Pradesh is concentrated during *maghi* (early rabi) and its impact on production is perceptible compared to kharif.

The 1975-76 season in Andhra Pradesh was wet resulting in delayed *maghi* plantings and there was no rain after sowing and this had some adverse influence on production. The 1975-76 statistics are not yet available.

Madhya Pradesh. Madhya Pradesh is a totally kharif *jowar* state and a very potential one for enhancing jowar production and productivity. With assured rains and retentive black soils, a good portion of Madhya Pradesh is an assured single crop belt for jowar and a potential two crop belt where jowar can be followed with a rabi crop. Production programmes have been of a limited magnitude and with the available varieties and hybrids and the necessary information on production technology, Madhya Pradesh could make rapid strides not only in advancing sorghum production but convert sorghum land into a two crop belt.

Other States. Production trends as well as programmes in other states do not reflect any particular trend but there is considerable scope to take advantage of available information and launch large scale production programmes.

Stability of Production

The years 1972-73 and 1975-76 probably represent the limits of rainfall with respect to the total precipitation as well as duration of the rainy season; 1972-73 was dry with a short rainy season whereas 1975-76 is a usually wet year with an extended monsoon (Table 1).

These two years furnish almost a life time experience and if crop yields are high and stable during

TABLE 1. RAINFALL ATTRIBUTES OVER TEST LOCATIONS

Year	*Total rainfall (mm)*	*No. of rainy days*	*C.V. (%) of monthly rainfall*
1972-73 (Av. of 29 locations)	634	42	153
1975-76 (Av. of 25 locations)	989	69	136

such extremes, they may be expected to be repeatable during every other year in spite of seasonal fluctuations.

During kharif, grain yields of traditional late locals were affected due to moisture stress during 1972-73 whereas during 1975-76, the limitation in some areas was earhead pests and not moisture limitation. Overall production of sorghum is certainly far higher during 1975-76 compared to 1972-73. While the performance of early hybrids and varieties was more stable during both the years, their performance was slightly better during the year 1972-73 when yield levels as well as grain quality of such entries was superior compared to 1975-76 (Table 2).

TABLE 2 MEAN GRAIN YIELDS (Kg/ha) OF PROMISING SORGHUM HYBRIDS AND VARIETIES

Hybrids/varieties	*Mean yields*	
	1972-73 (35 locations)	*1975-76 (32 locations)*
Hybrids		
CSH-1	3602	2869
CSH-5	3925	3658
CSH 6	4013	3166
Varieties		
CSV-1 (Swarna)	3372	2245
CSV-3 (370)	—	2547
CSV-4 (CS3541)	2716	2292

This could be due to greater weed competition, less opportunities for cultivation and even low seed weights resulting from soaking of grains at harvest during 1975-76.

In 1972-73 rabi season, traditional varieties with traditional sowing dates failed for want of adequate profile moisture and advanced sowings with early hybrids returned satisfactory yields. During 1975-76, September plantings of high-yielding varieties returned substantially higher yields while delayed plantings which went into November returned low yields. In spite of heavy rains, delayed plantings suffered due to low temperatures at germination resulting in slow growth and absence of rain during crop growth resulted in early cracking of soils.

Thus, during both the years the performance of high-yielding hybrids and varieties of 100-110 days maturity was superior during kharif while during rabi early planting of suitable varieties returned high and stable yields. Sorghum production technology has, therefore, to follow these principles with suitable adjustments to suit local needs during scanty as well as surplus years of rainfall.

Crop Performance versus System Performance

While traditional varieties exhibit wide fluctuations in yield levels in abnormal and normal years, average production of early high-yielding hybrids and varieties *tends to be* reasonably stable in their yield levels. Does this mean that the new varieties did not get the advantage of an extended or better monsoon and to that extent productivity of the land in question has suffered? This leads us to a study of agricultural systems.

All agricultural systems are time-dependent and dynamic; dryland agricultural systems are also cimate-dependent. Traditional dryland agriculture, either in the form of growing sole crops or mixed crops, provides for a greater survival value rather than confer advantages of greater productivity. Any alternative system has not only to provide for crop productivity in a stress year but should also take into account the system productivity if prevailing rainfall situation provides for adequate moisture.

Intercropping systems. With particular reference to dryland agriculture, an intercropping system needs to be designed in such a way that in case of unfavourable weather at least one crop will survive to return economic yields thereby providing the necessary insurance against the unpredictable weather. In case the year happens to be normal, with respect to rainfall the intercropping system as a whole should prove to be more profitable than growing either of the crops.

Studies on intercropping systems in the project involved development of suitable genotypes which offer least competition and development of suitable planting patterns so as to identify remunerative intercropping systems.

Data showed that while maintaining the yield levels of sole crop of sorghum, additional yields with the intercropping have been realised in various systems. Since a food legume is involved in most of the systems, it will not only enhance the income of the farmer but would also provide the much-needed protein to supplement predominantly cereal diets of sorghum-consuming population.

Sequence cropping Of the total area under sorghum, approximately 4-5 million hectares may be considered as a potential two-crop belt.

But for the genotypic change, a two crop sequence is virtually unthinkable and hence genotypic changes have to be the fore-runners to changes in dryland cropping systems. A two crop system is economically more productive and profitable than manipulating productivity of a single crop during a better rainfall year. Similarly, the practice of growing *mung* followed by rabi *jowar* or groundnut-rabi jowar as in Nellore district of Andhra Pradesh in otherwise single cropped rabi belts is a useful practice both from the point of view or enhanced productivity as well as soil fertility build-up.

Some constraints in the practice of such systems are illustrated by the following instances. 'CSH-1' is no doubt productive in dry and wet years, but the grain deterioration in wet years renders the grain unattractive and hence is of low market value. If it is a variety its germinability during the successive season may also be low.

If productivity of drylands has to go up, the traditional system has to yield to an alternative system sooner or later and in this process problems like grain deterioration, germinability, etc. should be guarded both by genotypic and management manipulations. The deterioration problems with 'CSH-5', 'CSH-6' and 'CS 3541' are much less compared to others. Future varieties may have capabilities of not only withstanding deterioration but still retain germinability even if caught in rains. Alternatively, offseason seed production or ratoon seed may circumvent these problems about which we should be conscious.

Current thinking to treat the entire country as one maturing zone and consciously working towards this would not only minimize ear-head pest problems, but could also enable the practice of two crop systems in normal years and return assured single crop yields in subnormal years. Production programmes should, therefore, get to a system approach from a crop approach.

Management during Kharif Season

Present situation on varietal choice is fairly clear. 'CSH-1, 'CSH-5' and 'CSH-6' among hybrids and 'CSV-3 (370)' and CSV-4' (CS 3541') among varieties have wide adaptation during kharif. The varieties 'CSV-2 (303)', 'CSV-5 (168)' and 'CSV-6 (604)' have been recommended for specific situations. Present variety recommendations for the country are given in Table 3.

Adequate research information on times of sowing, levels and times of fertilizer application and population levels is available.

Time of sowing. Sowing with the onset of monsoon during kharif eliminates shootfly attack and returns high yields. This involves no money but continuous education to the farmers and propagation by extension agencies

Plant population. Unlike locals about 1,80,000 to 2,00,000 plants per hectare are essential if we are to realise the full potential of high-yielding varieties and hybrids and this could be accomplished by using a seed rate of 10 to 12 kg ha. Seed costs are relatively low and in case of varieties they could be much lower. A plant at every 4" to 6" in rows spaced 18" apart is essential.

Fertilizer use. In addition to use of compost and farmyard manure, 30 to 40 kg N and 30 to 40 kg P_2O_5 per hectare in the form of inorganic fertilizers to the high-yielding varieties would return per kg of nitrogen three times more grain yield than locals. In black soils all nitrogen and P_2O_5 could be applied basally whereas in light-textured soils, nitrogen should be given in two doses, half basal and the other half at 30 to 40 days after sowing Applying available fertilizer to high-yielding varieties in itself results in efficiency of fertilizer use. Nitrogen responses are optimum up to 80 to 100 kg N/ha and should be applied when fertilizer supplies are not limiting.

Pest avoidance and pest control. Most sorghum pests can be avoided. Planting with the onset of monsoon avoids shootfly. Enbloc coverages and varietal choice of similar maturing types would avoid midge. Both these aspects need only education and changes in the emphasis of extension efforts. If planting is necessary during shootfly build-up seed treatment with carbofuran 5 parts (AI) for 100 parts of seed gives effective control.

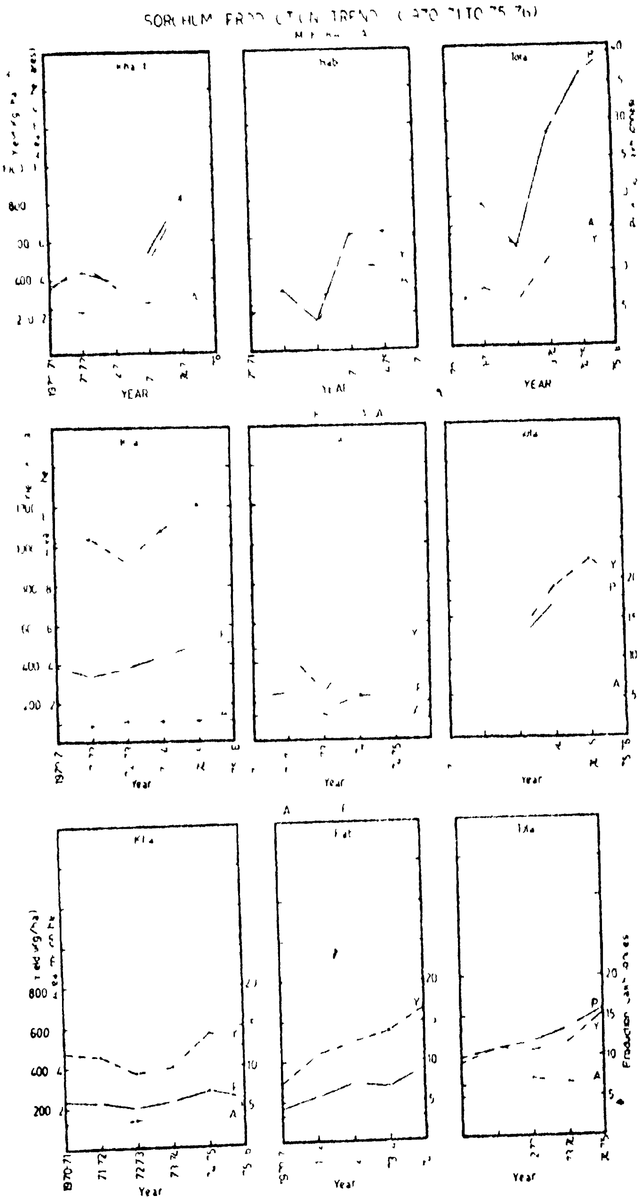
Stem borer damage can be checked by one or two applications of granules of 4 per cent endosulfan, 4 per cent carbaryl or 2 per cent lindane in the whorls.

Midge is effectively controlled by spraying earheads before flowering (at about 50 per cent panicle emergence) with endosulfan (35 per cent EC) one litre, carbaryl (50 per cent WP) 3 kg, lindane (20 per cent EC) 1 to 2 litres in 500 to 600 litres of water per hectare. Repetition of the spray after 4-8 days is desirable. Four per cent endosulfan dust or 10 per cent carbaryl dust or 10 per cent BHC dust at 20 kg/ha is also effective. Two applications will be necessary as in the case of sprays.

Pre-emergence application of Atrazine 0.5 kg (AI) ha followed by a late weeding controls weeds.

Generally, the locals have exhibited greater tolerance to shootfly compared to some of the high yielding hybrids and varieties. Present efforts are to recommend high yield hybrids at optimum time of sowing when there is no shootfly build up. Treatments like Carbofuran seed treatment are recommended only in endemic areas or under conditions of pest build up. As far as midge is concerned, the locals exhibited greater susceptibility and current efforts are to check this first through suitable varietal planning and resort to protection only as the next step. Thus the emphasis on insects control is through pest avoidance rather than chemical killing.

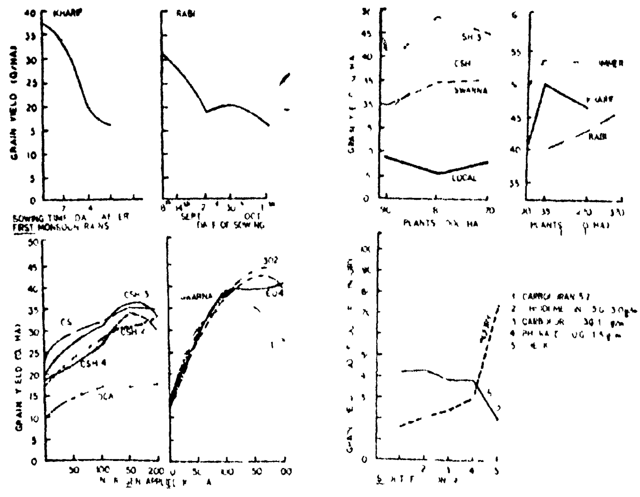
From the point of view of disease resistance, all hybrids are superior to locals. Amongst varieties, downy mildew resistant and susceptible varieties are available and care is taken to avoid susceptible varieties in endemic areas. Diseases have not been a major constraint to sorghum yields. Superior varieties combining high yields, better grain quality and tolerance to pests and diseases are in the offing.



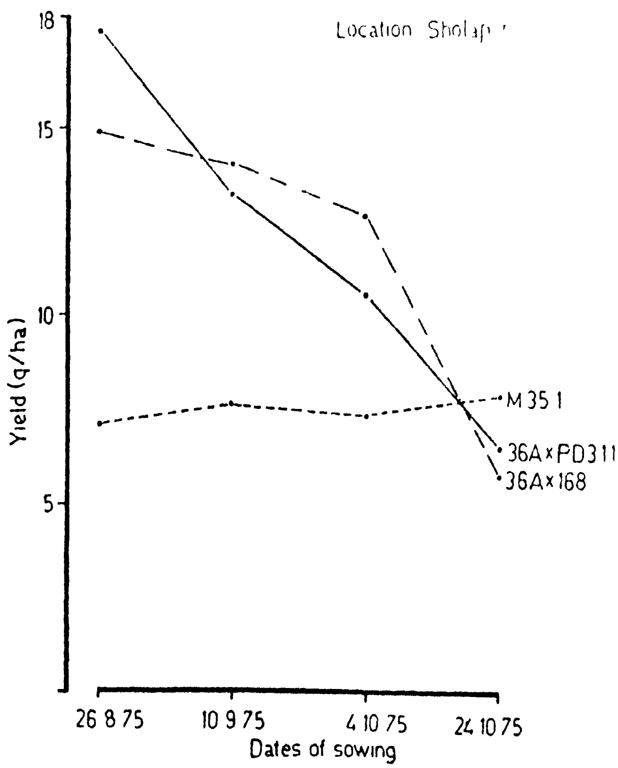
Area, production and productivity of sorghum in Maharashtra Karnataka and Andhra Pradesh (1970 71 to 1975 76)

A planned experiment with high and low managements as treatments was laid out at five locations during kharif 1974 and 1975. The high management comprised 80 kg N/ha and full plant protection. The low management plots received 40 kg N/ha and no plant protection. It is evident that the high-yielding hybrids and varieties are superior to locals both under low as well as high managements.

From available evidence, it appears that what is more important is the choice of varieties based on their insect and disease reaction and appropriate duration to suit a given tract in kharif.



Component of production



Yield of sorghum as affected by different dates of sowing

Once this choice is made the management practices, whether it is local or high yield hybrid or variety do not really change. The only difference is that the response of the high yield varieties is several times that of locals to all management inputs.

Rabi Jowars

Rabi jowar yields are generally lower compared to kharif. Since most rabi jowars depend on residual soil moisture and practically no rains are received during crop growth their yields are a function of kharif rains and in years when late monsoon rains fail, rabi yields tend to get further reduced.

Varietal situation The varietal situation in rabi has not been as good as during kharif. Presently the situation has improved and there is some promise with respect to hybrids as well as varieties.

The performance of the hybrids 'CSH 7R' and 'CSH 8R' and the variety 'SPV-86' and a few IR varieties has been particularly promising under advanced dates of planting and could serve the immediate needs.

Dates of planting The results of advancing dates of planting have been striking during 1972-73 as well as during 1975-76. During 1975-76 September plantings returned higher order yields whereas late October-November plantings returned low yields. The performance of new hybrids and varieties under early plantings is striking whereas under the traditional system their superiority is not reflected and under such conditions 'M 35-1' may still be the best.

Fertilizer application Opportunities for fertilizer application under advanced plantings are greater compared to traditional late sowings. The use of a fertiliser drill like the Maharashtra Token Yantra on a large scale is worth attempting.

Population levels Traditionally lower seed rates have been recom-

TABLE 3. VARIETAL RECOMMENDATIONS FOR DIFFERENT STATES

States	Hybrids	Varieties
		KHARIF
Maharashtra	CSH 1, CSH-4, CSH-5, CSH-6	CSV-2 (302/303), CSV-3 (370), CSV-4 (CS3541), CSV-5 (148/168), CSV 6 (604), CSV-1 (Swarna)
Karnataka	CSH-1, CSH 2 CSH-5, CSH 6	CSV-3 (370), CSV-5 (148 168), CSV-4 (CS3541), CSV-1 (Swarna)
Andhra Pradesh	CSH-1, CSH-5 CSH 6	CSV-3 (370), CSV 4 (CS3541), CSV-1 (Swarna), CSV 2 (302,303), CSV 6 (604), 329
Madhya Pradesh	CSH 1, CSH-5 CSH-6	CSV-3 (370), CSV 2 (302/303), CSV 4 (CS3541) CSV-6 (604)
Rajasthan	CSH-1, CSH-5 CSH-6	CSV 3 (370), CSV-2 (302/303), CSV-4 (CS3541), CSV 6 (604)
Gujarat	CSH-1, CSH-5 CSH 6	CSV-3 (370), CSV-2 (302/303), CSV-6 (604)
Uttar Pradesh (Bundelkhand region)	CSH-1, CSH-5 CSH-6	CSV-2 (302,303), CSV-3 (370), CSV 4 (CS3541) CSV 6 (604)
Tamilnadu	CSH-1, CSH-5 CSH-6	CSV-1 (CS3541), CSV-5 (148/168)
		RABI
Maharashtra	CSH 7R, CSH-8R, CSH-1, CSH-4, (CSH-1, & CSH-3 when profile moisture is very low)	M. 35-1, CSV-7R (R-16) (For early planting only)
Karnataka	CSH-1, CSH-7R, CSH 8R	M 35-1, CSV-7R (R-16) (For early planting only)
Andhra Pradesh	CSH-1, CSH-7R, CSH-8R	CSV-2 (302/303), CSV 4 (CS3541), CSV 5 (148/168) (For uplands), CSV 7R (R-16)
Tamilnadu	CSH-1, CSH-7R Kovilpatti Tall, CSH-5, CSH-6, CSH-8R	CSV 4 (CS3541), CSV-5 (148/168)
Gujarat	CSH-1, CSH-7R CSH-8R	CSV-7R (R-16)
		SUMMER IRRIGATED
Tamilnadu	CSH-1, CSH-5, CSH-6	CSV-1 (Swarna), CSV-5 (148/168)
Karnataka and Andhra Pradesh	CSH-1, CSH-5 CSH-6	CSV-1 (Swarna), CSV 5 (148/168)

mended for rabi. Under advanced dates of planting, seed rates should be almost like kharif 9-10 kg/ha and the response of high-yielding varieties is superior to locals. A population level of 130,000-140,000 plants/ha is optimal.

Carbofuran seed treatment At least in the initial stages of rabi production programme carbofuran seed treatment may have an advantage for it provides protection against seedling pests like sootfly as well as delfacids and helps in stand establishment.

Subject to operational limitations rabi production programmes should emphasize:

(1) Advanced dates of planting with new hybrids and varieties
(2) All basal fertilization
(3) Higher population levels
(4) Carbofuran seed treatment
(5) A preceding mung or some other short season legume

Global Opportunities For Indian Sorghums

Though not in a systematic way, the hybrids and varieties of sorghum developed under All India Co-ordinated Sorghum Improvement Project have been tested sporadically in different parts of the world.

'CSH-1' was used in rice based cropping systems in Philippines and a direct planted rice followed by 'CSH-1' and its ratoons yielded maximum food per hectare per year. The performance of 'CSH-1' was also promising in several parts of Africa and Bangladesh.

'CSH-2' tried in Brazil along with several commercial US hybrids topped the list, but subsequent studies were not taken up.

'CSH-5' and 'CSH-6' exhibited their superiority in Pakistan, Senegal, Upper Volta, Philippines and other areas.

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early July) plantings both the parents of 'CSH-5' were found to flower almost at the same time at most of the locations, while the parents of 'CSH-6' differ by 10-15 days, the female being early. In the September plantings a sort of reverse trend is seen. While there is a widening of gap between the parents by about 7 days in 'CSH-5' the male being early, the gap is narrowed down to 5-7 days in 'CSH-6' the female continues to be early. From October onwards throughout rabi season and up to January plantings in 'CSH-6' the differences between the parents are only marginal, while in CSH-5' wide disparity in flowering ranging from 10-30 days has been observed depending upon the location as well as time of planting. During this entire period (October-January) the male line is earlier than the female line in 'CSH-5'. In October plantings the differences usually range between 10-20 days and during the period November-January the differences are of higher magnitude.

A critical analysis of the data on flowering reveal that the male line 'CS 3541' is least affected by changes in day length and temperature. It usually flowers in about 70-75 days during kharif and summer and 75-85 days during rabi. On the other hand, the female parent 2077A is quite sensitive to variation in temperature. Thus both in winter and summer it tends to flower very late. In June-September plantings it flowers in 70-80 days while in October-January plantings it takes 90-110 days for flowering. But, in locations which do not exhibit wide fluctuations between day and night temperature during winter as in coastal Andhra Pradesh and Coimbatore area and where the summer temperatures are not very high as in Coimbatore and Bangalore areas the delay in flowering of '2077A' is not so pronounced. However, an early flowering sister line of '2077A' and late flowering sister line of 'CS 3541' are now available. Replacing one of these lines in the production of 'CSH-5' is expected to solve the nicking problem in this hybrid soon.

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SORGHUM REVOLUTION

Amongst varieties, 'Swarna' (CSV-1), CSV 2 (302), CSV-4 (CS 3541) and CSV-5 (168) performed well in Upper Volta, Philippines and Pakistan.

Systematic studies could reveal areas of adaptability for Indian sorghum hybrids and varieties in different parts of the world.

Thus, it is seen that both during kharif and rabi seasons, there is adequate research information to support production programmes. Presently available research data not only support sorghum production programmes but also sorghum-based cropping systems, thus enhancing land productivity of a vast sorghum belt. Some of the hybrids and varieties developed under the All India co-ordinated sorghum Improvement Project also offer immense potentialities for different parts of the world.

GENETIC ANALYSIS OF SOME EXOTIC × INDIAN CROSSES IN SORGHUM XVIII. BREEDING FOR RESISTANCE TO GRAIN DETERIORATION

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The problem of grain deterioration in *kharif* season sorghums resulting from continuous rains received during maturity has been under investigation. In an earlier paper, Rana *et al.* (1977) observed that the characters tan plant type, low water absorption capacity and hardness of seed furnished criteria for selecting types resistant to grain deterioration. The present paper examines the breeding behaviour of crosses involving parents exhibiting diversity for the above characters and provides guidelines in breeding for resistance to grain deterioration.

Materials and Methods

Two sets of experiments were conducted to estimate the nature of gene action for characters conferring resistance to grain deterioration.

Experiment 1: The first experiment comprised 40 hybrids based on five male sterile lines (36A, 296A, 2277A, 2947A and 3660A) and eight male parents (148, 168, 232, 287, 641, 887, 1324 and CS 3541). The male parents except CS 3541 were derived from exotic × Indian crosses and are referred to as derivatives. The parents, 296A, 2277A, 2947A among females and 148, 168, 641, 887 and CS 3541 among males were 'tan' while the rest of the females and males had purple pigment on their leaves and leaf sheaths. This experiment was conducted during *kharif*, 1975. The rainfall extended upto November and seeds in panicle were exposed to intermittent rain for several days after maturity. The seeds of different entries were examined for mold development and classified into six grades, grade-I being most deteriorated and grade-VI, the least. Seeds from a panicle were sub-divided into relatively clean, slightly deteriorated and completely deteriorated fractions to account for the within head variation. The percentage of seeds in I to III grades to total seeds in a sample was termed as per cent grain deterioration. Grain hardness in terms of breaking strength in kg and water absorbed by 200 grains at two hours were recorded on five random plants per plot.

Experiment 2: Two parents, CS 3541 (CSV-4) and 168 (CSV-5), from the above study were selected to initiate a breeding programme for resistance to grain deterioration. A set of agronomically desirable lines including these two varieties and four other promising high yielding, tan lines developed from the derivatives of exotic × Indian crosses were chosen and each of them were crossed with five exotic lines: IS 12573, P 721, SB 1066, ESGPC-35 and Giza 114 and U. Ch. V-2, a line developed from a composite population. IS 12573, SB 1066 and U. Ch. V-2 are early and tolerant to grain weathering while P-721 is an established high lysine line from Purdue, USA, and Giza-114 is an Egyptian fast growing variety. This experiment consisting of 36 hybrids was grown during *kharif*, 1976. The rains terminated by first week of September *ie.*, before maturity and it was not possible to screen for grain deterioration under natural conditions. Data on grain hardness and water absorption by 200 grains which correlated well with resistance to grain deterioration were recorded.

Both experiments were grown in randomized complete block design with three replications. The plot consisted of two rows 5m long and 45 cm apart. The parents were also evaluated in separate blocks during both years. Parents with breaking strength more than 7 kg were regarded as hard seeded parents. Combining ability analysis was done following Kempthorne (1957).

Table 1

Mean values of grain deterioration (%), grain hardness and water absorption (gm/200 grains) Experiment 1

Females	Males 148	168	232	287	641	887	1324	CS 3541	Hybrid Mean	Gca effect	Parental mean
				Grain deterioration (Angular transformed values)							
36 A	52·7	62·2	61·9	56·7	56·2	54·4	76·1	39·3	57·4	0·01	71·99
296A	48·9	48·8	69·5	88·2	50·4	67·2	76·5	46·9	61·2	4·64	74·44
2277A	44·5	37·0	71·4	61·8	42·7	64·6	69·0	56·8	55·9	-1·43	56·10
2947A	45·7	37·9	75·0	63·5	67·2	65·4	72·3	43·9	58·8	1·43	68·17
3660A	44·3	41·8	44·8	69·9	53·7	61·4	60·6	45·6	52·7	-4·65	52·40
Hybrid mean	47·2	45·6	64·5	68·0	54·0	62·6	70·9	46·5			
Gca effect	-10·18**	-11·87**	7·09*	10·60**	-3·39	5·19	13·49**	-10·91**			
Parental mean	51·79	56·05	53·84	88·19	47·60	83·04	88·19	30·74			
					Grain hardness (kg)						
36A	6·80	6·60	5·57	5·93	7·20	7·43	6·50	7·67	6·7125	0·05	6·67
296A	6·75	6·47	4·76	5·03	5·70	5·03	7·30	7·93	6·1187	-0·55**	4·83
2277A	6·60	6·17	4·93	6·57	6·10	6·57	7·50	7·10	6·4425	-0·22	4·47
2947A	6·57	6·50	5·53	6·16	5·67	5·37	6·53	7·07	6·1750	-0·49*	5·03
3660A	7·53	8·33	6·27	8·43	6·00	8·07	9·57	8·83	7·8787	1·21**	7·00
Hybrid mean	6·846	6·814	5·412	6·424	6·134	6·494	7·480	7·72			
Gca effect	0·18	0·15	-1·25**	-0·24	-0·53*	-0·17	0·81**	1·05**			
Parental mean	7·10	6·37	5·87	5·33	5·33	5·40	5·17	8·47			

TABLE 1—(*Contd.*)

Females	Males								Hybrid Mean	Gea effect	Parental Mean
	148	168	232	287	641	887	1324	CS 3541			
					Water absorption/200 grains (gm)						
36A	1·249	1·119	1·023	1·532	1·031	0·954	1·216	0·924	1·131	0·103**	1·505
296A	1·353	0·844	0·934	1·408	1·150	1·000	0·987	1·213	1·111	0·083*	1·445
2277A	0·986	0·882	0·730	1·108	0·957	1·048	0·853	0·902	0·934	–0·094*	1·007
2947A	0·918	0·910	0·911	1·403	1·065	1·111	0·963	1·147	1·054	0·026	0·916
3660A	0·986	0·869	0·800	1·069	0·817	0·868	0·922	0·939	0·909	–0·119	0·732
Hybrid mean	1·099	0·925	0·880	1·304	1·004	0·997	0·988	1·025			
Gca effect (g_j)	0·071	–0·103*	–0·148**	0·276**	–0·024	0·031	–0·040	–0·003			
Parental mean	1·186	1·201	0·858	1·721	1·006	0·945	1·015	1·137			

*Significant at 5%; **Significant at 1%; Grain deterioration $SE(g_j)=2·99$; Grain hardness $SE(g_j)=0·25$; $SE(g_i)=0·20$; Water absorption, $SE(g_j)=0·045$; $SE(g_i)=0·037$.

Results

Mean values for various characters related to grain deterioration are presented in Tables 1 and 2 and analysis of variance in Tables 3 and 4.

Differences among hybrids were significant for grain deterioration (%), water absorption/200 grains (W.A.) and grain hardness (Tables 1 and 3). The hybrids of 296A, 2277A, 2947A and 3660A with tan type male parents such as 148, 168, 641 and CS 3541 exhibited relatively less grain deterioration. Grains of hybrids either with 36A as female or with 232, 287 and 887 as male parents got highly deteriorated. Within and between group differences among tan × tan, purple × tan and purple × purple crosses were significant for grain deterioration. Significant between group differences revealed that tan × tan crosses were relatively tolerant to grain deterioration than other groups of crosses (Table 4). While tan pigment imparted resistance to grain deterioration, significant within tan × tan group variation can be attributed to the variation in other characters conferring resistance to grain deterioration. A comparison of means of hard × hard, hard × soft and soft × soft groups showed characteristic gradation for grain deterioration. The hard × hard crosses were least deteriorated while this increased proportionately to softness in hard × soft and soft × soft crosses.

The overall differences among tan × tan crosses were not significant for grain hardness but these differences were significant for purple × tan and purple×purple crosses (Table 3). The breaking strength of hard×hard purple pigmented crosses was significantly higher than the hybrids involving either hard × soft or soft × soft seeded parents (Table 4). Hard × soft crosses were, however, harder than soft × soft crosses in all the three groups—tan × tan, purple × tan and purple × purple. There was gradation for hardness from purple × purple, purple × tan to tan × tan crosses, purple × purple crosses being hardest. Hardness contributed to resistance to grain deterioration only in tan (homozygous or heterozygous) background rather than in purple (homozygous) background.

The purple × purple crosses absorbed more water than purple × tan crosses (Table 3 and 4) whereas soft × soft crosses absorbed more water than hard × soft crosses within purple × purple group. Significant differences among tan pigmented soft × hard crosses revealed that tan × tan crosses absorbing appreciably less water may be selected.

The comparison of parental performance with their hybrids revealed that the hybrids involving less deteriorated tan parents such as 148, 168 and CS 3541 and a hard seeded female 3660A (purple) were quite resistant to grain deterioration. Similarly, parents with hard seeds also contributed this character to hybrids.

Hybrids between derivative × exotic parents were significantly different for grain hardness and water absorption (Table 2 and 3). Though the variation within tan × tan and purple × tan groups was significant for both the characters, the grains of tan × tan crosses were harder than the grains of purple × tan crosses

TABLE 2

Mean values for grain hardness and water absorption (Experiment 2)

Derivatives	IS 12573	P 721	Exotic parents U.Ch.V-2	SB 1066	ESGPC-35	GIZA114	Hybrid mean	Gca effect	Parental mean
				Grain hardness (kg)					
CSV-4 (CS 3541)	8·484	8·772	7·176	8·924	12·708	7·552	8·936	0·1163	7·012
CSV-5 (168)	7·374	6·960	7·100	9·208	12·056	6·858	8·259	–0·5604	6·652
SPV-96 (113)	10·003	8·848	8·128	9·996	13·960	8·432	9·894	1·075*	7·164
SPV-97 (255)	9·880	8·608	6·994	9·456	10·600	6·983	8·753	–0·0662	7·264
SPV-108 (284)	9·853	8·420	7·292	10·396	10·768	6·504	8·872	–0·0526	7·420
SPV-114 (875)	9·064	6·662	7·860	9·374	8·700	7·556	8·203	–0·6170	5·648
Hybrid mean	9·110	8·045	7·425	9·559	11·465	7·314			
Gca effect	0·2903	–0·7747*	–1·3947*	0·7393*	2·6453**	–1·5057**			
Parental mean	8·50	6·26	6·71	9·07	11·40	4·83			
				Water absorption by 200 grains (gm)					
CSV-4 (CS 3541)	0·798	0·984	0·824	0·786	0·843	1·156	0·898	–0·094**	1·182
CSV-5 (168)	0·852	0·856	0·780	1·002	1·136	1·102	0·955	–0·037	1·100
SPV-96 (113)	0·920	0·884	0·950	1·344	1·194	1·438	1·122	0·129**	1·158
SPV-97 (255)	0·974	0·968	0·892	1·044	1·208	1·456	1·090	0·097**	0·934
SPV-108 (284)	0·734	0·595	0·669	0·942	1·198	1·191	0·888	–0·104**	1·320
SPV-114 (875)	0·872	0·904	0·896	0·736	0·968	1·636	1·002	0·009	1·192
Hybrid mean	0·858	0·865	0·835	0·975	1·091	1·329			
Gca effect	–0·134**	–0·127**	–0·157**	–0·017	0·098**	0·337**			
Parental mean	0·866	0·882	0·700	0·898	1·210	1·326			

*Significant at 5%; **Significant at 1%; SE (gj) = SE(gi)—Grain hardness = 0·3367; Water absorption = 0·0305.

TABLE 3

Analysis of variance

Source	Experiment 1				Experiment 2		
	DF	Grain det. (°)	Grain hardness	WA/200 grains	DF	Grain hardness	WA/200 grains
Replications	2	911·4	0·79	0·031	1	41·818	0·4470
Hybrids	39	473·2**	3·60**	0·096**	35	6·090**	0·1064**
Tan × Tan crosses (T×T)	14	328·3**	1·63	0·060*	17	8·567**	0·0522**
Hard × Hard (H×H)					7	6·116**	0·0746**
Soft × Hard (S×H)	8	107·5	0·80	0·127	7	5·630**	0·0358*
Soft × Soft (S×S)	5	326·1*	0·87	0·015	1	0·577	0·0134
S×H *vs* S×S	1	2106·1**	11·99**	0·016	1	2·411	0·0096
H×H *vs* (S×H + S×S)					1	60·440**	0·0916**
Purple × Tan crosses (P×T)	18	5167·2**	4·04**	0·101**	17	2·853*	0·1483
H×H	2	10·9	1·29	0·010	3	0·822	0·1062**
S×H	4	255·2	2·13	0·099*	9	1·808	0·1548**
S×S	10	282·2*	3·32**	0·133**	3	0·296	0·2552
S×H *vs* S×S	1	2321·4**	5·70*	0·009	1	9·088**	0·0403
H×H *vs* (S×H + S×S)	1	3124·4**	22·72**	0·055	1	19·786**	0·0033
Purple × Purple crosses (P×P)	5	351·9*	7·57**	0·197**			
H×S	2	485·2*	8·43*	0·054			
S×S	2	300·9	0·67	0·198**			
H×S *vs* S×S	1	187·3	19·63**	0·479**			
P × T *vs* P × P	1	15946·8**	0·98	2·911**			
T × T *vs* (P × T + P × P)	1	2784·4**	6·19*	0·002			
T × T *vs* T × P					1	18·995**	0·3144**
Error	78	134·8	0·99	0·030	35	1·361	0·0112

*Significant at 5%; **Significant at 1%.

TABLE 4

Group means for Tan × Tan, Purple × Tan and Purple × Purple pigmented crosses in relation to grain hardness

Pigment/Grain hardness	Experiment 1				Experiment 2		
	No. of crosses	Grain det. (°)	Grain hardness (kg)	WA/200 grains (gm)	No. of crosses	Grain hardness (kg)	WA/200 grains (gm)
Tan × Tan crosses	15	51·20	6·37	1·0326	18	9·333	0·9272
Hard × Hard	—	—	—	—	8	10·782	0·9836
Soft × Hard	9	45·62	6·79	1·0174	8	8·348	0·8931
Soft × Soft	6	59·58	5·73	1·0556	2	7·480	0·8380
Purple × Tan crosses	19	61·00	6·77	1·0029	18	8·306	1·0594
Hard × Hard	3	43·89	8·23	0·9314	4	9·693	1·0415
Soft × Hard	5	53·88	7·01	0·9958	10	8·270	1·0405
Soft × Soft	11	68·88	6·27	1·0257	4	7·009	1·1245
Purple × Purple crosses	6	61·67	7·04	1·0937			
Hard × Soft	3	58·45	8·09	0·9306			
Soft × Soft	3	64·90	6·00	1·2569			

in Experiment 2. All the crosses of ESGPC-35, IS-12573 and SB-1066 were harder than CSV-4 (CS 3541) crosses, ESGPC-35 crosses being the hardest (Table 2).

Water absorption of tan × tan crosses was significantly lower than of purple × purple crosses (Table 2). Significant variation for water abosrption in hard × hard crosses in tan × tan group provided further opportunity to select crosses with low water absorption and hard seeds. CSV-4 (CS 3541) hybrids except with Giza-114 and IS-12573 and U.Ch.V-2 hybrids with rest of the females were some of the crosses which absorbed less water.

The male sterile lines used as female parents did not contribute differently in crosses for grain deterioration while their contribution was different for grain hardness and water absorption (Table 5). The male effects were significant for all the three characters indicating significant differences in combining ability effects. However, specific combining ability effects (female × male interaction) were not significant for any of the characters. Estimates of variance showed that contribution of male parents in crosses was much higher than male steriles (females) for grain deterioration and water absorption while additive genetic variance was more pronounced for grain hardness and water absorption in both the experiments.

In derivative × exotic crosses, the general combining ability (*gca*) effects due to females and males were significant (Table 5). Heritability of grain deterioration was lower compared to other characters. Grain hardness and water absorption characters were, therefore, more heritable than grain deterioration *per se*.

A comparison of combining ability effects in Experiment-1 showed that 168 (CSV-5) and CS 3541 (CSV-4) were good general combiners for low grain deterioration (Table 1). Negative *gca* for water absorption in 168 (CSV-5) and positive *gca* for grain hardness in CS 3541 primarily contributed to grain deterioration resistance. Among male steriles 3660A was a general combiner for grain hardness and low water absorption. SB-1066 and ESGPC-35 were other good combiners for grain hardness (Table 2). Comparison of σ^2 gca (m) in both experiments and *gca* effects in derivative × exotic crosses showed that the contribution of exotic males in crosses was higher than the male parents considered better in Experiment-1.

Discussion

Early maturing hybrids and varieties of sorghum confer stability to production levels in years of subnormal rainfall and enable practice of two crop systems in years of adequate rainfall (Rao, 1977). While these advantages are substantial, they are vulnerable to late rains if received in October resulting in grain deterioration and consequent low market quality. The problem of conferring resistance to grain deterioration is, therefore, of considerable significance.

TABLE 5

Analysis of variance for combining ability

Source	Experiment 1				Experiment 2		
	DF	Grain det.	Grain hardness	WA/200 grains	DF	Grain hardness	WA/200 grains
Replications	2	911·4*	0·79	0·310	1	41·82**	0·447**
Hybrids	39	473·25**	3·60**	0·096**	35	6·09**	0·105**
Female effects	4	284·2	12·38**	0·250**	5	7·48**	0·110**
Male effects	7	1600·0**	8·08**	0·247**	5	49·77**	0·439**
Female × Male interactions	28	221·3	1·23	0·036	25	4·60**	0·037**
Error	78	134·8	0·99	0·030	35	1·36	0·011
$\hat{\sigma}^2$ gca (f)		2·62	0·465	0·0088		0·288	0·0061
$\hat{\sigma}^2$ gca (m)		91·91	0·456	0·0142		4·517	0·0335
$\hat{\sigma}^2$ gca		36·96	0·461	0·0118		2·403	0·0198
$\hat{\sigma}^2$ sca		28·82	0·092	0·0021		1·619	0·0129
$\hat{\sigma}^2$ gca/ $\hat{\sigma}^2$ sca		1·28	5·01	5·62		1·483	1·5314
$\hat{h}^2$		33·38	52·95	40·83		53·69	51·83

*Significant at 5%; **Significant at 1%.

Earlier studies identified tan plant type, low water absorption rate and hardness of seeds (breaking strength > 7 kg) as selection criteria for breeding resistant types (Rana *et al.*, 1977). Present studies which involve two sets of experiments revealed that significant between groups differences exist for these characters in crosses involving diverse parents.

The tan × tan crosses and hard × hard crosses exhibited generally less deterioration and as the degree of softness of seeds increased, the degree of deterioration also increased. Hardness contributed to resistance primarily in the tan background rather than in the purple background.

The influence of tan or purple plant type on water absorption rate is not significant, but the purple × purple and soft × soft crosses absorb relatively more water whereas tan × tan and hard × hard crosses absorb relatively less water. Thus, the breeding behaviour of the various groups further confirm that a combination of tan plant type, hard seed and low water absorption rate are useful in breeding types resistant to grain deterioration.

Estimates of combining ability for these characters revealed predominance of *gca* for grain hardness as well as rate of water absorption indicating that selection for these characters could be effective.

Based on several crosses studied, crosses involving the females 2277A, 2947A and 296A, which are tan types, exhibit resistance features in all the attributes. The males, CS 3541 and 168 which are also tan, yielded hybrids resistant to grain deterioration. The exotic variety, ESGPC-35, which is an African *zerazera* characterized by tan plant, yielded hybrids with highest values for breaking strength of grain. Several parents with resistant as well as susceptible attributes have been identified and their behaviour in cross combination studied. This information could be valuable in breeding for resistance to grain deterioration.

Summary

The problem of conferring resistance to grain deterioration in early maturing *kharif* season sorghums has been further examined. Tan plant type, hardness of grain and water absorption rate together furnish useful criteria for breeding resistant types. The inheritance of hardness of seed and rate of water absorption are predominantly additive and selection for these characters could be effective. Hard × hard crosses within tan types are likely to yield quick results. The male steriles 296A, 2277A and 2947A, the males CSV-4 (CS 3541) and CSV-5 (168) and amongst germplasm materials ESGPC-35, an African *zerazera*, are identified as most promising materials resisting grain deterioration.

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GENETIC ANALYSIS OF SOME EXOTIC × INDIAN CROSSES IN SORGHUM XIX. PATTERNS OF DRY MATTER AND NUTRIENT ACCUMULATION

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SINCE sorghums in India are grown essentially as rainfed crops, year to year changes in yield levels closely follow fluctuations in the amount and distribution of rainfall. Most traditional varieties being late maturing are vulnerable to climatic changes (Rao *et al.*, 1975). First steps to correct for climatic vulnerability should involve genotypic alteration of tropical sorghums to reduce the excessive dry matter production and furnish a more efficient redistribution between the stalk and ear together with reduced duration. The present paper attempts an analysis of dry matter distribution and nutrient uptake patterns in some exotic and Indian sorghums and their derivatives.

MATERIALS AND METHODS

The experimental material consisted of: CSH-1, CSH-3 and CSH-5, hybrids whose parents are of exotic origin, *Swarna*, a variety of exotic origin; *Aispuri* and BP-53, traditional improved varieties of Indian origin and 302 (CSV-2), 604 (CSV-6) and R-16 (IS-2954 × M. 35–1), derivatives from exotic × Indian crosses.

The experiments were grown in replicated and randomised blocks during *Kharif* (July-November) and *rabi* (October-February) seasons. Periodical plant samples were taken at six physiological stages and analysed for dry matter production and nutrient uptake using standard laboratory procedures and Maldandi 35-1 an improved local.

RESULTS

Data on morphological and physiological attributes for *kharif* and *rabi* seasons are presented in Table 1. The distribution of dry matter between vegetative and reproductive parts is depicted in Fig. 1.

During the *kharif* season, the tropical Indian varieties, which are late and tall are characterized by production of large amount of dry matter; uptake of nutrients is also the highest. On the other hand, the exotics and derivatives produced less of dry matter and consequently total nutrient uptake was also comparatively low. The dry matter distribution between vegetative and reproductive parts varied between 41% (vegetative) and 59% (reproductive) in exotics and derivatives. In the tropical Indian varieties only 33% of the total dry matter accumulated in the ear (Fig. 1).

During *rabi* season, where rainfed sorghums grow primarily with residual moisture in the profile, the local M. 35–1 itself has 48% of the dry matter

TABLE 1

Morphological and physiological characters of sorghum varieties and hybrids at harvest

Variety	Average height (cm)	Average no. of leaves	Dry matter of vegetative parts (g/pl)	Dry matter of ear (g/pl)	Dry matter of grain (g/pl)	Total dry matter production	Harvest index	Total uptake of N (mg/pl)	Total uptake of P_2O_5 (mg/pl)
				(A) KHARIF					
Exotic									
CSH-1	161·5	11	56·9	81·5	66·9	138·4	48·3	1563	275
CSH-2	168·8	15	108·6	114·7	92·0	223·3	41·2	2093	691
CSH-3	210·6	12	97·6	119·0	105·8	216·6	48·8	2452	621
Indian									
Aispuri	337·0	—	267·5	134·0	110·2	401·5	27·5	3700	587
BP-53	345·0	—	264·8	143·2	120·6	408·0	29·5	3749	561
Derivatives									
302	185·7	12	96·0	139·4	112·5	235·4	47·7	2758	478
604	238·5	13	115·5	102·8	84·5	235·4	38·7	2186	572
				(B) RABI					
Exotic									
CSH-1	140·4	7	37·8	68·7	57·8	106·5	54·3	1147	332
CSH-2	142·1	7	41·5	92·4	80·1	133·9	59·8	1779	513
CSH-3	129·6	7	34·6	75·8	65·4	110·4	59·2	1191	357
CSH-4	166·3	8	46·9	75·8	62·9	121·7	51·6	1336	510
Swarna	130·5	9	41·3	72·5	62·5	113·8	54·9	1248	446
Indian									
M. 35-1	177·8	10	78·5	71·6	62·5	150·1	41·6	1600	573
Derivative									
R 16	170·1	8	43·0	81·1	67·1	124·1	54·1	1440	401

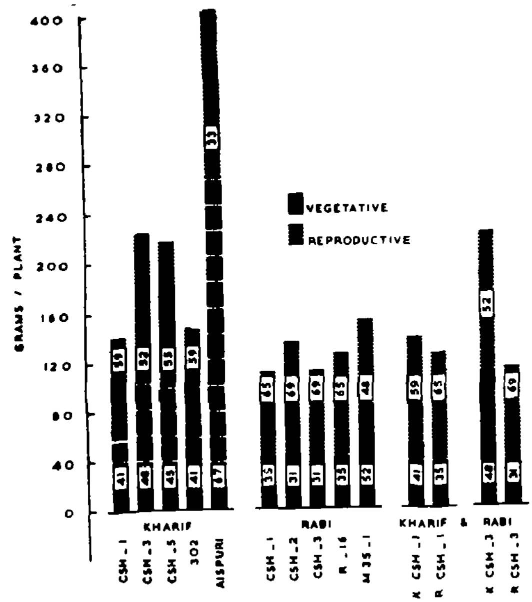

FIG. 1: Dry matter distribution in vegetative and reproductive parts

accumulated in the ear while in the hybrids particularly CSH-2 upto 70% of the dry matter got accumulated in the ear.

An examination of the rates of dry matter production during *kharif* (Fig. 2) reveals that in case of exotics, there are two peaks for dry matter production, one before flowering (approximately 45 days) and a second peak about 15–20 days before harvest. On the other hand, the Indian varieties have a single peak, coinciding with the flowering time. The derivatives of exotic × Indian crosses resemble the exotic parents in pattern of dry matter production.

During *rabi* season (Fig. 3), both exotic and Indian varieties exhibit two peaks in the rate of dry matter production while the derivative R-16 seems to be an improvement over both. In case of R-16, rapid accumulation of dry matter in the ear possibly renders the stem very weak and a large proportion of the plants lodges and this process is further accentuated by the incidence of charcoal rot disease in the basal nodes of the stem.

DISCUSSION

Crosses between tall and late tropical sorghums and the dwarf, relatively early maturing temperate sorghums have now become an integral part of sorghum improvement in tropics as well as temperate regions. Rao *et al.* (1975) have pointed out that most *kharif* sorghums of Deccan have a disproportionately longer duration (> 5 months) compared to the duration of monsoon (approximately

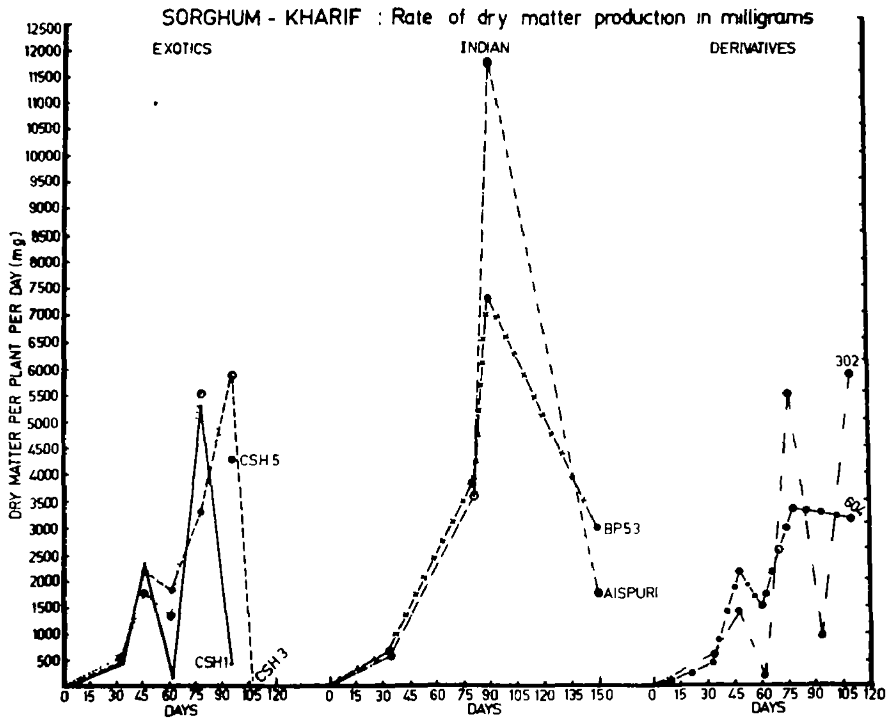
SORGHUM - KHARIF : Rate of dry matter production in milligrams
EXOTICS
INDIAN
DERIVATIVES
DRY MATTER PER PLANT PER DAY (mg)
CSH 5
CSH1
CSH 3
BP53
AISPURI
302
DAYS

Fig. 2

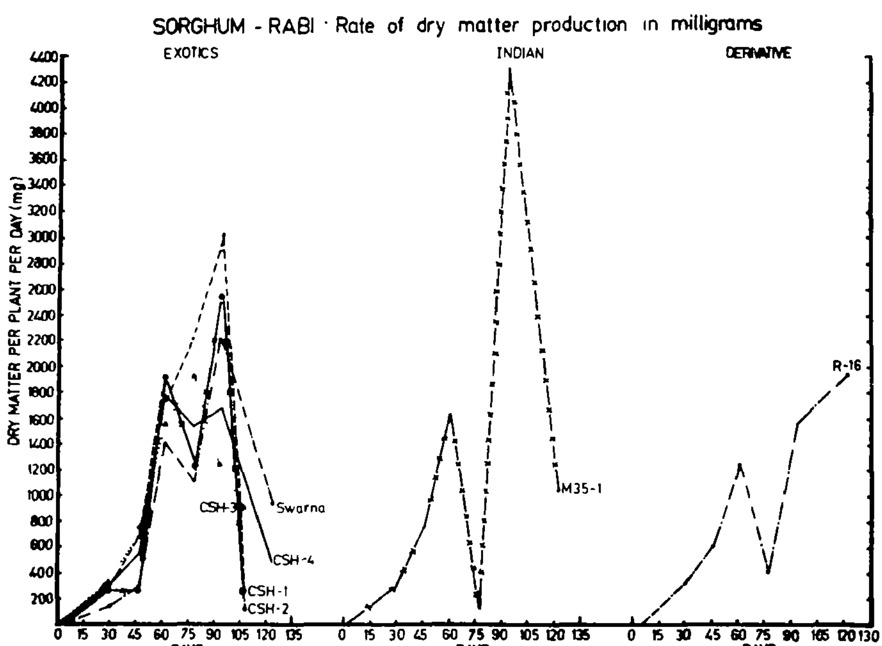
SORGHUM - RABI · Rate of dry matter production in milligrams
EXOTICS
INDIAN
DERIVATIVE
DRY MATTER PER PLANT PER DAY (mg)
Swarna
CSH-3
CSH-4
CSH-1
CSH-2
M35-1
R-16
DAYS

Fig. 3

three months). They are also generally characterized by larger body weight and a good proportion of the dry matter accumulates in the stem. In years of reduced duration of monsoon or subnormal amounts of rainfall such sorghums fail to return economic yields or even result in crop failures. The first correction to minimize such risks resulting from subnormal rains lies in genotypic alterations leading to reduction of maturity period so that the duration of rainy season and crop duration are suitably matched. This together with a reduction of total dry matter produced by the plant but with better distribution between the stalk and the ear could enable the plant return economic yields inspite of fluctuations in rainfall.

Earlier studies on genetic analysis of exotic × Indian (temperate × tropical) crosses in sorghum have revealed that the dominant genes for yield are present in the tropical sorghums (Rao, 1970). When there is no stress, the tropical sorghums are no doubt individually superior, but their community performance is inferior to relatively dwarf types. It was also idicated that certain derivatives of exotic × Indian crosses in the intermediate height and maturity range probably represented optimal production peaks (Rao *et al.*, 1973). Breeding of superior genotypes of sorghum with stabilized levels of perfoımance has, therefore, to capitalize on the assets of the tropical and temperate types.

Rao and Venkateswarlu (1971) have observed that F_1 hybrids of exotic × Indian crosses behaved like their tropical parents. Since the accumulation of dry matter after flowering was mostly in the stem, the advantage of hybrid vigour for grain yield was not felt inspite of reduced duration. Selection in exotic × Indian crosses, however, resulted in recombining the desirable attributes of both groups, although such selected recombinants represented a small proportion and resulted from a few selected crosses.

As could be seen from the present study the hybrids and derivatives of exotic × Indian crosses have reduced duration and reduced total dry matter on per plant basis but a better distribution between ear and stalk (Fig. 1). Besides, the two peak situation in the rates of growth (Figs. 2 and 3) confer a definite advantage not only for higher economic yields but also enable them withstand the influence of inevitable seasonal fluctuation common with sorghums almost wholly grown as rainfed crops. Uptake of major nutrients and their distribution also follow the pattern for dry matter. This advantage could even be greater during *rabi* where sorghums grow only on residual moisture and they run out of soil moisture even by flowering time. Compared to *kharif*, where significant progress has been made, recombinant genotypes with less risk and higher levels of production are yet to be developed for *rabi* and the present studies could provide some guidelines.

SUMMARY

The patterns of dry matter production and distribution along with major nutrients N, P in some exotic (temperate) and Indian (tropical) sorghums and

their derivatives was studied. Hybrids and some of the recombinant derivatives of exotic × Indian crosses exhibit higher and stable levels of production. This is primarily attributable to a reduction of duration to match the duration of rainy season, a reduction of total dry matter but better distribution between stalk and ear, two peaks for rates of growth and a superior community performance. Recombinant genotypes with such attributes could be isolated from exotic × Indian crosses although their occurrence may be confined to a few selected crosses.

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The authors are grateful to Dr. H. K. Jain, Director, I.A.R.I., and Dr. M. S. Swaminathan, Director-General, I.C.A.R., for their interest and encouragement.

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GENETIC ANALYSIS OF SOME EXOTIC × INDIAN CROSSES IN SORGHUM XX. GENOTYPIC DIFFERENCES FOR ROOT ACTIVITY

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WITH particular reference to sorghum, while adequate attention has been paid to various components of yield as selection criteria (Rao *et al.* 1973 and Tripathi *et al.* 1976), the root system has received less attention. The studies so far have been limited to root activity distribution patterns (Nakayama and Van Bavel, 1963), water consumption in relation to root activity in dryland sorghums (Kafkafi *et al.* 1965) and a comparison of the root systems of corn and sorghum (Lavy and Eastin, 1969). With the exception of an unpublished report on the root activity of M. 35–1 and CSH-1, no attempt seems to have been made to study varietal differences for root activity. The present study attempts an analysis of differences for root activity in exotic and Indian sorghums and the derivatives obtained from their crosses.

MATERIALS AND METHODS

The experimental material for the present investigation comprised the following:

(a) Exotic varieties and hybrids msCK60 (male sterile combine *kafir* 60, the female parent for CSH-1 and CSH-2); CK60B (fertile counter part of msCK60); IS 84 (A selected yellow endorsperm *feterita* and male parent of the hybrid CSH-1); IS 3691 (A selected yellow endosperm *hegari* and male parent of CSH-2); *Swarna* (exotic origin, dwarf and early, high yielding variety); CSH-1 (Commercial hybrid) CSH-2 (Commercial hybrid).

(b) Indian varieties *Aispuri* and BP-53 (Improved Indian varieties, tall and late).

(c) Derivatives from exotic × Indian crosses 148—(IS 3687 × *Aispuri*, dwarf and early); 302—(IS 3922 × *Karad* local, dwarf and early) and 604—(IS 3922 × *Aispuri*, medium height and mid-late).

The material was sown during *kharif* season in non-replicated blocks. The soil type was 'regur'. Sowings were done in rows 30 cms apart with a spacing of 15 cms between plants. The entire area was uniformly fertilized to give, 80 kg N and 60 kg P_2O_5/hect. The rainfall was adequate and no irrigations were provided. Cultural and other operations were uniform over all the entries.

The radio active isotope, ^{32}p (carrier free) was placed at 3 lateral distances (5, 10 and 20 cm) and 3 vertical depths (10, 20 and 40 cm) in the soil at knee-high stage as per the technique described by Hall (1953) at the rate of 80 μc of ^{32}p/plant. Each treatment was replicated thrice.

Leaf samples were collected twice; 3rd and 4th leaf from the top, were sampled one week after ^{32}p application as first sample and the flag leaf at flowering stage as the second sample. After the material was digested with HNO_3, ^{32}p assay wa done by standard methods described by IAEA and the total phosphorus in the plant sample was estimated by the Vanadomolybdate method (Jackson, 1958). Correlations for ^{32}p counts were made upto sampling time with respect to the counts obtained for each treatment. Based on the corrected counts and the pooled data for all combinations of depths, percent root activity at each depth was computed and the split plot technique was followed for statistical analysis of data.

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Results

Active root distribution pattern at knee-high stage

Data on per cent active root distribution of sorghum hybrids, parents and varieties at knee-high stage are presented in Table 1, the analysis of the variance in Table 2. The varietal differences for active root disribution are highly significant. The first order interactions E × V and L × V and the second order interaction E × L × V are also highly significant. The E × L interaction is not significant.

It is observed from Table 1 that with the exception of 'CK 60 A' in most of the dwarf varieties 'Swarna', '302', '604', '148' and 'CSH-1' root activity is maximum at 10 cm depth (V_1) whereas for the tall Indian variety 'Aispuri', the activity is the least at 10 cm depth and the highest at 40 cm depth (V_3). Thus at 5 cm lateral distance (L_1) dwarf varieties have the most active roots at surface level whereas for the Indian variety they are at 40 cm depth, the only exception among dwarf varieties being 'CK 60A', the behaviour of which will be discussed later.

At 10 cm lateral distance (L_2), root activity is maximum at the deeper layers 20 cm (V_2) and 40 cm (V_3) for dwarf varieties 'CK 60 B' and 'Swarna'. The hybrid 'CSH-1' and several dwarf varieties still have their active root system at surface. In the tall Indian variety 'Aispuri', root activity is more at surface (10 cm depth) as compared to 5 cm lateral distance (L_1) stage.

At 20 cm lateral distance (L_3) root activity is maximum at deeper layers (40 cm depth V_3) for dwarf varieties 'IS 3691', 'CSH-1', '302' and '148'. For the variety 'Aispuri' maximum activity is at 20 cm depth (V_2).

Thus, an examination of the root system in diverse genotypes reveals distinct differences. In case of high yielding dwarf varieties root activity is mostly at the surface at 5 cm lateral distance (L_1), and the activity is generally more in the deeper layers 20 cm and 40 cm depths at 10 and 20 cm lateral distances respectively. The situation with the Indian variety Aispuri is almost the reverse. It has the most active roots deeply placed at 5 cm lateral distance whereas at 20 cm lateral distance the roots are relatively superficial.

Active root dittribution pattern at flowering stage

The percentage distribution of active roots at various lateral distances and vertical depths are also presented in Table 1 and the analysis of variance in Table 2 for the flowering stage.

From the analysis of variance it is seen that the differences due to entries which were highly significant at knee-high stage are not significant at flowering. On the other hand, the differences due to vertical depths, the first order interactions, L × V, E × V and the second order interaction E × L × V are highly significant. It is thus clear that there is a similarity in the behaviour of active root system at knee-high and flowering stages in so far as it pertains to the

TABLE 1

Per cent active root distribution in various depths at knee-high and flowering stages

Vertical depths (cm)	Genotype CK 60A	CK 60B	IS 84	IS 3691	CSH-1	CSH-2	*Aispuri*	*Swarna*	302	604	148
A. KNEE-HIGH STAGE											
(L_1) *Up to a lateral distance of* 5 *cm*											
V_1 (10 cm)	17·5	42·6	63·1	53·6	91·8	40·7	17·5	90·4	65·5	71·8	70·0
V_2 (20 cm)	23·8	41·2	12·9	24·3	4·6	41·8	23·8	4·9	11·7	24·0	19·5
V_3 (40 cm)	58·7	16·2	24·0	22·1	3·6	17·5	58·7	4·7	22·8	4·2	10·5
(L_2) *Up to a lateral distance of* 10 *cm*											
V_1 (10 cm)	38·5	30·1	41·8	46·2	89·0	10·7	38·5	13·5	32·0	47·8	80·6
V_2 (20 cm)	32·5	42·8	37·7	14·5	5·6	74·5	32·5	38·3	41·3	46·0	8·9
V_3 (40 cm)	29·0	27·1	20·5	39·3	5·4	14·8	29·0	48·2	26·7	6·2	10·5
(L_3) *Up to a lateral distance of* 20 *cm*											
V_1 (10 cm)	17·8	56·3	36·9	29·5	19·4	46·6	17·8	44·8	20·2	50·2	22·7
V_2 (20 cm)	59·1	28·9	34·2	29·2	34·4	27·0	59·1	32·5	34·9	42·0	24·0
V_3 (40 cm)	23·1	14·8	28·9	41·3	46·2	26·4	23·1	22·7	44·9	7·8	53·3
B. FLOWERING STAGE											
(L_1) *Up to a lateral distance of* 5 *cm*											
V_1 (10 cm)	24·3	54·0	38·6	45·0	54·4	61·6	41·5	89·9	61·1	64·2	67·6
V_2 (20 cm)	27·4	37·3	32·7	24·6	27·4	25·6	43·2	5·6	29·2	34·9	23·8
V_3 (40 cm)	48·3	8·7	28·7	30·4	18·2	12·8	15·3	4·5	9·7	0·9	8·6
(L_2) *Up to a lateral distance of* 10 *cm*											
V_1 (10 cm)	25·4	28·9	71·7	47·2	45·8	19·4	47·6	14·1	26·3	55·5	33·3
V_2 (20 cm)	36·5	43·2	14·7	17·0	27·9	63·1	23·8	37·8	36·9	38·3	33·7
V_3 (40 cm)	38·1	27·9	13·6	35·8	26·3	17·5	28·6	48·1	36·8	6·2	32·5
(L_3) *Up to a lateral distance of* 20 *cm*											
V_1 (10 cm)	29·3	53·2	14·9	29·5	20·9	46·3	49·4	40·8	8·2	67·3	22·4
V_2 (20 cm)	52·7	27·0	27·4	44·0	34·6	44·0	13·1	39·6	21·2	22·2	31·0
V3 (40 cm)	18·0	19·8	57·7	26·5	44·5	9·7	37·5	19·6	70·6	10·5	46·6

TABLE 2

Analysis of variance for active distribution at knee-high and flowering stages

Source	DF	Mean squares	
		Knee-high stage	Flowering stage
Replications	2	0·008	0·532
Entries (E)	10	10·070**	8·508
Group I			
Parents + Hybrids	5	12·258**	2·258
Parents (P)	3	0·060	1·250
Hybrids (H)	1	24·790**	6·060
P *vs* H	1	36·320**	1·480
Group II			
Varieties	4	7·075**	12·317
Group I *vs* Group II	1	11·100**	24·520*
Error (a)	20	0·156	4·418
Lateral distance (L)	2	16·732	10·260
Vertical depths (V)	2	5903·419**	2979·904**
L × V	4	1794·160**	1398·247**
E × L	20	3·831	3·776
E × V	20	665·837**	438·766**
E × L × V	40	517·194**	446·783**
Error (b)	176	16·037	12·533

**Significant at 1%; *Significant at 5%.

depths of root system and its interaction with varieties and lateral distances only.

At 5 cm lateral distance (L_1), most dwarf varieties, 'CK 60B', 'IS 84', 'IS 3691', 'CSH-1', 'CSH-2', 'Swarna', '302', '604' and '148' have their active root system still at surface. The tall Indian variety 'Aispuri' has its active root system both at 10 cm and 20 cm vertical depths (V_1 and V_2).

As we go away from the plant (10 cm and 20 cm lateral distances), in the dwarf varieties '302', '148', 'CSH-1' and 'Swarna', increased activity is at deeper layers. At 20 cm lateral distance (L_3) the root system of '302', 'CSH-1' is the most active at 40 cm depth, whereas in the tall 'Aispuri' surface root system is still quite active.

It may, therefore, be inferred that varieties '302' and hybrid 'CSH-1' could be relatively more drought tolerant since their active root system is well spread in the deeper layers and away from the plant (*i.e.*, 20 cm lateral distance). Hence, they have greater opportunities to extract moisture and nutrients from larger area and greater depths.

PHOSPHORUS CONTENT

Phosphorus content in the third and fourth leaves at knee-high stage and the flag leaf at flowering stage are presented in Table 3 and the analysis of variance in Table 4.

TABLE 3

Phosphorus content (%) at knee-high and flowering stages

Entries	Mean total phosphorus (%)	
	Knee-high stage	Flowering stage
CK 60 A	0·523	0·397
CK 60 B	0·473	0·378
IS 84	0·546	0·441
IS 3691	0·496	0·382
CSH-1	0·421	0·446
CSH-2	0·308	0·350
Aispuri	0·434	0·353
Swarna	0·203	0·461
302	0·241	0·445
604	0·183	0·396
148	0·401	0·447

Varietal differences for leaf phosphorus are highly significant at both the knee-high and flowering stages. The phospho rus uptake by the plant is also obviously related to its placement both lateral and vertical. Differences due to lateral distances are highly significant both at knee-high and flowering stages. On the other hand the differences due to vertical depths are highly significant only at the knee-high stage.

The first order interaction L $\times$ V is also significant, only at knee-high stage. On the other hand, the first order interactions E $\times$ L and E $\times$ V and second order interaction E $\times$ L $\times$ V are highly significant at both the stages.

The pattern of phosphorus content in different entries shows distinct differences. In case of high yielding hybrids and varieties, 'CSH-1', 'CSH-2', 'Swarna', '302', '604' and '148' there is an increase in leaf phosphorus content at flowering compared to leaf phosphorus at knee-high stage. On the other hand in parental material 'CK60A', 'CK60B', 'IS 84', 'IS 3691' and the tall Indian variety 'Aispuri' there is a drop in the leaf phosphorus content at flowering. compared to knee-high stage. Thus, it is clear that there is a greater utilization of phosphorus in the high yielding varieties.

TABLE 4

Analysis of variance for total phosphorus

Source	DF	Mean squares	
		Knee-high stage	Flowering stage
Replications	2	0·001	0·079
Entries (E)	10	11·051**	1·466**
Group I			
Parents + [illegible]s	5	3·686**	1·386**
Parents (P)	3	0·5[illegible]	0·623**
Hybrids (H)	1	3·110**	4·930**
P *vs* H	1	13·720**	0·130**
Group II			
Varieties	4	9·885**	1·655**
Group I *vs* Group II	1	52·540**	1·110**
Error (a)	20	0·025	0·023
Lateral distance (L)	2	0·257**	0·504**
Vertical depths (V)	2	0·360**	0·118
L × V	4	0·114**	0·023
E × L	20	0·395**	0·415**
E × V	20	0·230**	0·201**
E × L × V	40	0·159**	0·250**
Error (b)	176	0·0116	0·043

**Significant at 1%.

DISCUSSION

The extent of lateral and vertical root development and the consequent uptake of water and nutrients are vital factors influencing agricultural productivity. Yet, the root system has received relatively less attention in the hands of geneticists and physiologists.

GENOTYPIC DIFFERENCES FOR ROOT ACTIVITY

Radio active tracers provide the means for non-destructive determination of root activity distribution in soils. Using the radio phosphorus injection technique, Nakayama and Van Bavel (1963) observed that 90% of the root activity in sorghum occurred in the region 36 inches in depth and 15 inches laterally from the plant. Roots grew at the rate of 0·75 to 2·00 inches per day. 80 to 90% of the water was depleted from the surface of 3 feet of a 5 foot soil profile. The next attempt to study the root activity of the dryland sorghum as measured by radio-phosphorus uptake and water consumption was by Kafkafi, Karhi, Albasal and Roodick (1965) who observed 60% phosphorus uptake from a radius of 25 cm at 60 and 90 cm depth, each zone contributing 30% activity.

Comparing the effectiveness of sorghum and corn root systems with respect to soil depth and plant age on ^{32}p uptake, Lavy and Eastin (1969) observed that both the root systems penetrated to a depth of 152 cm and extended laterally to 238 cm. Sorghum at 59 days old took up more ^{32}p than corn. Beyond 66 cm lateral distance, there was little activity in case of both corn and sorghum.

While the genotypic differences for drought tolerance and various other traits are well established in sorghum, such differences with regard to the root system and their relationship to yield and drought tolerance do not appear to have been studied in the past. The genetic differences with respect to the differentiation of traidtional tall, late Indian sorghums and dwarf, early exotics with respect to distribution of genes, gene action and character association have been well brought out in the studies of Rao and his co-workers (Rao, 1972). The differentiation with respect to the root system has, however, not been studied so far.

A study of the active root system of some dwarf exotics, derived lines from exotic × Indian crosses and hybrids at knee-high and flowering stages reveals distinct differences. The knee-high stage has been chosen since the seedlings get well established by then and it is at this stage a second dose of fertilizer is being recommended. In case of dwarfs, root activity at the knee-high stage is mostly at the surface at a lateral distance of 5 cm (L_1) and as we go away from the plant (L_2 and L_3) the activity increases at deeper layers (20–40 cm). With regard to the tall Indian variety 'Aispuri' the active roots are placed at 5 cm lateral distance whereas the activity is relatively superficial at L_2 and L_3.

As growth proceeds from knee-high to the flowering stage, the differences in root activity due to genotypes get insignificant indicating that genotypic differences are more pronounced for seedling vigour than at adult stage.

When we examine the differences due to lateral and vertical distances and their interactions, at both stages it is the differences due to vertical depths which are highly significant and the interactions E × V, L × V and E × L × V. The differences due to lateral distances and the E × L interaction is not significant.

Thus, in the selection of the genotypes seedling vigour for root activity, differences due to vertical depths and the interactions E × V, L × V and E × L × V should be given due consideration.

Root activity in high yielding hybrids and varieties

A comparison of maximum root activity for the high yielding varieties and hybrids is diagramatically presented in Fig. 1.

At knee-high stage, the active root systems of 'CSH-1', 'Swarna', '148', '604' and '302' exhibit similar pattern with more of surface activity at 10 cm depth. At flowering in addition to considerable activity of roots at 10 cm depth for the above varieties, upto 40 cm, the varieties, '302', 'Swarna' and

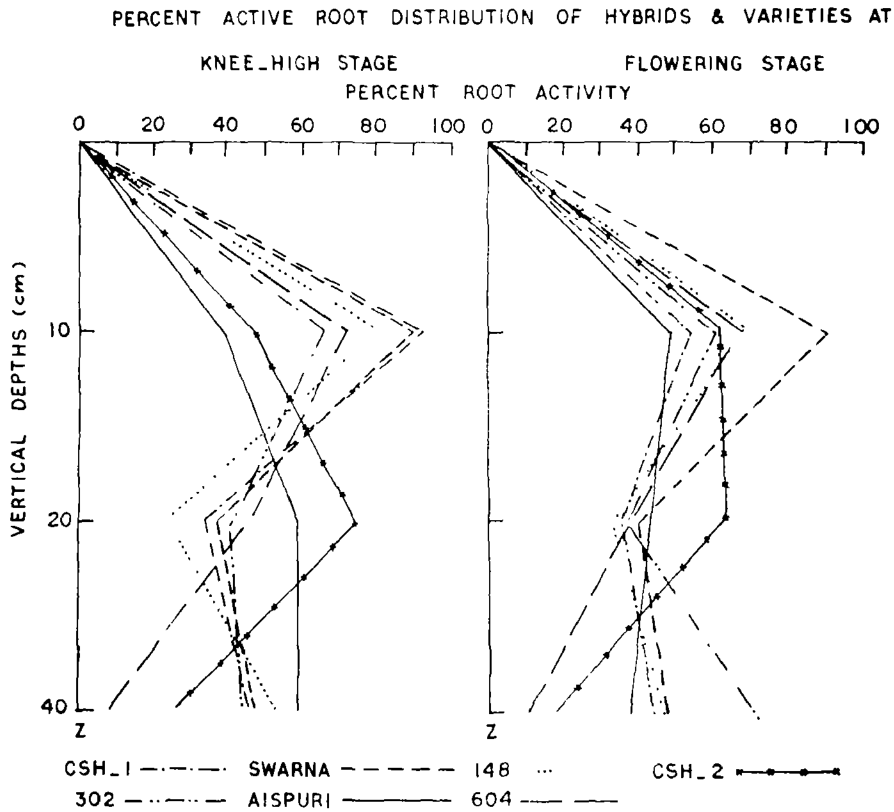

Fig. 1

'CSH-1' reflect increasing root activity. The variety 302 in particular has the maximum root activity at deeper layers.

During this year rainfall was more than adequate and no moisture stress was felt. During 1972–73 *kharif* season, which reflected one of the worst drought years, the entries '302', 'CSH-1' and 'Swarna' gave the highest yields in All India trials. The active root system of these three varieties exhibits a similar pattern at deeper layers and it is this activity which is apparently responsible for high yields during last year's drought. It may, therefore, be inferred that 'CSH-1', 'Swarna' and '302' will do well under stress when the surface layers of the soil are depleted of moisture.

Phosphorus accumulation

The phosphorus content in the third and fourth leaves at knee-high stage and in the flag leaf at flowering reveals interesting varietal differences. While the flag leaf P at flowering is lower compared to the third or fourth leaf, P content at knee-high stage in 'CK60A', 'CK60B' 'IS 84', 'IS 3691' and 'Aispuri', the flag leaf P is more in the hybrids 'CSH-1', 'CSH-2' and the improved varieties 'Swarna', '302', '604' and '148'. The increased accumulation of P at flowering appears a characteristic common to hybrids and high yielding varieties and may be used as an index for selection of high yielding varieties.

It is realised that much more information is needed on specific variation in root weight and activity (Loomis, Williams, and Hall, 1971) and it is in this context the present information on root activity which correlates well with verietal performance for economic yields is of significance.

Summary

The studies reported comprised varietal differences in relation to root activity using radio-active tracer ^{32}p.

1. Improved dwarf varieties of sorghum, which are mostly derived from exotic × Indian crosses, two commercial hybrids and their parents, and the tall Indian variety 'Aispuri' exhibited distnct patterns of root activity at knee-high and flowering stages. The differences were pronounced at the knee-high stage, the root activity of dwarfs being more at the surface at 5 cm lateral distance (L_1) and in deeper layers at 10 cm (L_2) and 20 cm (L_3) lateral distances. In case of the tall parent, while the root activity was relatively deeper at L_1, at L_2 and L_3 the activity was relatively superficial.

At flowering the genotypic differences for root activity were not significant. The interactions E × V, L × V and E × L × V were highly significant at both stages. In the selection of genotypes, seedling vigour for root activity, differences due to vertical depths and the interactions E × V, L × V and E × L × V should be given weightage.

2. The patterns of root activity of hybrids and high yielding varieties exhibited similarities in certain respects. The improved variety '302' appears to be most tolerant to drought followed by 'CSH-1' and 'Swarna'. The root activity correlated well with varietal performance in All India Trials.

3. Phosphorus accumulation in hybrids and high yielding varieties followed a similar trend. While there was a decreae in leaf phosphorus in parents and the Indian variety 'Aispuri' at flowering, the P content in the flag leaf increased in the high yielding hybrids and varieties. Increasing accumulation of leaf P at flowering compared to knee-high stage may be used as a criteria for selection of high yielding varieties.

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HETEROSIS FOR ROOT ACTIVITY IN GRAIN SORGHUMS

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HETEROSIS in sorghum for yield and its components has been studied fairly extensively (Quinby, 1963). Heterosis with respect to yield and yield components in exotic × exotic, exotic × Indian and Indian × Indian crosses has been studied by Rao (1970), but even here the root system has not received any attention. The present study attempts an analysis of root activity in two commercial hybrids, CSH-1 and CSH-2, and their parents.

MATERIALS AND METHODS

The material comprised of two commercial hybrids, CSH-1 and CSH-2, their common female parent msCK60 and their respective male parents IS-84, a yellow endosperm *feterita* and IS-3691, a yellow endosperm *hegari*.

Root activity was measured by employing radio-tracer techniques which have been described in detail in an earlier paper (Damodar, Subba Rao and Rao 1978).

RESULTS

HETEROSIS FOR PLANT CHARACTERS

From the analysis of means pertaining to the dry weights of roots, stem, panicle, total dry weight and grain presented in Table 1, it will be seen that

TABLE 1

Analysis of means for oven dry weights (gm plant) at harvest

Parents/Hybrids	Root	Stem	Panicle	Total dry weight	Grain
CK 60 B	12·75	41·25	57·25	111·25	47·45
IS 84	16·50	51·25	63·25	131·00	51·80
IS 3691	9·25	31·75	37·25	78·25	29·95
CSH-1	30·75	59·25	83·00	173·00	68·00
CSH-2	59·75	169·25	81·75	310·75	58·50
S.E.	2·80	6·13	2·21	9·19	2·06
C.D. at 5%	8·63	18·90	6·82	28·32	6·34

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the differences between parental values and hybrids are highly significant indicating considerable heterosis. Hybrids are superior over the parents for all the characters.

Heterosis in relation to active root distribution

Active root distribution of parents and hybrids at the respective lateral and vertical distances are presented in Table 2. It will be seen that in

Table 2

Per cent active root distribution of parents and hybrids at knee-high and flowering stages

Vertical depth (cm)	Parents/ hybrids	Knee-high stage			Flowering stage		
		L_1	L_2	L_3	L_1	L_2	L_3
V_1 (10 cm)	CK 60 A	17·5	38·5	17·8	24·3	25·4	29·3
	CK 60 B	42·6	30·1	56·3	54·0	28 9	53·2
	IS 84	63·1	41·8	36·9	38·6	71·7	14·9
	IS 3691	53·6	46·2	29·5	45·0	47·2	29·5
	CSH-1	91·8	89·0	19·4	54·4	45·8	20·9
	CSH-2	40·7	10·7	46·6	61·6	19·4	46·3
V_2 (20 cm)	CK 60 A	23·8	32·5	59·1	27·4	36·5	52·7
	CK 60 B	41·2	42·8	28·9	37·3	43·2	27·0
	IS 84	12·9	37·7	34·2	32·7	14·7	27·4
	IS 3691	24·3	14·5	29·2	24·6	17·0	44·0
	CSH-1	4·6	5·6	34·4	27·4	27·9	34·6
	CSH-2	41·8	74·5	27·0	25·6	63·1	44·0
V_3 (40 cm)	CK 60 A	58·7	29·0	23·1	48·3	38·1	18·0
	CK 60 B	16·2	27·1	14·8	8·7	27·9	19·8
	IS 84	24·0	20·5	28·9	28·7	13·6	57·7
	IS 3691	22·1	39·3	41·3	30·4	35·8	26·5
	CSH-1	3·6	5·4	46·2	18·2	26·3	44·5
	CSH-2	17·5	14·8	26·4	12·8	17·5	9·7

L_1=5 cm; L_2= 10 cm; L_3=20 cm.

CSH-1 there is considerable heterosis for root activity at knee-high stage. At 5 cm lateral distance (L_1) heterotic root activity is confined to the surface levels upto a depth of 14 cm. At 10 cm lateral distance heterotic activity is spread over greater area and confined to a depth of 28 cm. At 20 cm lateral distance there is no heterotic activity in surface layers but there is evidence of heterosis in the deeper layers below 32 cm. After flowering no heterotic root activity was observed upto a depth of 40 cm.

It will be also seen that the patterns of root activity are somewhat different for CSH-1 and CSH-2. In CSH-2, at knee-high stage there is no heterosis upto a depth of 14 cm at L_1 (5 cm away from the plant). But at a lateral distance of 10 cm, heterotic activity is considerable at depths of 14 cm to 36 cm. At 20 cm lateral distance no heterotic root activity was observed. At flowering also heterotic root activity in CSH-2 is apparent in the surface and middle layers at lateral distances of 5 cm and 10 cm and almost negligible at 20 cm lateral distance. This could obviously be due to certain amount of tillering which is common with CSH-2.

Root activity in male sterile and its fertile counter part

Active root distribution in CK 60A and CK 60B lines at both knee-high and flowering stages are given in Table 3.

Table 3

Per cent active root distribution of CK 60A and 60B at knee-high and flowering stages

Vertical depths	Genotype	Knee-high stage			Flowering stage		
		L_1 (5 cm)	L_2 (10 cm)	L_3 (20 cm)	L_1 (5 cm)	L_2 (10 cm)	L_3 (20 cm)
V_1 (10 cm)	CK 60 A	17·5	38·5	17·8	24·3	25·4	29·3
	CK 60 B	42·6	30·1	56·3	54·0	28·9	53·2
V_2 (20 cm)	CK 60 A	23·8	32·5	59·1	27·4	36·5	52·7
	CK 60 B	41·2	42·8	28·9	37·3	43·2	27·0
V_3 (40 cm)	CK 60 A	58·7	29·0	23·1	48·3	38·1	18·0
	CK 60 B	16·2	27·1	14·8	8·7	27·9	19·8

The differences are surprisingly striking even though the nuclear constitution of both the lines is the same.

It will be seen that at 5 cm lateral distance CK 60A has least root activity at 10 cm depth and the activity gradually increases, the maximum activity being at 20 cm depth. On the other hand in CK 60B maximum activity at 5 cm lateral distance is in the surface and gradually increases as the depth increases and as we go away from the plant.

While this trend of root activity is generally maintained at lateral distance of 5 cm and 20 cm for CK 60B, there is considerable change in the trend of activity for CK 60A. The activity for CK 60A at lateral distances 5 cm and 20 cm is considerably more at middle depths. At flowering stage also the differences between CK 60A and CK 60B for root activity persist. At lateral distance of 5 cm, CK 60A has maximum activity at 40 cm depth whereas CK 60B has maximum activity at 10 cm depth.

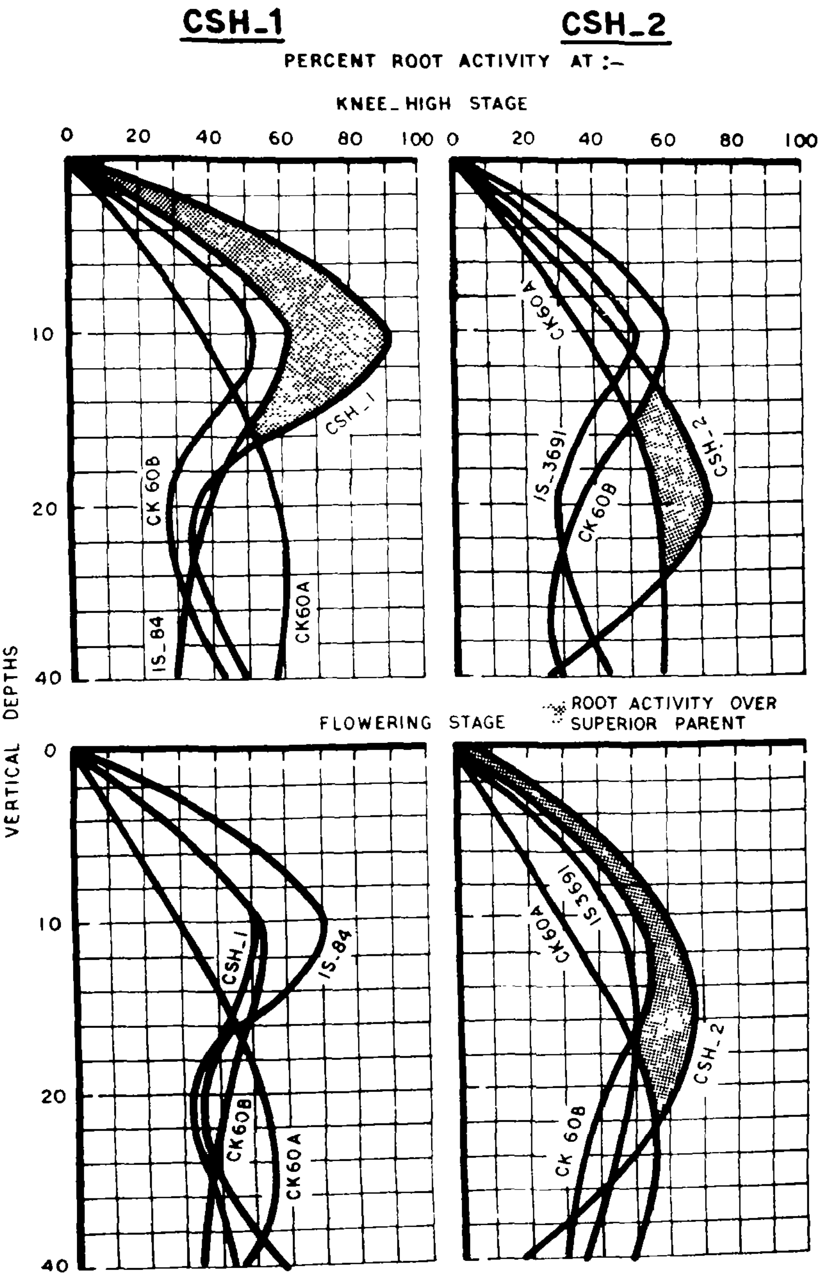

Fig. 1

Discussion

A summary of the root activity in CSH-1 and CSH-2 in relation to their parents, presented in Fig. 1, reveals different patterns.

In case of CSH-1, at knee-high stage there is increasing heterosis for root activity the maximum being at 10 cm depth which gradually decreases and beyond a depth of 18 cm there is no evidence of heterosis for root activity. At deeper layers, the active root system follows the pattern of the superior parent IS-84 which apparently contributes for drought tolerance. At flowering there is no evidence of heterosis for root activity, the patterns for CSH-1 and IS-84 being similar. Thus as far as CSH-1 is concerned, the seedling vigour is the result of heterosis for root activity and its capacity to stand drought later is apparently contributed by IS-84. It is, therefore, possible that drought tolerance and heterosis for root activity at later stage of growth may be independent.

The pattern of root activity for CSH-2 differs from that of CSH-1. The male parent of CSH-2, IS-3691 has inferior root activity compared to CK 60. Unlike CSH-1 heterosis for root activity in CSH-2 at knee-high stage is evident between 12–22 cm depth and at flowering it extends even to the surface layers, the maximum activity being still at 14–18 cm depth. While the later surface activity in CSH-2 may be attributed to initiation of tillers, the persistence of heterotic activity at flowering is a more striking difference from that of CSH-1. The drought tolerance of CSH-2 may be due to heterosis for root activity at deeper layers. CSH-2 may suffer most if there is no moisture in the top 30 cm layer of the soil at flowering.

Rao and Murty (1970) observed that in case of CSH-1 the nature of gene action in yield heterosis is predominantly the result of additive and additive $\times$ additive interactions whereas in CSH-2 the non-additive epistatic interactions predominate. Rao and Venkateswarlu (1971) felt that heterosis for rate of uptake of P_2O_5 in case of CSH-2 may be related to the differences in the nature of gene action. Similarly, whether the two types of gene action, i.e., predominant general combining ability in case of CSH-1 and predominance of specific combining ability in case of CSH-2 are attributable to seedling heterosis only for root activity in CSH-1 and extended heterotic activity in deeper layers in case of CSH-2 needs further analysis and confirmation.

The root activity differences in CK 60A and CK 60B are strikingly diverse. In the A-line root activity is generally more deep seated both at knee-high and flowering stages when compared to the activity in the B-line. Sullivan *et al.* (1968) who studied differences in drought tolerance also observed the A line to be more tolerant to drought than the B-line. Since the activity studies are at the knee-high and flowering stages, the differences cannot be attributed to the differences in the filling capacity of the two types. The only difference between the two lines is in the cytoplasm. While the A-line has *milo* cytoplasm and *kafir* nuclear factors, the B has *kafir* cytoplasm and *kafir* nuclear factors. It is rather difficult at this stage to attribute these differences in root activity to the cytoplasm unless further studies are carried out.

Summary

Heterosis for root activity in sorghum hybrids exhibited different patterns. Heterosis for root activity in CSH-1 was marked at the knee-high stage. As the lateral distance increased from 5 to 20 cm, heterosis for root activity was deeper and deeper, being upto a depth of 14 cm at L_1 (5 cm), 28 cm at L_2 (10 cm) and 32 cm at L_3 (20 cm). Maximum heterotic activity at knee-high stage was at 10 cm depth. At flowering no heterosis for root activity was observed in CSH-1. In CSH-2 heterosis persisted at flowering as well. Unlike in CSH-1 heterosis for root activity at knee-high stage was deeper between 12–22 cm depth and at flowering it extended to surface layers also. Possible relationship between predominantly *gca* for yield heterosis in CSH-1 and *sca* in case of CSH-2 and the different patterns of root activity is discussed.

The male sterile and its fertile counter part exhibited distinct differences in root activity. The greater drought resistance of A line correlates well with its pattern of root activity compared to the B line. The role of cytoplasm in influencing root activity needs to be investigated.

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Breeding Sorghums for Disease Resistance in India

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Breeding for resistance to prevalent diseases or control through fungicide usage have not received adequate attention in attempts to improve traditional subsistence-level culture of sorghums in the semi-arid tropics. Seed treatment through Sulfur or other fungicides to control smuts has been, by and large, the major recommendation. In transforming traditional sorghum culture to productive agriculture and attaining stability at higher levels of production, incorporation of disease resistance in future cultivars assumes particular importance — not only in order to provide resistance to known disease hitherto not considered serious enough to cause economic losses, but also to avoid possible occurrence of diseases in epiphytotic proportions. As explained in its annual reports, combining resistance to more than one disease in future cultivars has been a major objective of the All India Coordinated Sorghum Improvement Project. Some of these efforts will be briefly outlined.

Head Molds and Grain Deterioration

One of the major breeding efforts to avoid climatic vulnerability of rainfed sorghums has been to develop cultivars whose duration would match with the duration of the rainy season, as against the disproportionately long duration of 5 to 6 months for traditional cultivars. While the development of hybrids and varieties that mature in 90 to 110 days confer stability of production, even in years of low rainfall, occasional late rains in October cause grain deterioration and consequent low market price. The problem has been to reconcile the need for earliness for yield stability and necessity of avoiding grain deterioration when rains arrive before harvest (Rao 1977). This situation occurs in several African countries as well.

Grain deterioration is the result of heads getting soaked during the grain-drying stage, and/or development of molds resulting in grain discoloration. The problem of head molds in India has been investigated by various workers including Narasimhan and Rangaswamy (1969a, 1969b); Koteswara Rao and Purnachandrudu (1971), and Ravindranath and Indira (1979). *Curvularia, Fusarium, Helminthosporium, Alternaria,* and *Phoma* have been reported to be the common genera of fungi associated with head molds. *Phoma* has been observed to occur under humid heat, particularly if harvests are delayed. In gooseneck types, only the exposed portion is infected by *Phoma;* the other side is relatively free. Experience also indicates that bagging prevents occurrence of *Phoma.*

From the point of view of breeding, it appears necessary that the total process of grain deterioration (involving fungal *and* physical aspects) should receive attention. Screening for resistance to head molds and grain deterioration has identified the released variety CSV-4 (CS-3541) as the best available. The released hybrids CSH-5 and CSH-6, which have CS-3541 in their parentage, are also desirable. In fact, the availability of CS-3541, CSH-5, and CSH-6 — which corrected for the drawback of grain discoloration of CSH-1 — has now enabled larger coverages in states like Andhra Pradesh and Tamil Nadu where molds are serious. It has also made practical the practice of double-cropping under rainfed conditions in parts of Maharastra, Madhya Pradesh, and Karnataka.

Further screening efforts have also identified CSV-5 (148/168), SPV-35, SPV-81, SPV-102, SPV-126, SPV-141, and SPV-249 as moderately

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resistant to head molds. Besides, IS-3927, IS-9327, IS-9333, and IS-9530 have been reported as resistant by ICRISAT workers, and may be used as genetic stocks.

Selection criteria to breed for resistance to grain deterioration have been developed by Rana et al. (1977). The three characters—tan plant type, low water absorption capacity when soaked for a period of 2 hr, and the breaking strength of grain — are the criteria used for selection of types resistant to grain deterioration.

The inheritance of hardness of seed and rate of water absorption are predominantly additive, and selection for these characters together with thetan plant type is effective. The tan x tan and hard x hard crosses exhibited less deterioration. As the degree of softness increased, the degree of deterioration also increased, and hard x hard crosses within tan types are the best (Rana et al. 1978).

From the crosses involving CSV-4, CSV-5, SPV-81, SPV-102, etc., several advanced generation progenies of economic worth have been isolated and are undergoing yield testing.

Downy Mildew

Downy mildew caused by *Peronosclerospora sorghi* has been more frequently observed in humid areas around Dharwar in Karnataka and adjoining areas of Maharashtra and parts of Tamil Nadu. Occurrence of downy mildew in the yellow locals of Andhra Pradesh was observed during the current rainy season. Even though most locals show a susceptible reaction, SDM rarely assumed epiphytotic proportions outside experimental fields. Even so, it is desirable to avoid release of highly susceptible cultivars in vulnerable areas.

Fortunately, very high levels of resistance have been built up in released hybrids and varieties. The following parents/hybrids/varieties are highly resistant to SDM:

Parents:	..	2219A and B, 2077A and B, 323A and B, CSV-4 (CS-3541), CSV-5 (148/168)
Hybrids: (released and experimental)	..	CSH-5, CSH-6, SPH-24, SPH-107
Varieties: (released and experimental)	..	CSV-4, CSV-5, SPV-35, SPV-81 (Uchv-2), SPV-104, SPV-105, SPV-126, and SPV-238

Among genetic stocks, QL-3, IS-173, and several others have been reported to be highly resistant.

Resistance to SDM appears quantitative in inheritance. F_3 progenies of resistant x susceptible crosses presented normal distribution (Rana et al. 1978a). However, there is a report by Puttarudrappa et al. (1972) indicating two complementary factors governing resistance.

F_1 hybrids between resistant and susceptible parents indicate partial dominance for resistance, their infection percentages falling between mid-parental values and the resistant parent. A detailed genetic analysis of inheritance to downy mildew is presently in progress. Available evidence indicates the highly heritable nature of resistance. Hence there should be no problems in transference.

Charcoal Rot

Charcoal rot caused by *Macrophomina phaseolina* becomes prominent under conditions of moisture stress, usually during the postrainy season, and when low soil moisture and high temperature occur during seed development, as sometimes happens in rainy season situations.

Screening of presently available cultivars identified the following moderately to highly resistant types:

Highly resistant:	..	CSV-5 (148/168) and SPV-104
Moderately resistant:	..	323B, 296B, SPV-34, SPV-35, SPV-105, SPV-106, SPV-126

Some efforts have been made to study the genetic basis of resistance to charcoal rot (Rana et al. 1978a), and further studies are in progress. Hybrids between resistant and susceptible parents show intermediate reaction or tend towards resistant parent. The F_2 range was within parental limits. In F_3, there was transgressive segregation and the distribution was continuous. The relationships between F_1 and F_2 and between F_2 and F_3 were significant at the 10% level only. This low degree of determination indicates that heritability of resistance may be low. Since F_1 hybrids tend to approach resistant parents, use of moderately resistant parents (or at least one resistant parent) in a hybrid program may confer advantage to the hybrid with respect to reaction to charcoal rot.

Leaf Diseases

Leaf diseases in India rarely cause economic losses. Rust usually appears before harvest and reduces forage quality. Breeding for resistance to several of the leaf spots is generally attempted. Common leaf spot diseases occurring in India include zonate leaf spot *(Gloeocercospora sorghi),* grey leaf spot *(Cercospora sorghi),* rough leaf spot *(Ascochyta sorghi),* blight *(Helminthosporium turcicum),* sooty stripe *(Ramulispora sorghi),* anthracnose *(Colletotrichum graminicola)* and rust *(Puccinia purpurea).*

Among released and advanced generation materials, the following exhibit high degree of resistance to more than one disease.

Parents: .. 2219A and B, 2077A and B, 296A and B, 323A and B, CS 3541 and 168/148

Hybrids: .. CSH-5, CSH-6, and SPH-61

Varieties: .. CSV-4, CSV-5, SPV-96, SPV-104, SPV-105, SPV-106, SPV-192, SPV-220, SPV-224, SPV-232, SPV-257 and several others.

The rust reactions of certain cultivars differ at Dharwar and other centers. Patil-Kulkarni et al. (1972) reported more than two pairs of genes, susceptibility being dominant. At Dharwar, where stocks rated as resistant to rust at other locations succumb to rust, the following were identified as resistant to rust: SPV-9 (SB 411), SPV-13 (SB 803), SPV-34, SPV-35, SPV-73 (SB 1079), SPV-81 (Uchv-2), SPV-126, SPV-193 (SB 905), SPV-248, SPV-257.

The following exhibit moderate degree of resistance to rust:

Parents: .. 2219B, 2077B, 296B, CS 3541

Hybrids: .. CSH-5, CSH-6, SPH-61

Varieties: .. CSV-4, SPV-96, SPV-104.

Genetic analysis of rust resistance by Rana et al. (1976) indicated that susceptibility is dominant and that three major genes govern resistance. Rust resistance is present in the tan and in the purple plant types.

There are indications that resistance to zonate leaf spot is governed by complementary genes. Detailed studies are in progress.

Present indications are that leaf spots may not pose serious problems, and resistance breeding is quite effective.

Multiple Resistance

Genetic stocks and breeding materials exhibiting resistance to more than one disease now

Table 1. Multiple disease-resistant sorghums.[a]

Cultivar		DM	CR	Rust	ZLS	Cer	An	SS	Helm	Asco	SD
SPV-104	(6)	X	X	X	X	X		X			
SPV-126	(6)	X	X	X	X	X					
SPV-178	(6)	X	X	X		X	X				X
CSH-5	(6)	X		X	X	X		X			X
CSV-4	(5)	X	X	X	X	X					
CSV-5	(5)	X	X		X	X					
SPV-193	(5)	X	X	X	X	X					
CSH-6	(5)	X		X	X	X					X
SPH-61	(5)		X	X	X	X					X
SPH-80	(5)	X	X		X	X			X		
SPV-70	(4)	X		X	X					X	

a. Number in parentheses indicates number of diseases to which this cultivar shows resistance; DM - Downy mildew; CR - Charcoal rot; ZLS - Zonate leaf spot; CER - Cercospora; AN - Anthracnose; SS - Sooty stripe; HELM - Helminthosporium; ASCO - Ascochyta (Rough leaf spot); SD - Sugary disease. x indicates resistant.

enable us to breed for resistance to several of the prevalent diseases.

Downy mildew, charcoal rot, and components of grain deterioration are polygenic in inheritance, while several of the leaf spot diseases are governed by relatively few genes. There is evidence that resistance to charcoal rot, SDM and leaf spots is independently inherited. This might hold good for other diseases as well — which should make possible an approach to more than one disease in a resistance-breeding program. It is also evident that, compared to purple-pigmented types, tan-plant types generally exhibit greater levels of resistance to most leaf diseases, and hence the tan plant is an important selection criterion. Biochemical characterization of tan and purple types would be useful.

Keeping some of these criteria in view, it has been possible to develop commercial cultivars, parents, hybrids, and varieties which exhibit high levels of resistance to several diseases. A list of such varieties is presented in Table 1.

Summary

High levels of resistance are available for most sorghum diseases. The nature of inheritance is quantitative for downy mildew and charcoal rot, and qualitative with respect to other diseases. Resistanceto various diseases is independently inherited. Heritability of resistance is high, except in the case of charcoal rot. Tan-plant types have generally higher degrees of resistance to foliar diseases. It appears feasible to combine resistance to several diseases together with higher yields in breeding cultivars with higher levels of productivity and stability.

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Stability, Productivity, and Profitability of Some Intercropping Systems in Dryland Agriculture

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Abstract

Keeping in view the emerging dry/and farming systems for semi-arid tropics, an attempt has been made to design and develop appropriate intercropping systems that reflect transgressive yielding, stability, and profitability.

Studies on competition between species enabled characterization of complementary, aggressive, and relatively neutral species. Under competition stress sorghum was the most stable species followed by pigeonpea, while groundnut has been found to be most sensitive.

At the varietal level, it has been demonstrated that suitable varieties of pigeonpea, like Hy-3a with no basal branches, are more stable at an appropriate population level in intercropping systems. Sowbhagya castor and CSH-6 sorghum are similar examples.

Studies on alternate planting patterns established that generally the interaction between intercropping systems and planting patterns was highly significant, but in certain specific systems based on pigeonpea and sorghum the interaction was not significant.

While the yields of intercropping systems generally tend to fall between the yield levels of component crops, transgressive yielding of the system is not ruled out. Apart from yield, prevailing prices also become an important factor in the choice of component crops. In seven of the most profitable intercropping systems identified, sorghum was a constant component, it is inferred that in-depth studies on factors involving transgressive yielding ability could further enhance stability, productivity, and profitability of intercropping systems.

Mixed cropping, an established system of traditional dryland subsistence agriculture in semi-arid tropics, needs different orientation in the context of the emerging productive dryland farming systems. Cultivar improvement involving genotypic alterations resulting in a reduction of total dry matter but a more efficient distribution between stalk and ear, shortening of duration to match the duration of rainy season, exploitation of advantages of hybrid vigor, increased input use, practice of improved cultural practices etc., result in minimizing climatic vulnerability and confer higher levels of productivity and stability (Rao 1977). In such a context, intercropping systems have to be viewed not only from the point of view of further risk cover but also transgressive yielding, stability, and profitability.

Keeping these objectives in view, a series of intercropping experiments were conducted at the IARI-Regional Station during 1971-78 to obtain information on (1) choice of crops and varieties, based on inter- and intra-species competition, (2) genotype x density interactions, and (3) alternate planting patterns. Sorghum, pigeonpea, groundnut, castor, and soybean were included as principal and/or companion crops. The results of some of the experiments have been reported earlier (Tarhalkar and Rao 1975; 1978). Based on some of these intercropping studies, an attempt is made to project various aspects pertaining to stability, productivity, and profitability of intercropping systems.

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Competition between Species and Stability of Performance

Studies during 1971-1973 (Tarhalkar and Rao 1975) indicated that soybean, pigeonpea, and groundnut as companion crops did not significantly reduce grain yields of the principal crop of sorghum; soybean and pigeonpea as companion crops were least competitive to groundnut, and pigeonpea and groundnut to the main crop of castor.

An examination of the competitive effects of principal (sorghum) and companion crops reveal that soybean performed well as a companion crop, mung bean was suppressed by sorghum, while pigeonpea and castor occupy intermediate positions (Fig. 1).

Further studies during 1973 and 1974 involving all possible intercropping systems based on four crops (Table 1) revealed that sorghum-based intercropping systems are the most productive followed by pigeonpea, castor, and groundnut. The interaction between principal crops and companion crops was highly significant (Table 2).

Analysis of the stability of the species under competition stress using regression approaches (Breese and Hill 1973) again points to sorghum as the most stable followed by pigeonpea, castor, and groundnut; groundnut was most sensitive to competition (Fig. 2).

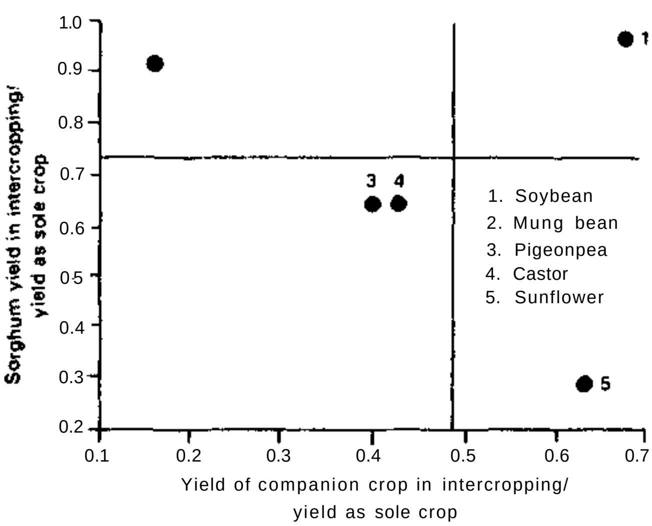

Figure 1. Species competition in sorghum-based intercropping systems, rainy season 1971.

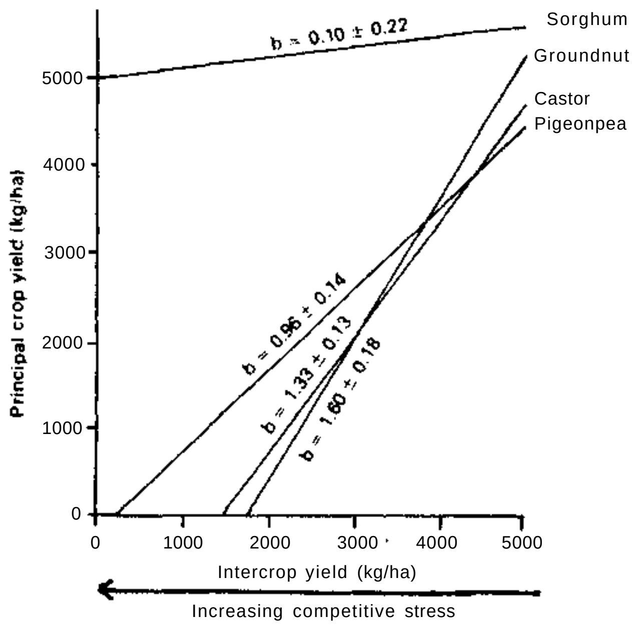

Figure 2. Regression of principal crop yield on intercrop yield over five planting patterns.

Table 1. Total yield (kg/ha) of Intercropping systems averaged over five planting patterns, rainy seasons 1973 and 1974.

Principal crop	Companion crop: Sorghum	Pigeonpea	Castor	Groundnut	Soybean	Stability parameters: Mean	$\hat{b}_i$	δ^2_{ij}
Sorghum	5285	5684	5216	5053	5553	5358	0.10 ± .22	81 788
Pigeonpea	3766	2654	2076	2380	2675	2710	0.96** ± .14	31 753
Castor	3624	2165	1405	1652	1872	2144	1.33** ± .13	29 593
Groundnut	3877	2315	1654	1132	1743	2144	1.60** ± .18	54 360
Mean	4138	3205	2588	2554	2961	3089		
Evn. Index	1048.8	115.8	-501.2	-535.2	-128.2			

** Significant at the 1% level.

Further analysis of competition among species based on diallel approaches (Table 3) indicates that both general and specific competitive abilities are highly significant. Reciprocal competitive effects are also highly significant indicating that it will not be possible just to interchange species in intercropping systems.

Table 2. Pooled ANOVA for total yield in intercropping systems.

Source	DF	MSS
Combinations	19	23 578 782**
Principal crops (P)	3	11 798 645**
Intercrops (1)	4	16 673 984**
P x I	12	28 825 416**
Average error	15	159 690

** Significant at the 1% level.

Competition within Species

Varietal differences within a species also account for differences in growth rhythms, canopy display, branching habit, and various morphological and physiological attributes. It is possible to manipulate one or more of these attributes which in turn influence competition.

As an example, two varieties of pigeonpea Hy-2 with basal branches and Hy-3A with no basal branches differ in their competitive abilities when grown with sorghum as the principal crop. Yield data involving two population levels for each variety in an intercropping system with sorghum are presented in Table 4 and analysis of variance in Table 5. It is interesting to note that the intercropping systems x planting patterns interaction is not significant. Stability analysis (Fig.3) reveals that Hy-3a at half population is least sensitive or more stable in yield. On the other hand, Hy-2 is

Table 3. ANOVA for competitive ability of species in five planting patterns.

		Total Yield				
		Planting pattern				
Source	DF	1	2	3	4	5
Replications	1	5 571 120**	2 633 510*	277 880	291 080**	304 780**
Combinations	15	12 143 806**	6 061 549**	3 411 929**	3 422 497**	3 091 693**
General competitive ability	3	45 362 600**	24 492 106**	14 190 286**	14 180 493**	12 468 533**
Specific competitive ability	6	1 491 053*	501 990	1 172 813**	1 019 923**	1 139 603**
Reciprocal competitive ability	6	6 187 179**	2 405 830**	261 866	446 070**	355 356**
Error	15	458 702	442 907	110 089	24 787	1 488

* Significant at the 5% level; ** Significant at the 1% level.

Table 4. Performance of sorghum/pigeonpea intercropping systems.

	Yield (kg/ha)			
Intercropping system	Sorghum	Pigeonpea	Sorghum + Pigeonpea	Monetary returns (Rs/ha)
Sorghum (pure)	6257		6257	6257
Sorghum + pigeonpea Hy-3[a] (H)[a]	5618	1182	6800	8926
Sorghum + pigeonpea Hy-3[a] (F)[b]	5291	1279	6570	8874
Sorghum + pigeonpea Hy-2 (H)	5337	1017	6354	8183
Sorghum + pigeonpea Hy-2 (F)	5108	1133	6241	8281

a. H = Half population — 27 500 plants/ha.
b. F = Full population — 55 000 plants/ha.

Table 5. ANOVA for yield (kg/ha) in sorghum/pigeonpea intercropping system.

Source	DF	Sorghum	DF	Pigeonpea	DF	Sorghum + Pigeonpea
Combinations	24	503 286**	19	77 383**	24	481 502**
Intercropping systems (IS)	4	2 018 986**	3	119331**	4	834 836**
Planting patterns (PP)	4	906 654**	4	224 505**	4	1 293 474**
IS x PP	16	23 519*	12	17 855**	16	190 175
Pooled error	20	8 412	15	459	20	100 198

* Significant at the 5% level; ** Significant at the 1% level.

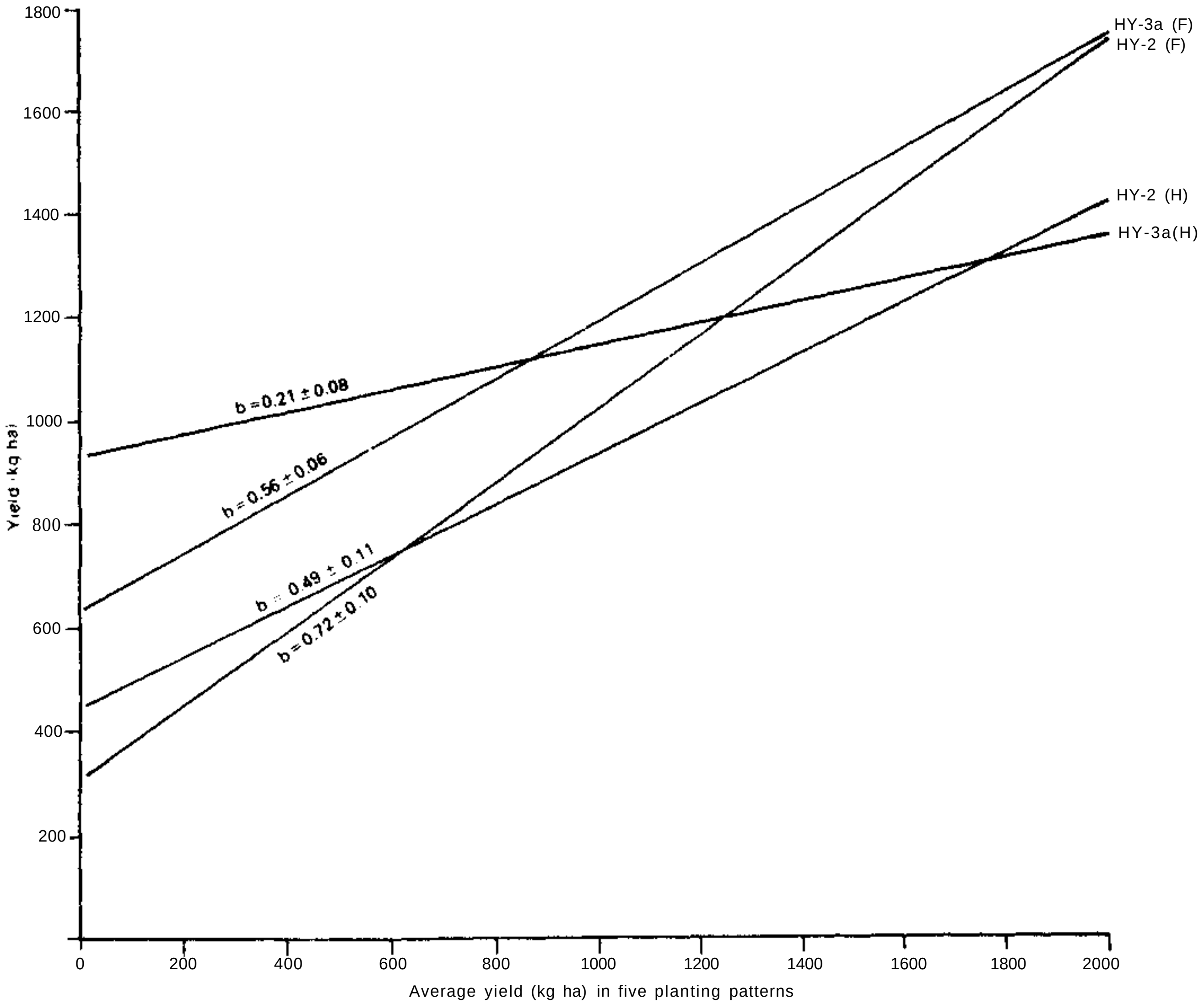

Figure 3. Stability of pigeon pea genotypes in sorghumlpigeonpea intercropping systems at two population levels: full (F) = 55 000 and half (H) = 27 500 plants/ha.

more sensitive and yield declines more rapidly under competitive stress. This illustrates the role of genotypic manipulations at varietal level to suit intercropping systems.

Sowbhagya, a variety of castor developed at our Station (Ankineedu et al. 1975) —a dwarf and compact plant type with shorter petioles — is suitable for intercropping while the traditional tall castors are decidedly not suitable for intercropping systems. Compared to the traditional tall and late sorghums, hybrid sorghums like CSH-6 with medium dwarf height and less foliage are favorable for Intercropping. The competitive advantages of such genotypes need to be quantified.

Population Density, Planting Patterns, and Stability

It has been fairly well established that at optimal population levels for any crop, there is considerable scope for manipulating planting patterns involving between- and within-row spacings. Adequate data on this aspect has been presented in progress reports of the All India Coordinated Sorghum Improvement Project and also by Tarhalkar and Rao (1975).

Table 6 presents analysis of variance for various intercropping systems based on sorghum, pigeonpea, castor, and groundnut. While the intercropping systems and planting patterns show significant differences, the interaction between them is not significant in pigeonpea-based systems and significant only at 5% for sorghum-based systems, indicating their greater stability.

Analysis of stability parameters for various intercrop combinations (Table 7) reveals that sorghum-based systems are the most productive and stable with high mean values and regression coefficients close to 1.0. This is followed by pigeonpea-based systems.

Productivity and Profitability

We have pointed out earlier (Rao et al. 1975) that unless improvements in dryland agriculture reflect a quantum jump and have the capacity to

Table 6. ANOVA for total yield (kg/ha) in different Intercropping systems, rainy seasons 1973 and 1974.

		Mean square for intercropping systems based on				
Source	DF	Sorghum	DF	Pigeonpea	Castor	Groundnut
Combinations	24	1 509 521**	19	1 488 050**	1 594 120**	2 494 950**
Intercropping systems (IS)	4	796 680**	3	807 764**	7 908 090**	10 628 800**
Planting patterns (PP)	4	790 431**	4	834 248**	1424 715**	2 429 419**
IS x PP	16	89 032*	12	58 588	72 099**	43 334**
Pooled error	20	38 363	15	67 567	18 150	9 653

* Significant at the 5% level; ** Significant at the 1% level.

Table 7. Stability parameters for total yield (kg/ha) in intercropping systems.

Principal crop															
	Sorghum				Pigeonpea				Castor				Groundnut		
IS	M	bi	δ^2_{ij}	IS	M	bi	δ^2_{ij}	IS	M	bi	δ^2_{ij}	IS	M	bi	δ^2_{ij}
S + P	5685	0.92	NS	P + S	4043	0.81	NS	C + B	3625	0.92	NS	G + S	3877	2.11**	**
s + c	3957	1.00	NS	P + C	1950	0.95	NS	C + P	2165	1.14	»»	G + P	2315	0.89	NS
S + G	5053	0.99	NS	P + G	2422	0.78	NS	C + G	1652	0.65*	NS	G + C	1654	0.51**	*
S + SB	5553	1.03	NS	P + SB	2675	1.46	NS	C + SB	1872	1.28*	NS	G + SB	1734	0.49**	**
Mean	5358				2273				2328				2395		
S.E.	61.9	NS			42.6	NS			95.3	0.09			31.1	0.11	

* Significant at tha 5% level; ** Significant at the 1% level; NS-Not significant.
S = Sorghum, P - Pigeonpea, C = Castor, G = Groundnut, SB = Soybean.
IS - Intercropping system.

Table 8. Yields and monetary returns of some intercropping systems over five planting patterns, rainy season 1973 and 1974.

Intercropping system	Yield (kg/ha)			Proportion (%) of principal crop in the system	Monetary returns (Rs/ha)[d]
	P1[a]	P2[b]	M 1.2[c]		
Sorghum + groundnut	5285	1132	5053	92.2	5378
Sorghum + pigeonpea	5285	2654	5684	88.3	7442
Sorghum + castor	5285	1405	5216	79.7	5364
Groundnut + sorghum	1132	5285	3877	53.2	4711
Groundnut + pigeonpea	1132	2654	2315	85.7	5948
Groundnut + castor	1132	1405	1654	74.3	3494
Pigeonpea + sorghum	2654	5285	3766	61.4	6979
Pigeonpea + groundnut	2654	1132	1380	72.0	6501
Pigeonpea + castor	2654	1405	2076	54.4	5071
Castor + sorghum	1405	5285	3624	71.3	4631
Castor + groundnut	1405	1132	1652	87.0	3411
Castor + pigeonpea	1405	2654	2165	78.1	5182

a. P1 = Principal crop yield as pure crop.
b. P2 = Companion crop yield as pure crop.
c. M = Total yield of intercropping system.
d. Rates/100 kg: Sorghum, Rs. 100; groundnut Rs. 225; pigeonpea Rs. 280; castor Rs. 200.

Table 9. Performance of most productive intercropping systems.

Intercropping systems	Yield (kg/ha)			Monetary returns (Rs/ha)	Stability over planting patterns
	P1[a]	P2[b]	M1.2[c]		
Sorghum + pigeonpea	4464	1221	5685	7022	Stable
Sorghum + Soybean	4949	604	5553	5971	Stable
Sorghum + groundnut	4726	327	5053	5400	Stable
Sorghum + castor	4105	712	4817	5392	Lowest yielding in sorghum-based systems
Pigeonpea + sorghum	1631	2412	4043	6443	Stable
Groundnut + sorghum	602	3275	3877	4630	Unstable
Castor + sorghum	1002	2623	3625	4626	Stable

a. P1 = Principal crop yield as pure crop.
b. P2 = Companion crop yield as pure crop.
c. M = Total yield of intercropping system.

break the environmental barrier, yield improvement may not be perceptible.

Yield data from 1973 and 1974 *kharif* (rainy) seasons involving all possible intercropping combinations among the four crops are presented in Table 8. The yields of various intercropping systems, by and large, tended to be between the yield levels of component crops. Several such situations have been listed by Trenbath (1974b). However, there are three cases where the yields of the systems exceeded yields of the component crops; in all these cases, one of the components was a legume. These increases may or may not be genuine cases of transgressive deviations.

Seven of the intercrop combinations were more profitable compared to their components grown as sole crops (Table 8). Apart from the competitive effects, prevailing prices become an additional and important factor in choosing components of intercropping systems. The value of the sorghum-based systems will be further enhanced if the value of the stover is also taken into account.

Based on data obtained during 1973 and 1974, further studies were undertaken in subsequent years to identify the most profitable intercropping systems based on sorghum, pigeonpea, groundnut, and castor. A summary of the more profitable systems observed is presented in Table 9. Out of the seven profitable systems, four are sorghum-based and the rest are based on pigeonpea, groundnut, and castor, but even in these cases sorghum formed the intercrop component.

The studies thus bring out the important role of sorghum in intercropping. As pointed out by Trenbath (1974b), systematic studies of such systems to capitalize on complementary use of environmental resources in time and space, nutritional complementation, favorable canopy configurations, enhanced water-use efficiency, and possible allelopathic effects could lead to development of stable, productive, transgressive yielding, and profitable intercropping systems.

TABLE I

Individual values of enzyme activity in groups of animals on Feb. 15 and Feb. 16 at the 16·00 hr time interval

Enzyme (units)	Enzyme activity							
	Feb. 15				Feb. 16			
NADH oxidase of erythrocyte membrane* (nmoles NADH. min⁻¹. mg protein⁻¹)	3·2,	1·6,	1·1,		31·7,	31·7,	19·0,	
NADH oxidase of hepatic microsomes (nmoles O_2. min⁻¹. mg protein⁻¹)	242,	124,	174,	212	213,	168,	206,	190
Tryptophan pyrrolase of hepatic cytosol (nmoles. hr⁻¹. mg protein⁻¹)	14·1,	26·4,	12·0,	18·3	20·1,	18·2,	27·7,	12·2,
HMGCoA reductase of hepatic microsomes (pmoles mavalonate. min⁻¹. mg protein⁻¹)	130,	214,	115,	210	115,	110,	71,	69

* *Only three samples were tested.*

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SORGHUM BASED CROPPING SYSTEMS TO MEET SHORTAGES OF PULSES AND EDIBLE OILSEEDS

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ABSTRACT

The shift from tall and late varieties of sorghum to early maturing hybrids has not only conferred greater levels of productivity and stability but has opened up opportunities for practice of new cropping systems in rainfed areas. Based on extensive experimentation, the opportunities for enhancing pulse and edible oilseed production on the existing areas of sorghum through practice of suitable inter- and sequence cropping systems have been analysed.

TRADITIONAL tropical dryland agriculture continues to be largely of the subsistence type. Tropical cultivars are generally tall and late (>150 days), the duration of the crop growing season being longer compared to the duration of rainy season. Subnormal rains or restricted duration of monsoon result in the reduction of yields or total crop failures (Rao *et al.*[3]). Traditional mixed cropping, practised over ages, has been predominantly a strategy of subsistence for farmers to alleviate total risk and to achieve some measure of security.

Genotype Alteration and Sole Crop Stability

Recent efforts at genotypic alterations involving corrections for duration, dry matter production and distribution and changes in growth rhythms have resulted in the development of a new set of sorghum cultivars with higher levels of performance and stability when grown as sole crops. They are less vulnerable to climatic fluctuations. Examination of comparative yield levels of locals and improved cultivars along with the corresponding coefficients of variation over several years reveals that locals are not only low yielding but also less stable in performance (Rao and Rana[4]). The productivity and stability of such altered sorghums over several years is reflected in Fig. 1.

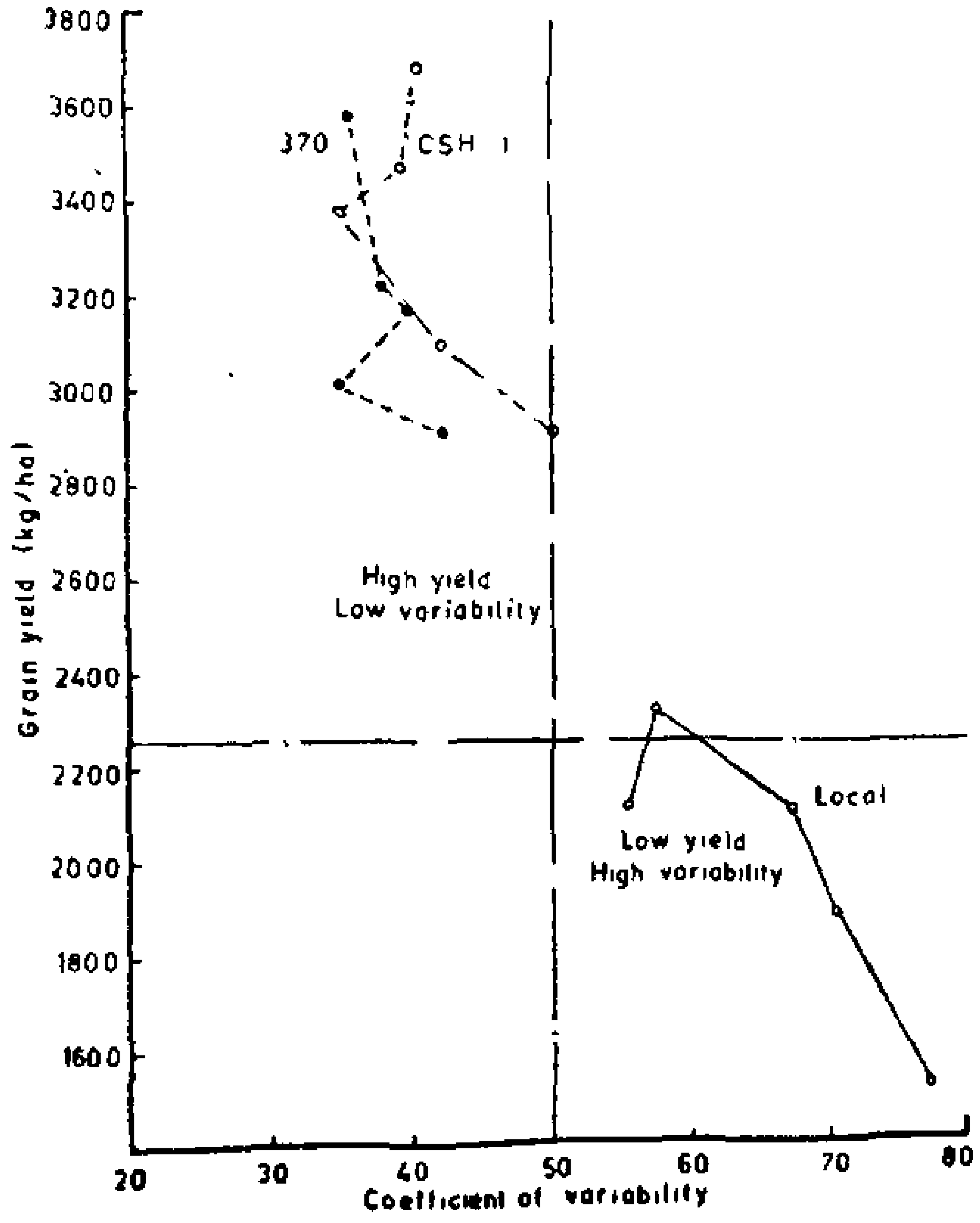

FIG. 1. Productivity and stability of local and improved cultivars of sorghum as sole crops.

Genotypic Basis for Alteration of Dryland Cropping Systems

The advent of newer genotypes with reduced duration, greater levels of productivity and stability of sole crops usher an emerging era of productive and stable dryland cropping systems involving scientific intercropping as well as sequence cropping. It is in this context that the sorghum based cropping systems could meet the shortages of pulses (grain legumes) and edible oilseeds.

Sorghums in India are essentially rainfed and are cultivated annually over an area of 17–18 million hectares primarily in the States of Maharashtra, Karnataka, Andhra Preadesh, Madhya Pradesh, Rajasthan, Gujarat, Tamil Nadu and the Bundelkhand region of Uttar Pradesh. The rainfall over this area ranges from 600–1200 mm received from the last week of June to mid-September or mid-October. The *kharif* sorghums constitute nearly 2/3 of the total area and the *rabi* the remaining 1/3. Most of the *kharif* area and the entire *rabi* constitutes retentive black soils; only parts of Tamil Nadu and Andhra Pradesh grow some sorghum in red soils.

The consumptive use of water for a 105-day hybrid sorghum during *kharif* is 368 mm and for a 130-day *rabi* variety 348 mm. Consumptive use of water for *mung* (65 days) is 207 mm, for soybean (110 days) 352 mm and *kharif* groundnut (110 days) 342 mm. These are for the Deccan region and should hold good for *Malwa* plateau and most other sorghum growing tracts (Kadam, Ramakrishna Rao and Varade[2]). This means, areas receiving over 750–800 mm of annual rainfall are suitable for growing more than one crop during a year even under rainfed conditions by using cultivars of appropriate duration. Areas which receive less than 700 mm of rainfall are more suited for practice of productive intercropping systems. Their productivity could even be higher if practised in better rainfall regions. That the maximum food production potential in different regions of India is much higher than what is being realised has been brought out by Sinha and Swaminathan[6].

Modern Intercropping Systems

The design and development of stable and productive intercropping systems takes into consideration, (1) the choice of crops and varieties based on inter- and intra-species competition, (2) genotype *x* density interactions and (3) alternate planting patterns so as to maintain the yields of the principal crop comparable to its sole crop yield and obtaining additional production of oilseed or pulse crops grown as intercrops (Rao, Rana and Tarhalkar[4]).

Data on sorghum based intercropping systems from the All-India Sorghum Project, IARI Regional Station, Hyderabad and the All-India Dryland Project (Choudhury[1]) over a seven-year period (1972–78), are analysed and presented in Table I. The sorghum yields in the intercropping system compare well to their respective sole crop yields at over 30 q/ha and the average yields of intercrops vary from 3–9 q/ha depending upon the crop. Approximately 95–97 % of the sole crop sorghum yield was realised in intercropping systems with groundnut/soybean, *mung* or pigeonpea. The yield levels of pulses and oilseeds

TABLE I

Production potential of oilseeds and pulses in sorghum based intercropping systems (Kharif 1972–78)

Intercrop	No. of experiments	(Avrage yield q/ha) Sorghum (sole crop)	Intercrop (sole crop)	Sorghum (in inter-cropping system)	Intercrop (in inter-cropping system)	Projected area million ha for 1 million ton production: Minimum yield potential	Average yield potential	Maximum yield potential
Oilseed Crops								
Groundnut	57	33·6±2·7	10·4±1·4*	33·1±1·8	4·8±·5	2·60	2·08	1·73
Castor	20	36·7±4·3	20·2±1·5*	32·9±2·0	5·3±·8	2·78	1·90	1·44
Sunflower	10	33·6±5·4	16·1±3·8	21·7±3·2	3·4±·9	8·00	2·99	1·84
Pulse Crops								
Pigeonpea (*arhar*)	115	35·8±1·9	16·5±0·9	32·4±1·4	9·4±·4	1·16	1·07	1·00
Soybean	60	33·0±1·9	13·9±0·7	32·2±1·8	5·5±·3	2·08	1·82	1·61
Greengram (*mung*)	38	33·5±2·7	8·2±0·7	32·7±2·0	3·1±·3	3·90	3·25	2·78
Blackgram (*urid*)	30	40·9±3·0	9·5±0·7*	33·8±2·1	2·8±·3	4·58	3·55	2·90
Cowpea	21	43·5±4·4	8·2±0·4*	38·1±4·1	2·7±·5	5·75	3·67	2·69

* Data based on less number of experiments.

when grown as intercrops in various All-India trials are depicted in Figs. 2 and 3. Pigeonpea and soybean among pulses and groundnut, in the case of oilseeds, have larger number of trials with higher levels of yield. With castor, the total number of trials is rather low. Based on the maximum, minimum and average yields of intercrops realized during different years, projections have been made for additional production of pulses and edible oilseeds. At average yield levels, one million tons of an intercrop could be produced from 1·07 m ha for pigeonpea, 1·82 m ha, for soybean and 2·08 m ha for groundnut. From the overall performance (Fig. 4), pigeonpea (*arhar*) and soybean among pulses and groundnut among edible oils offer greater opportunities for additional production on the existing areas of *kharif* sorghum. They are more stable in intercropping systems and relatively more productive.

The advent of high yielding sorghum hybrids have turned farmers towards growing them as sole crops since they are more remunerative than traditional mixed cropping. The hybrid sorghum area, particularly in low rainfall areas, could practise more productive intercropping with pigeonpea or soybean. In such areas, the duration of pigeonpea should not be excessively longer as it would then become subject to moisture stress. Soybean is less susceptible to competition compared to traditional pulses like *mung* and may have an increasing scope in years to come. Groundnut yields are low in sorghum based intercropping systems, but the haulms enrich the value of the fodder and if practised over a million hectares the groundnut production during *kharif* could be substantial. In groundnut based systems, sorghum yields are not at all reduced.

Policy decisions could delineate areas for appropriate intercropping systems of sorghum and pulses or oilseeds to meet the shortages. The advantages of intercropping systems from the point of view of promoting soil fertility, possibly a non-polluting means of controlling pests and diseases and capitalizing on allelopathic effects, is also receiving increasing attention (Trenbath[7]).

Two Crop Sequences

Black soil areas receiving over 750–800 mm rainfall are assured single crop areas with new hybrids of sorghum and potential two-crop areas. Data on two crop sequences are presented in Table II. Safflower as an edible oil and chickpea (gram) as a pulse are the most potential crops that could follow a *kharif* hybrid sorghum. A crop like *mung* could precede a *rabi* sorghum in assured rainfall areas of Maharashtra, Karnataka and Andhra Pradesh. In the black soil areas, the land during *kharif* usually remains fallow. *Mung* under heavy rains is subject to virus diseases; *urid* is of longer duration though less susceptible. Development of virus resistant *mung* or *urid* comparable in duration to *mung* and perfection of their production technology during *kharif*

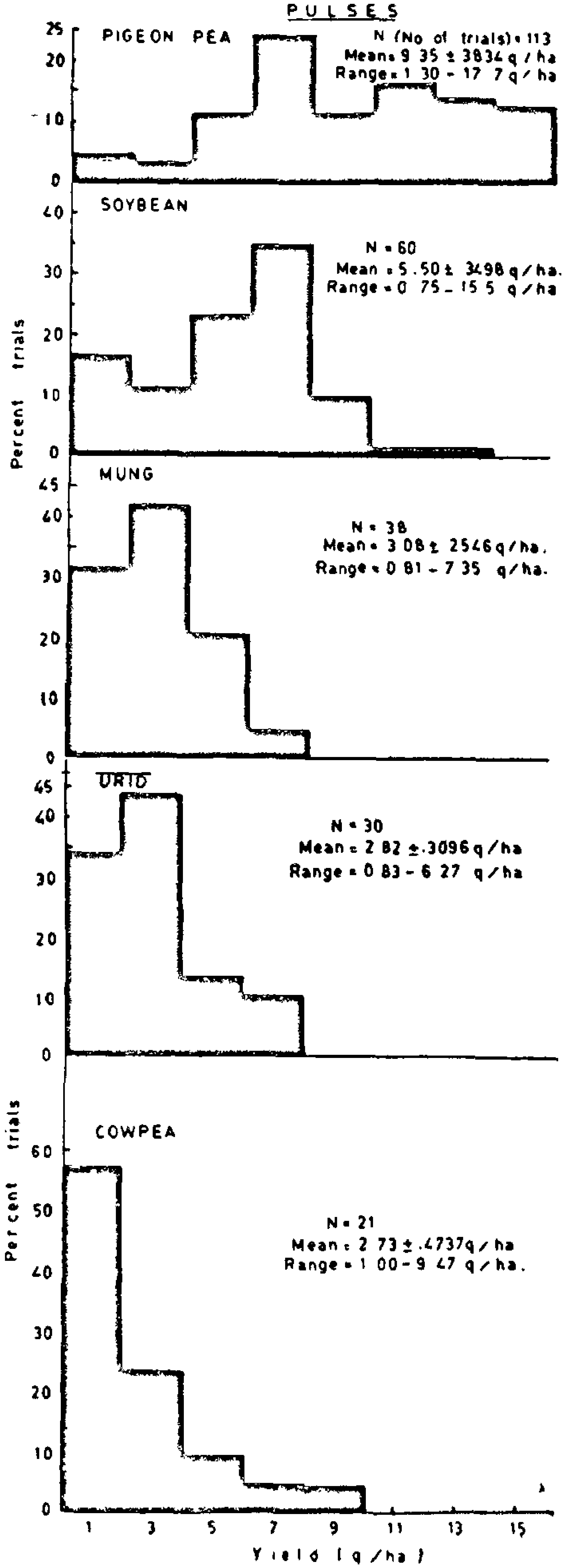

FIG. 2. Yield levels of intercrops in various trials from sorghum based intercropping systems—Pulses.

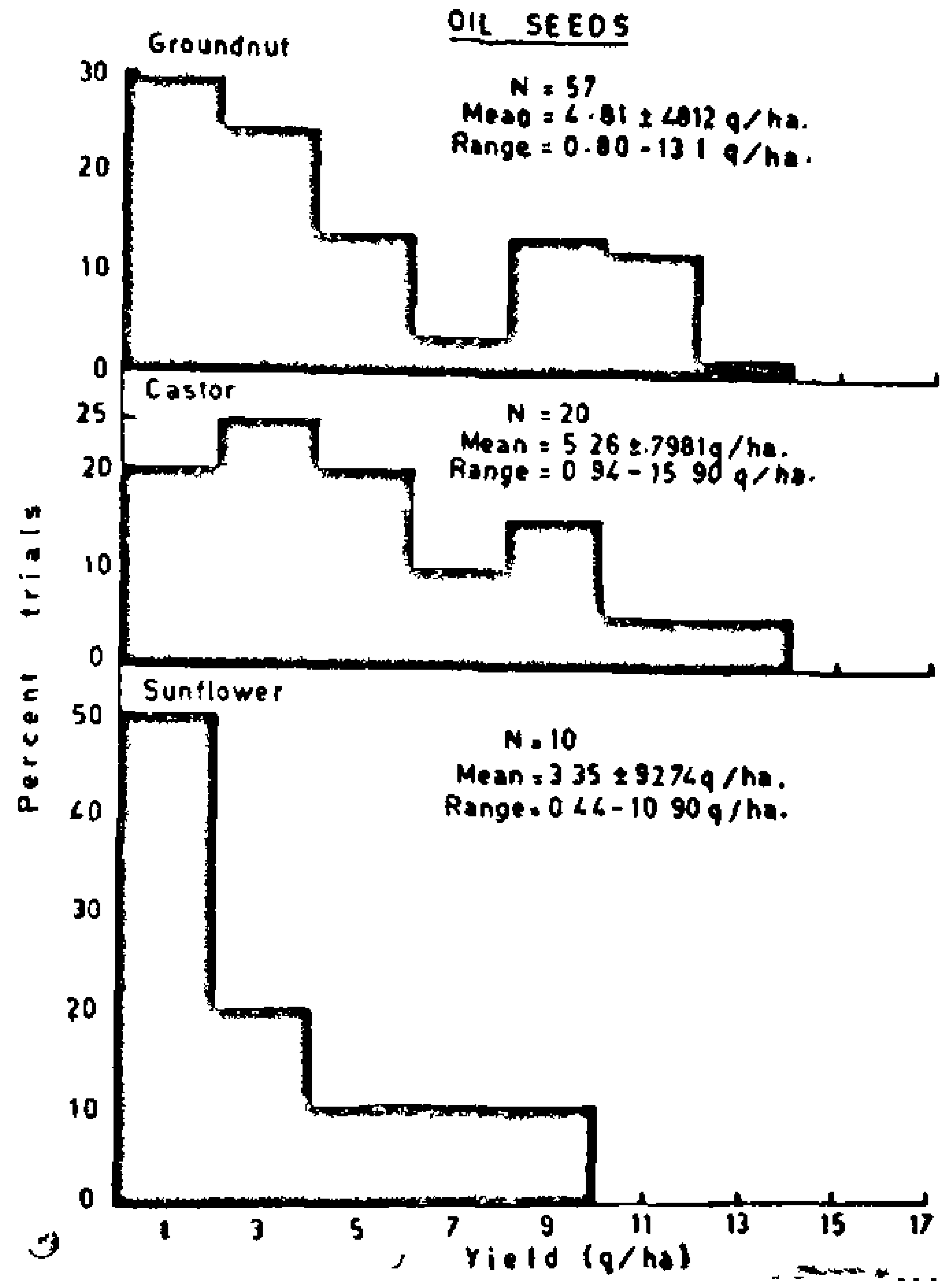

FIG. 3. Yield levels of intercrops in various trials from sorghum based intercropping systems—Oilseeds.

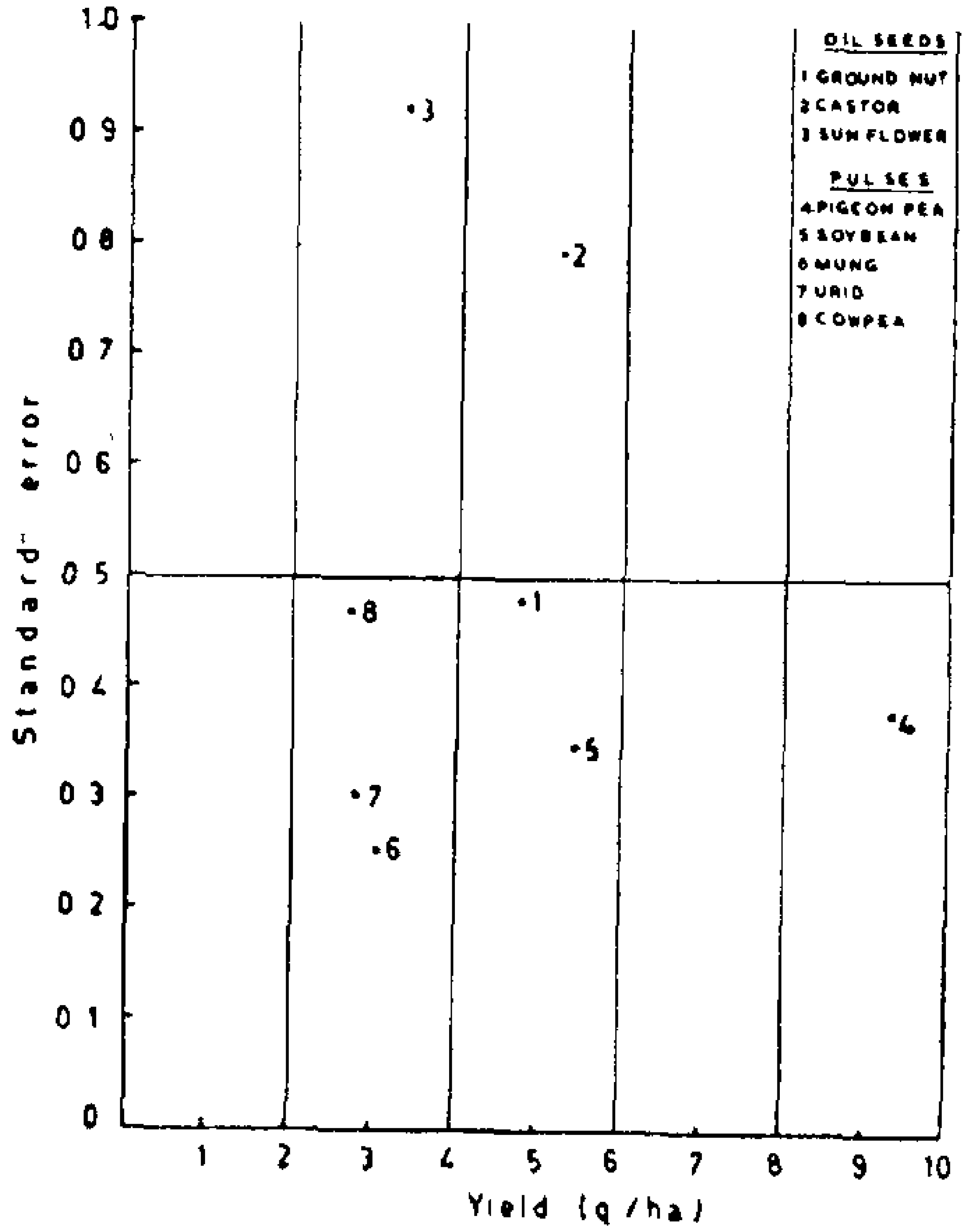

FIG. 4. Average yields of intercrops in relation to the respective standard errors.

TABLE II

Production potential of oilseeds and pulses in sequence cropping in sorghum growing areas

Sequence crop	No. of experiments	Average yield (q/ha)	Projected area (million ha) for 1 million ton production		
			Minimum yield potential	Average yield potential	Maximum yield potential
Safflower (after *kharif* sorghum)	10	9·55±1·62	1·70	1·05	0·76
Chickpea (gram) (after *kharif* sorghum)	5	6·49±1·48	4·20	1·54	0·94
Mung (before *rabi* sorghum)	4	7·05±1·15	2·97	1·42	0·93

could add to pulse production. Short duration sesame could also play an important role as a preceding crop. Based on a two-crop sequence, a million tons of safflower could be produced on an average from 1·05 m. ha, gram from 1·54 m ha, and *mung* from 1·42 m ha. An area of 3 million hectares during *kharif* is an assured single crop area for hybrid sorghums (Fig. 5), particularly hybrids like CSH-5 and CSH-6 which could stand grain deterioration even if late rains are received. The hybrid sorghum could then be followed with a sequence crop of safflower or chickpea.

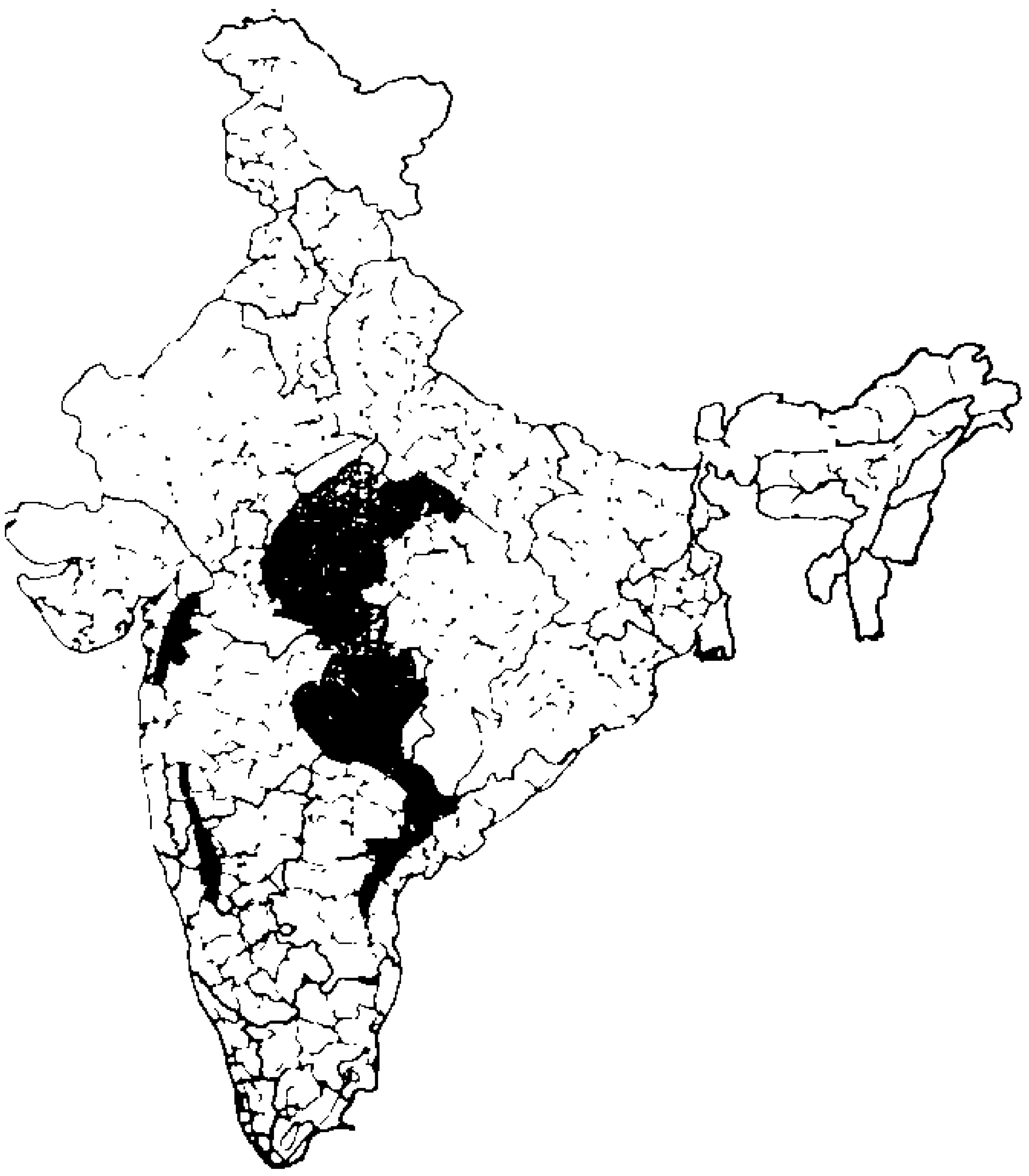

FIG. 5. Sorghum growing districts for potential double cropping under rainfed conditions.

The practice of such sorghum based inter- and sequence cropping systems based on pulse and oil-seed crops enhance the production and productivity of, particularly, small farms. Since pulses and oil-seeds are high value crops, they also compensate for price fluctuations of sorghum and enhance profitability of dryland cropping systems. The introduction of high monetary value crops in cropping systems towards further diversification is now receiving attention.

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EARLY TEST CROSS PROCEDURES FOR SELECTION OF SUPERIOR PARENTS*

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IN the development of commercial sorghum hybrids in recent years, greater attention has been paid to diversification of germplasm sources as in the conversion programme of USA and utilisation of tropical × temperate crosses in India (Rao, 1972). The procedures for identification of parents have largely been through trial and error by testing experimental hybrids in yield trials. The statement of Lerner (1958) that "in spite of several brave attempts at formulating the quantitative theory of selection for heterosis, most of the information available is based on trial and error" is still largely true. A rational method of selection of parents leading to superior commercial hybrids in self-pollinated crops is yet to be developed and would furnish useful guidelines to plant breeders. Except for studies of Singhania and Rao (1975) where performance of males correlated well with hybrid performance, studies specifically aimed at developing methodologies for selection of superior males and females seem to be lacking. The role of early testing as a method of identifying superior males does not appear to have received much attention. The present study is an attempt in this direction.

MATERIALS AND METHODS

The base populations for these studies were furnished by F_2 generation of the following ten high yielding crosses:

(1) 512 × M 35-1	(6) 548 × BP 53
(2) 393 × M 35-1	(7) R24 × R 16
(3) 512 × *Aispuri*	(8) 771 × 512
(4) 699 × *Aispuri*	(9) 699 × 512
(5) R 16 × BP 53	(10) R 16 × 512

The ten crosses were selected from an earlier diallel analysis involving 19 parents. Parents 512, 393, 699, R 16, R 24 and 771 are derivatives from exotic × Indian crosses, while M 35-1, *Aispuri* and BP 53 are improved Indian varieties. The same crosses were advanced and selected lines were used in further test crosses as male parents.

The female parents 2219A, 3660A, CK 60A, 36A were used at various stages of test crossing.

RESULTS

PERFORMANCE OF F_2 TEST CROSSES

Thirty-five to sixty-four promising F_2 plants in each of the crosses were

*This contribution is the XXI part of a series on "Genetic analysis of some Exotic × Indian Crosses in Sorghum".

test crossed to male sterile 2219A. The resulting crosses were grown in a compact family block design with all the test crosses based on the F_2 being treated as a family. There were two replications. In each replication, the families were first randomised and the crosses were randomised within each family. The experiment was grown during *kharif* season. The means and ranges are presented in Table 1 and analysis of variance in Table 2.

TABLE 1

Performance of F_2 test crosses on 2219A

Cross	Yield per plant (g)		Plant height (cm)		Days to 50% flowering	
	Mean	Range	Mean	Range	Mean	Range
512 × M 35–1 (46)*	51.54	24–78	271.50	211.5–312.5	64.13	57–72
393 × M 35–1 (55)	74.77	42–102	213.80	174.0–285.0	60.02	54–64
512 × Aispuri (35)	52.85	34–78	283.58	242.5–318.5	68.61	68–72
699 × Aispuri (46)	58.16	28–86	233.87	169.0–291.5	63.49	57–70
R 16 × Aispuri (44)	62.18	22–102	253.15	196.0–284.0	65.66	60–72
548 × BP 53 (55)	48.80	12–78	233.81	165.0–297.5	63.57	55–72
R 24 × R 16 (58)	79.88	48–124	176.00	115.0–221.0	61.19	57–66
771 × 512 (31)	62.82	44–82	223.11	182.0–258.0	66.00	63–68
699 × 512 (56)	57.83	20–84	205.23	160.5–259.0	62.39	53–70
R 16 × 512 (64)	64.64	22–94	197.10	160.5–241.0	63.11	57–70

*No of test crosses made.

The data reveal that crosses R 24 × R 16 and 393 × M 35–1 yielded highest yielding test cross hybrids. The crosses R 16 × 512, 699 × 512 and R 16 × BP 53 were also superior compared to the rest and these crosses could possibly contribute useful male parents on further selection.

Analysis of variance (Table 2) for grain yield reveal significant differences between crosses within a family for the following crosses:

R 24 × R 16, 393 × M 35–1, R 16 × 512, R 16 × BP 53, 512 × *Aispuri* 548 × BP 53 and 771 × 512.

For other characters also, most crosses revealed significant differences.

The test cross performance is indicative that the significantly higher yielding crosses (families) which also exhibited significant between-cross differences might be potential for selecting superior male parents.

EVALUATION OF F_3 PROGENIES AND THEIR TEST CROSSES

Based on F_2 test cross performance, progenies of the following crosses only were selected for further evaluation: R 16 × 512, 393 × M 35–1, R 24 × R 16 and 771 × 512.

TABLE 2

Analysis of variance

Source	MS between families	512 × M 35–1	393 × M 35–1	512 × Aispuri	699 × Aispuri	R 16 × BP 53	548 BP 53	R 24 × R 16	771 × 512	699 × 512	R 16 × 512
		Mean squares between crosses within a family									
					Yield per Plant (g)						
Between families	10489·91**	386·88	445·16**	216·25**	359·65	618·07**	483·94**	651·91**	215·42**	262·78	325·66**
	(9)	(45)	(54)	(44)	(45)	(43)	(54)	(57)	(30)	(55)	(63)
Error	1219·66	266·19	157·68	16·94	260·73	303·14	227·80	264·42	104·21	230·21	148·22
	(9)	(45)	(54)	(44)	(45)	(43)	(54)	(57)	(30)	(55)	(63)
					Plant height (cm)						
Between families	107434·42*	1069·33**	1240·07**	875·07**	1472·17	1057·64**	2433·44**	994·11**	2152·02**	1382·64**	802·10**
	(9)	(45)	(54)	(44)	(45)	(43)	(54)	(57)	(30)	(55)	(63)
Error	31735·94	418·46	77·22	2·05	996·67	193·40	541·30	150·28	299·25	306·67	201·24
	(9)	(45)	(54)	(34)	(45)	(43)	(54)	(57)	(30)	(55)	(63)
					Days to 50% flowering						
Between families	523·32**	40·69**	9·15**	2·87**	35·89**	32·01**	40·43**	12·29**	5·25**	42·55**	25·47**
	(9)	(45)	(54)	(34)	(45)	(43)	(54)	(57)	(30)	(55)	(63)
Error	35·53	3·75	4·74	1·08	5·86	240·46	8·20	3·80	2·38	5·97	5·65*
	(9)	(45)	(54)	(34)	(45)	(43)	(54)	(57)	(30)	(55)	(63)

**Significant at 5% level; **Significant at 1% level; Figures in parentheses indicate d.f.

The F_3 progenies were evaluated during summer in randomised blocks with three replications. The performance of F_3 progenies studied is summarised in Table 3 and analysis of variance in Table 4. Performance of progenies reveal highly significant differences for all characters. The progenies from the crosses R 24 × R 16 and R 16 × 512, were the highest yielding.

TABLE 3

Performance of F_3 progenies

Cross	Yield per plant (g)		Plant height (cm)		Days to 50% flowering	
	Mean	Range	Mean	Range	Mean	Range
R 24 × R 16 (28)*	75.7	51.0– 97.0	117.8	91.0–137.2	76.4	68.6–80.6
771 × 512 (20)	50.7	30.6– 59.6	109.1	93.8–124.8	65.2	61.3–68.0
R 16 × 512 (34)	73.8	51.2–103.1	112.6	82.0–134.0	74.1	68.3–78.0
393 × M 35–1(34)	58.2	36.4–82.8	136.6	105.4–165.6	72.1	68.3–84.0
Checks (11)	61.2	40.4–89.2	110.0	91.4–159.2	75.7	69.0–85.0

*No of F_3 progenies.

TABLE 4

Analysis of variance

Source	d.f.	Mean squares		
		Yield per plant (g)	Plant height (cm)	Days to 50% flowering
Replications	2	11685.00	3311.35	7.40
Progenies	125	673.78**	779.14**	64.60**
Error	250	265.76	117.53	13.35

F_3 progenies of the crosses R 24 × R 16, 771 × 512, R 16 × 512 and 393 × M 35–1, were test crossed to the male sterile 3660A and the resulting crosses were grown in randomised blocks, replicated three times during the following *kharif* (1974.) The F_3 test cross performance is summarised in Table 5, and analysis of variance in Table 6.

The progenies of the cross R 24 × R 16 resulted in the highest yielding hybrids. The between family test cross differences for yield were significant only for the crosses R 24 × R 16 and R 16 × 512, indicating their promise for further selection.

TABLE 5

Performance of F_3 test crosses

Cross	Yield per plant (g)		Plant height (cm)		Days to 50% flowering	
	Mean	Range	Mean	Range	Mean	Range
R 24 × R 16	92.96	46.8–132.8	207.06	140.0–259.3	64.40	60.0–69.3
771 × 512	78.04	57.9– 94.6	220.95	200.0–236.6	69.70	63.6–71.0
R 16 × 512	70.28	45.6–114.0	218.15	170.6–243.6	64.23	61.3–72.0
393 × M 35–1	72.80	61.6– 89.2	235.87	198.3–263.3	63.08	58.0–67.3
Checks	79.33	72.1–115.3	154.66	137.3–240.3	59.33	53.0–65.0

TABLE 6

Analysis of variance for F_3 test cross performance

Source	d.f.	Mean squares		
		Yield/plant (g)	Plant height (cm)	Days to 50% flowering
Replications	2	1577.50**	20581.00**	422.00**
Hybrids	90	1511.88**	2116.70**	27.39*
Between families	4	6002.87**	176182.00**	2929.75**
R 24 × R 16	28	2055.70**	2809.80**	19.03**
771 × 512	7	579.60	544.00	3.00
R 16 × 512	37	1079.40**	4913.70**	338.94**
393 × M 35–1	12	284.50	1499.00**	14.91**
Checks	2	3540.00**	1803.00**	193.00**
Error	180	368.99	248.90	4.25

PARENT-OFFSPRING REGRESSIONS

Regression of test crosses on their corresponding parents in the respective generations was studied to establish the relationships between parental values and test cross performance. The regression coefficient between F_2 plants used as parents during summer and their corresponding test crosses grown during the following *kharif* are presented in Table 7.

TABLE 7

Regression of F_2 test crosses on F_2 parents

Cross	Yield per plant (g)		Plant height (cm)		Days to 50% flowering	
	b	F value	b	F value	b	F value
512 × M 35–1	–0.1017	0.0158	0.3685	5.8600*	0.1692	1.5200
393 × M 35–1	0.1980	5.1300	0.5797	42.2300**	0.0871	1.8900
512 × Aispuri	–0.0533	0.5422	0.2609	3.3020	0.1461	27.3890**
699 × Aispuri	–0.1832	4.6400*	0.2542	2.7800	0.2329	2.0170
R 16 × BP 53	–0.0814	0.5640	0.8018	417.5200**	0.2151	0.6400
548 × BP 53	–0.0527	0.3560	0.8325	27.8200**	0.3958	1.8210
R 24 × R 16	0.2624	9.3900**	0.4586	11.4600**	0.2496	0.9570
771 × 512	0.0812	0.9600	0.5095	3.8700	0.0388	0.1720
699 × 512	0.0371	0.3517	0.4427	10.5900**	0.6443	11.6400**
R 16 × 512	–0.2911	23.6400**	–0.2759	4.4800	0.0024	0.0599

b = Regression coefficient. ** = Significant at 1% level. * = Significant at 5% level.

The regression coefficients for yield are positive and significant only in the case of the crosses based on F_2 plants of R 24 × R 16, indicating that this may be the most potential cross.

The relationship between the performance of F_2 plants and its F_3 progenies was also studied and the data are presented in Table 8. The regression coefficients for yield are generally not significant except in the case of R 16 × 512 progenies, where the significance is at 5 per cent only. The same cross exhibited highly significant 'b' values for plant height ond flowering as well.

Regression coefficients for F_3 test crosses on F_2 progenies and vice versa are also presented in Table 8. For yield, the 'b' values are not significant. By and large, the 'b' values for all characters are not significant, except for flowering in case of the cross R 24 × R 16 and plant height in case of R 16 × 512.

The regression coefficients for F_3 test crosses on F_2 test crosses are also presented in Table 8 which do not reveal any significant differences, except in isolated cases.

TABLE 8

Parent offspring regressions

Crosses	Yield		Height		Days to 50% flowering	
	b	F value	b	F value	b	F value
	Regression of F_3 progenies and F_2 progenies					
R 24 × R 16	-0.0772	0.0632	0.2717	3.0186	-0.2586	3.4306
771 × 512	-0.0478	0.0147	-0.7876	4.5924	-0.1601	0.4806
393 × M 35-1	-0.0619	0.0323	-1.0733	9.0645*	-0.0376	0.0018
R 16 × 512	0.3042	7.5580*	-0.6689	46.8440**	0.8453	33.5103**
	Regression of F_3 test cross hybrids on F_3 progenies					
R 24 × R 16	-0.0667	0.2923	0.1357	1.3952	1.2706	20.2079**
771 × 512	0.0583	0.0220	0.2867	0.8607	-1.2451	0.4848
393 × M 35-1	0.2306	0.1445	0.5935	1.7200	1.9638	2.9500
R 16 × 512	0.1074	0.3613	0.3094	6.2100*	-0.0829	0.2138
	Regression of F_3 progenies on F_3 test cross hybrids					
R 24 × R 16	-0.1666	0.2925	0.3753	1.3952	0.3442	20.2300**
771 × 512	0.0627	0.0220	0.4375	0.8607	0.0600	0.4900
393 × M 35-1	0.0676	0.1426	0.8975	8.4500*	0.1258	2.2960
R 16 × 512	0.0926	0.3613	0.4757	6.2500*	0.0711	0.2136
	Regression of F_3 test crosses on F_2 test crosses					
R 24 × R 16	-0.1238	3.0510	-0.4164	1.6210	0.4833	9.0400*
771 × 512	0.0331	0.1673	0.1131	1.1910	-1.0112	0.5880
393 × M 35-1	0.0231	0.0457	0.0719	1.1930	-0.0800	0.0890
R 16 × 512	0.1598	1.4600	0.5959	16.8700**	0.6598	12.1200**

*Significant at 5% level; **Significant at 1% level.

DISCUSSION

Early generation testing of progenies and test crosses has been a subject of study in self as well as cross pollinated crops, and in recent year there is renewed interests in such procedures. Studies of Genter (1973) in maize indicated that test-cross based selection was effective in increasing frequency of genes contributing to yield in crosses but not in populations *per se*, while S_1 selection increased population yield. Genter (1976) felt that selection for earlier generation segregates may be an advantage since they may have carried a lighter load of deleterious genes.

Recognising that yield of F_2 plants is a character having low heritability and that it is difficult to apply selection pressure in F_2 generation, Knott (1972 attempted to study whether selection for yield among F_2 plants could be made sufficiently efficient since this would save on time and growing large number of progenies in later generations. His results indicated that selection in spaced

F_2 population under uniform growing conditions did have some effect on F_3 progenies' yields. Extending these studies, Boerma and Cooper (1973) and Knott and Kumar (1975) found that single seed descent method, where a single seed was taken from an F_2 plant, was effective and comparable to other methods.

In the present study, 10 high-yielding F_2 crosses with marked specific effects were chosen as base populations and were test crossed to the male sterile 2219A. Since the female is a homozygous line and the male parent (F_2 plant) is heterozygous, this is analogous to an 'inbred × variety' cross or top-cross. From each cross 34–64 plants were used to pollinate male sterile and the resulting hybrids were evaluated. Analysis of data established significant differences for yield between test crosses resulting from different F_2 families and also between test-crosses within a family. This means, F_2 test-crosses themselves enabled identification of superior F_2's and superior plants within particular F_2's; only four crosses were identified for further studies, viz., R 16 × 512, R 24 × R 16, 393 × M 35–1 and 771 × 512.

Continuation of test cross studies with F_3 generation of these selected crosses led to identification of R 24 × R 16 and R 16 × 512 as the most potential crosses since their progenies had the highest mean yields and between test-cross differences were also significant indicating that further selection in these crosses could be rewarding. The F_3 test crosses have not only made it possible to further reduce the material to be selected upon, but also provided information on within cross differences.

Regression coefficient of F_2 test cross performance on F_2 parental plants were positive and significant only in case of the crosses R 24 × R 16 and R 16 × 512. It is interesting to note that the potential crosses identified as a result of F_3 test crosses are also the same. Regression analysis during F_3 did not establish any significant differences.

It, therefore, appears that test crosses based on F_2 could play a potential role in identifying crosses which could yield superior parents. F_2 test cross performance together with test cross F_2 regression on F_2 and F_3 test cross performances would enable us to limit the number of progenies to be selected upon till homozygosity is attained to develop parents of predictable performance.

Summary

The base populations for the study were provided by 10 high yielding F_2 populations with marked specific effects. F_2 test crosses to male sterile enabled identification of superior F_2 families and superior plants within particular F_2's leading to identification of only four crosses viz., R 16 × 512, R 24 × R 16, 393 × M 35–1 and 771 × 512, as promising.

Further continuation of test crosses studied during F_3 resulted in identification of only two crosses viz., R 24 × R 16 and R 16 × 512 as the most potential ones. Their progenies had the highest mean yields and the differences between test crosses were also significant indicating scope for further selection.

Regression of F_2 test cross performance on F_2 plant yields also led to the same conclusion as F_3 test crosses resulting in identification of R 16 × 512 and R 24 × R 16 as most promising for isolation of superior parents.

Therefore, test crosses based on F_2 enable identification of promising crosses which could yield superior parents. F_2 and F_3 test crosses limit the number of progenies to be selected and lead to isolation of lines that could yield potentially superior hybrids upon crossing with male steriles.

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IMPLICATIONS OF PARENTAL SELECTION PROCEDURES ON HYBRID PERFORMANCE AND ADAPTABILITY

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A question that needs to be answered is whether performance levels of hybrids are maintained when parents are chosen on the basis of performance at a single location. Liang and Walter (1966) observed that in sorghum hybrids, second order interactions were larger than the first order interactions and that recommendations based on a single year or location may be inadequate. Rao (1970) felt that within the *kharif* season, there were no geographical barriers of adaptation to hybrid performance and if significant superiority is established over diverse locations, release recommendations could be made over shorter periods of testing. He also observed that both first order and second order interactions were significant. Singhania and Rao (1976a) recorded that the linear component of G $\times$ E interaction was greater in parents than in F_1 hybrids and that heterosis was generally associated with greater sensitivity to environment. In the present study, the thirteen parents in F_4 generation selected on test cross performance (Mishra and Rao, 1980) were crossed to four male steriles and the resulting hybrids were evaluated at three diverse environments, two in *kharif* and one during *rabi*. The results are presented in this paper.

Materials and Methods

Based on previous studies (Mishra and Rao, 1980), seven promising F_4 progenies from the cross R 24 $\times$ R 16 and six from R 16 $\times$ 512 were selected and crossed to four female parents, CK60A, 2219A, 36A and 3660A. The hybrids were grown during *kharif* at two locations, Hyderabad and Parbhani, and during *rabi* at Parbhani. The experiment was laid out in randomised blocks, replicated three times.

Results

Means and analysis of variance

The mean performance, averaged over males and females, is presented in Table 1. Amongst females, CK 60A, 2219A and 3660A gave hybrids whose performance is almost on par, while hybrids with 36A are relatively low yielding. All the selected males yielded hybrids of satisfactory performance and the yield differences are statistically significant. Amongst males derived from the cross

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R 24 × R 16, 11–1, 12–1, 12–3 and amongst those derived from R 16 × 512, 74–2 are the most superior.

TABLE 1

Mean performance of females averaged over males and males averaged over females (pooled over three environments)

	Parents	Days to 50% flowering	Plant height (cm)	Panicle length (cm)	Panicle weight (g)	100 seeds weight (g)	Yield per plant(g)
Females	CK 60A	74.95	187.94	27.36	80.27	3.21	55.53
	2219A	74.04	176.04	28.29	82.34	3.09	55.77
	36A	81.87	184.21	21.81	63.87	3.22	36.62
	3660A	78.19	201.75	25.66	77.27	3.24	52.85
	SEM	0.247	1.015	0.149	1.390	0.029	1.100
	CD 5%	0.69	2.83	0.42	3.88	0.08	3.06
	1%	0.91	3.72	0.55	5.11	0.11	4.03
Males	4–1 (R 24 ×R 16)	74.67	189.09	23.95	74.16	3.39	50.04
	10–2 ,,	77.08	185.75	23.56	65.81	3.31	44.80
	11–1 ,,	76.50	196.45	24.78	79.16	3.37	55.03
	12–1 ,,	75.33	186.69	25.86	80.56	3.18	54.31
	12–3 ,,	75.61	195.41	25.36	81.17	3.39	55.10
	23–5 ,,	77.19	179.97	23.55	67.76	3.18	44.66
	25–2 ,,	78.03	199.65	25.75	68.98	3.23	46.64
	65–4 (R 16 × 512)	81.03	191.30	27.06	79.68	3.12	49.15
	65–6 ,,	77.33	186.94	24.85	73.93	2.98	48.34
	69–2 ,,	77.53	176.46	28.67	75.52	3.30	48.07
	69–4 ,,	77.00	177.14	28.01	74.61	3.27	50.96
	71–6 ,,	79.47	188.39	24.24	83.42	2.94	48.78
	74–2 ,,	77.64	184.18	27.50	82.40	2.82	56.62
	C.D. 1%	1.64	6.71	0.99	9.21	0.19	7.27

The pooled analysis of variance (Table 2) reveals highly significant differences for most of the characters. The magnitude of the MS for males is generally lower compared to females for all characters. The magnitude of the MS for male × environment interaction is also considerably lower compared to female × environment indicating that the selected male parents have conferred greater stability.

ESTIMATES OF COMBINING ABILITY

Estimates of combining ability are presented in Table 3. It is evident that for grain yield, the estimates of σ^2_{gca} (m), σ^2_{gca} (m) × env. and σ^2_{sca} × env. are not significant. On the other hand, the *gca* estimates for females and their interaction with environments are highly significant. This is indicative that selected males conferred greater stability to the hybrids derived from them.

TABLE 2

Pooled analysis of variance

Source	D.F.	Mean squares					
		Days to 50% flowering	Plant height	Panicle length	Panicle weight	100 seed weight	Yield per plant
Females (F)	3	1475.13**	13469.66**	958.86**	8076.63**	0.562**	9787.00**
Males (M)	12	101.22**	1286.50**	100.23**	1193.85**	1.170**	568.85**
F × M	36	19.19**	358.36**	6.97**	730.34**	0.108	383.05**
Environments (E)	2	33752.50**	388782.50**	1354.81**	99088.50**	3.010**	62590.05**
M × E	24	21.82**	242.97**	3.65	299.84	0.165*	246.77*
Females × environments F × E	6	41.96**	3453.68**	29.64**	2908.18**	0.451**	1579.41**
F × M × E	72	12.83*	152.83*	2.36	263.84	0.137*	165.33
Error	306	7.16	120.66	2.61	227.29	0.098	141.62

* Significant at 5% level; ** Significant at 1% level.

TABLE 3

Estimates of variance components

Component	Days to 50% flowering	Plant height	Panicle length	Panicle weight	100 seeds weight	Yield per plant
Gca (f)	12.190**	83.850	7.900**	40.180	0.001	68.280**
Gca (m)	2.020**	38.270**	2.550**	11.870	0.028*	2.890
Gca	9.800**	73.120**	6.640**	33.520*	0.007**	52.900**
Sca (f × m)	0.706**	22.830**	0.512**	51.830**	-0.003	24.190**
Gca (m) × env.	0.749*	7.510	0.107	3.000	0.002	6.780
Gca (f) × env.	0.747**	84.630**	0.699**	67.810**	0.008**	36.250**
Gca × env.	0 747**	66.490**	0.560**	52.550**	0.006**	29.320**
Sca × env.	1.880**	10.720*	-0.082	12.180	0.013*	7.900
Gca/σ^2 sca	13.880	3.200	12.970	0.650	-2.330	2.190
Gca × env./σ^2_{gca}	0.076	0.909	0.084	1.568	0.857	0.554
Sca × env./σ^2 sca	1.416	0.469	-0.160	0.235	-4.333	0.326

* Significant at 5% level; ** Significant at 1% level.

The proportion of *gca* to *sca* indicates that *gca* is generally predominant for most of the characters. However, the proportion of the estimates of σ^2_{gca} and σ^2_{sca} indicates that a relatively sizeable portion of *sca* is involved for panicle weight and grain yield. The proportion of σ^2_{gca} × evn./σ^2_{gca} is less than 1·0 for all characters, except panicle weight, indicating stability of additive component. The proportion of σ^2_{sca} × env./ σ^2_{sca}, shows stability for plant height, panicle weight and yield per plant of non-additive components.

STABILITY OF F_4 TEST CROSS HYBRIDS

Analysis of variance (Table 4) for stability across environments reveals that pooled deviations are not significant, except for panicle weight. The mean squares for hybrids (genotype) are significant for all characters. The hyb. × E(L) interaction was not significant for flowering, panicle weight and yield, indicating that these characters are relatively stable. It is, therefore, evident that almost all hybrids are stable in their performance and emphasis has to be on mean performance for which there are significant differences.

CHARACTER ASSOCIATIONS

Simple and multiple correlation coefficients for each of the three locations as well as pooled over locations have been calculated. The pooled data for simple correlations are presented in Table 5 and only significant relations for multiple correlations from pooled data as well as individual locations are

TABLE 4

Analysis of variance for stability

Source	D.F.	Mean squares			
		Days to 50% flowering	Panicle length (cm)	Panicle weight (g)	Yield per plant (g)
Total	155	162.54**	15.90	665.97**	435.23**
Hybrids	51	45.20**	27.71	428.39**	327.42**
E + (Hyb × E)	104	220.08**	10.10	782.48**	488.10**
E (L)	1	22321.30**	893.20	66568.70**	41579.60**
Hyb × E (L)	51	8.80	1.85	126.23**	88.26
Pooled deviations	52	3.17	1.19	160.96**	90.02
Pooled error	306	10.76	370.04	80.67	140.45
CD (M)		2.850	1.752	20.30	15.18
CD (b)		0.238	0.732	0.982	0.930

TABLE 5

Pooled phenotypic (P) and environmental (E) correlation coefficients

Characters		Plant height (2)	Panicle length (3)	Panicle weight (4)	100 seeds weight (5)	Yield per plant (6)
(1)	P	0.1129	−0.5254**	−0.4164**	−0.0942	−0.5560**
	E	−0.1018	−0.0207	−0.0701	−0.3650	−0.1071
(2)	P		−0.1402	0.0084	0.2433**	0.0186
	E		0.0141	0.1686**	0.0370	0.2143**
(3)	P			0.5834**	−0.1835*	0.6156**
	E			0.5051**	−0.0431	0.4520**
(4)	P				−0.0366	0.9108**
	E				0.1315**	0.8356**
(5)	P					0.0082
	E					0.1824**
(6)	P					
	E					

* Significant at 5% level; ** Significant at 1% level. (1)=Days to 50% flowering

presented in Table 6. Simple phenotypic correlations (Table 5) reveal that in hybrids, high yield and earliness could be combined. The associations are also

TABLE 6

Some multiple regression equations

							R	R^2
Hyderabad Kharif	P	Y=	47.2137	-0.8340 x1 (β_1= -0.2242**)	+0.6817 x4 (β_4=0.7978**)	+4.2165 x5 (β_5=0.0871*)	0.9698	94.05
	E	Y=	-22.5248	+0.0871 x2 (β_2= 0.1048**)	+0.7330 x4 (β_4= 0.9603**)		0.9481	89.89
Parbhani Kharif	P	Y=	42.1730	-0.9299 x1 (β_1= -0.2575**)	+0.7708 x4 (β_4= 0.8269**)	+4.8473 x5 (β_5= 0.0839*)	0.9737	94.81
	E	Y=	15.9940	-0.6628 x1 (β_1= -0.1704**)	+0.0955 x2 (β_2= 0.0712**)	+0.8240 x4 (β_4= 0.8761**)	0.9672	93.54
Parbhani Rabi	P	Y=	-2.9476	+0.6031 x4 (β_4= 0.8147**)			0.8147	66.37
	E	Y=	-35.1456	+0.9792 x3 (β_3= 0.1473*)	+0.4657 x4 (β_4= 0.6356**)	+0.1237 x5 (β_5= 0.1737**)	0.7549	56.98
Pooled	P	Y=	48.7871	-0.6634 x1 (β_1= -0.2139**)	+0.6935 x4 (β_4= 0.8217**)		0.9317	86.73
	E	Y=	-14.4733	+0.0818 x2 (β_2= 0.0755*)	+0.6495 x4 (β_4= 0.8288**)		0.8389	70.37

Values of standard partial regression coefficients (β) are given below the corresponding coefficients in parentheses
*=Significant at 5% level; **=Significant at 1% level; P=Phenotypic; E=Environmental.

positive and significant between panicle length, weight and yield. The multiple correlations (Table 6) also bring out more or less the same conclusion, indicating that early flowering and seed weight are important factors in contributing for yield.

Discussion

Hybrids based on males selected at a single location performed well over all the three environments. It is interesting to note that the mean squares for males is generally lower compared to females for all characters and the male × environments interaction is considerably lower compared to females × environments interaction indicating that selected males have conferred greater stability or hybrid performance. In previous studies in India, females were generally more stable than males; the present results indicate improvement of males for this attribute as well.

Analysis of combining ability further confirms this finding. The estimates σ^2_{gca} (m), σ^2_{gca} (m), × Env. and σ^2_{sca} × Env. for yield are not statistically significant while σ^2_{gca} (f), σ^2_{gca} (f) × Env. for yield are highly significant.

While *gca* and *sca* are important in yield heterosis, the time is not far when we have to capitalise on *sca* if we are to get over plateauing of hybrid yield levels. While continued augmenting of genetic resources will enable to tackle us this problem, appropriate selection schemes and mating systems only could furnish pathways of utilising diversity generated.

It has been stated that selection between populations at the very beginning of a programme of genetic improvement is wasteful because the additive variance within the groups discarded is not utilised (Lerner, 1958). While this may be so, absence of selection in early stages leads to unmanageable progeny numbers. Hence there is definitely a case for early testing procedures and rightly so, there has been emphasis on early selection in cross-as well as self-pollinated crops. Studies of Mishra and Rao (1980) brought out the value of F_2 test crosses in selecting superior F_2 for further selection of parents to the used in hybrid breeding. The F_2 test cross on male steriles is analogous to top cross and initially a test for *gca*.

Since promising F_2 plants are selfed in subsequent generations, it may be difficult to initially separate the effects of selection from the effects of inbreeding. Since F_3 and F_4 lines will be moving towards homozygosity, test cross performance should provide for capitalisation of non-additive genetic variance also. Such a procedure may, therefore, lead towards performance based on both *gca* and *sca*.

In the present study, with F_4 test crosses, about 70 per cent of the variation in yield is due to *gca* and only 30 per cent due to *sca*. Thus *gca* continues to predominate yield heterosis; yet a good portion of *sca* is also involved and the test cross methodology used in this study seems to have contributed to this.

Parameters of stability further confirm G × E analysis data. The regression coefficients did not significantly differ from unity for all the 52 hybrids for yield and in a vast majority of cases, the deviations were also not significant. Pooled deviations were not significant, except for panicle weight. The hybrid $\times$ E(L) interaction is also not significant for flower in, panicle weights and yield pointing out that these characters are stable. The hybrids are more stable than varieties was also brought out in earlier studies (Rao and Harinarayana, 1969; Singhania and Rao, 1976b). Stability having been taken care, emphasis has, therefore, to be on levels of performance.

Thus, selection of males based on early generation test cross performance has resulted in superior as well as stable performance of hybrids across environments. Comparative data on males and females and their interactions bear evidence as to the effects of selection at one location, on adaptability.

A study of character associations based on simple and multiple correlation coefficients indicate as to how this has been accomplished. All high yielding hybrids are early maturing and the attributes, early flowering, and seed weight emerged as the most important factors. Obviously, seed numbers were not adversely effected. The selected males furnished greater diversity for seed size which also seem to have contributed to higher yields.

Besides establishing the effects of selection, this study has also enabled identification of superior males with desirable *gca* effects and specific cross combinations of superior performance such as CK 60A $\times$ 11–1 2219A $\times$ 71–6, 2219A $\times$ 74–2, 36A $\times$ 65–4, 36A $\times$ 65–6, 3660A $\times$ 4–1 and 3660A $\times$ 69–2.

SUMMARY

(1) Male parents selected at one location during summer resulted in hybrids of wide adaptation. The magnitude of male $\times$ environment interaction was considerably lower than female $\times$ environment interaction indicating that selected males have conferred greater stability of performance to hybrids.

(2) Further, estimates of σ^2_{gca} (m), σ^2_{gca} (m) $\times$ Env. were not significant indicating that the *gca* due to males is also stable while similar interactions with females were highly significant indicating their sensitivity. The σ^2_{sca} $\times$ Env. interaction was also not significant indicating specific combining ability to be stable.

(3) The early test cross procedure, while capitalising largely on additive genetic variance also seem to usilise some non-additive genetic variance. In the present study, where test cross procedures were used 30 per cent of genetic variation used was of the non-additive type, while in other studies only 10 per cent of the variation was due to *sca*. The implications of early test cross procedures as breeding tools have been discussed.

(4) Studies on character association revealed that when seed numbers are not adversely effected, early flowering and seed weight were the most important attributes influencing yield. Selected males furnished greater diversity for seed size.

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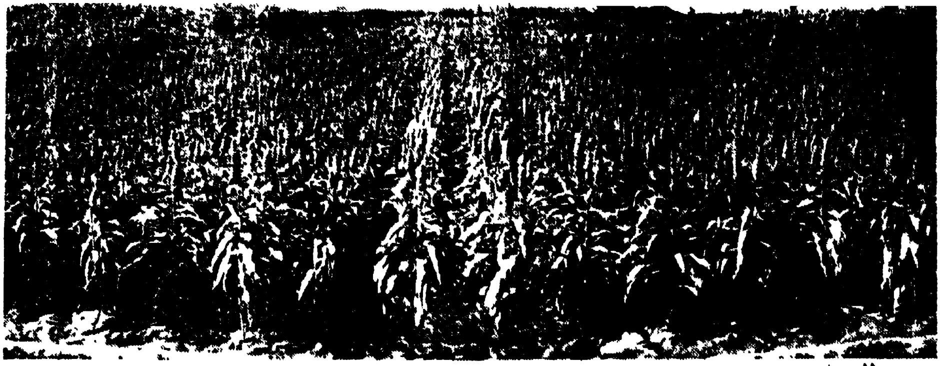

High yield potential of sorghum hybrid 'CSH-1'

Indian Farming, 1980. 30(7): 31-35.

NEW TECHNOLOGY FOR HIGHER SORGHUM PRODUCTION

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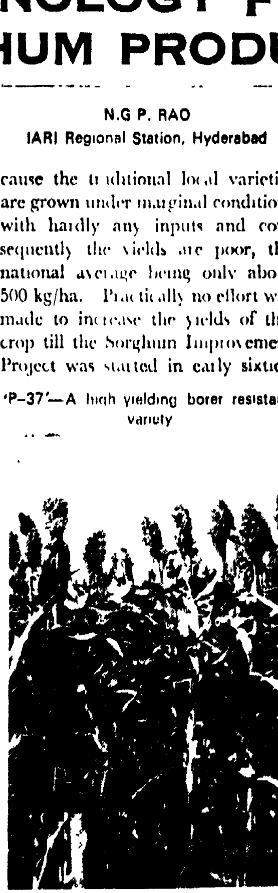
SORGHUM, popularly known as jowar in India, is one of the major food and fodder crops of Asia and Africa. Out of the total world area of about 52 million hectares, 10.8 million hectares are grown in these two continents. As compared to other countries India has the largest area of about 16 million hectares (FAO Production year Book, 1979).

Jowar is mainly grown as a rainfed crop with the annual rainfall ranging from 400 to 1000 mm. The States which have sizable acreage are Maharashtra, Karnataka, Andhra Pradesh, Madhya Pradesh, Gujarat, Rajasthan, Uttar Pradesh (Bundelkhand region) and Tamil Nadu. In Punjab and Haryana it is mainly grown for fodder purposes. Kharif (July-November) is the main season when 62 to 64 per cent area is grown, while rabi jowar is mainly grown in the Deccan Plateau of Maharashtra and Karnataka.

Jowar has often been referred to as a 'poor man's crop', mainly because the traditional local varieties are grown under marginal conditions with hardly any inputs and consequently the yields are poor, the national average being only about 500 kg/ha. Practically no effort was made to increase the yields of this crop till the Sorghum Improvement Project was started in early sixties, with the major centre of research at the Indian Agricultural Research Institute, New Delhi.

'P-37'—A high yielding borer resistant variety



Era of High-Yielding Cultivars

The traditional local varieties, through centuries of natural selection are well adapted for stress environments of moisture, fertility and resistance to pests and diseases. However, they also possess the undesirable character of being tall (prone to lodging), late maturing, photo sensitive and low yielding.

The Sorghum Improvement Project therefore undertook the onerous task of genetically restructuring the crop to exclude the undesirable characters and retain the desirable attributes so that full advantage could be taken of the available improved technology.

The availability of male sterile like 'Kafir-60' from U.S.A., provided the opportunity to exploit hybrid vigour and thus usher in the era of high yielding hybrids in India. The first Sorghum hybrid 'CSH-1' was commercially released in 1964 and immediately gained popularity due to its early maturity and high yield potential of 2000 to 3000 kg/ha under average growing conditions and as high as 7,000 kg ha under optimal conditions.

An intensive hybridization programme was continued in which new sources of male sterility were used and also the exotic lines were crossed with promising Indian and African varieties and the selected derivatives were used for evolving high yielding hybrids and varieties By these processes not only yield potential has been improved, but some advantage has been gained in respect of avoiding high susceptibility to insects and grain moulds. From this co-operative programme already eight hybrids and eight varieties have been officially released for cultivation in different sorghum growing areas This provides ample choice of hybrids or varieties for different agroclimatic zones The data on average yields of released cultivars as compared to 'CSH-1' and locals are presented in Table 1

The performance of the released high-yielding hybrids and varieties has been satisfactory not only in India but also in a number of other countries 'CSH-1' was found to be promising in Bangladesh, Philippines and several parts of Africa 'CSH-5' and 'CSH-6' have proved their superiority in Pakistan, Senegal, Upper Volta, Ethiopia and the Philippines Similarly, the varieties have also proved their worth in the countries where these have been tested

The All-India Co-ordinated Sorghum Improvement Project has provided an excellent forum for the co-ordinated inter-disciplinary approach for increasing sorghum production Simultaneously with the development of improved cultivars, the research work has been in progress on the agronomic, entomological and pathological aspects to evolve

TABLE 1. RELEASED HYBRIDS AND VARIETIES AND THEIR AVERAGE YIELD PERFORMANCE*

*Hybrid Variety***	*Average grain yield kg/ha*		
	Hybrid/variety	*CSH-1*	*Local*
Kharif			
CSH-1 (1964)	2714	—	1573
CSH-2 (1965)	3002	2465	1700
CSH-3 (1970)	3831	3275	2211
CSH 4 (1973)	3151	2678	1793
CSH-5 (1974)	4240	3629	1966
CSH-6 (1976)	4145	3592	1989
CSV-1 (1968)	3744	3682	2358
CSV-2 (1974)	3247	3396	1694
CSV-3 (1974)	3654	3531	1765
CSV-4 (1974)	3126	3215	1487
CSV-5 (1974)	3196	3616	1677
CSV-6 (1974)	3262	3199	1714
Rabi			
CSH 7R (1977)	2755	—	2314
CSH-8R (1977)	2756	—	2314
CSV-7R (1974)	2506	—	1893
SPV-86 (1979)	3299	—	2881

* Average or 3 years multilocation trials

** Year of release in brackets

sound production and protection technologies The technical leadership for these disciplines has been provided by the IARI

Agronomic Research

Time of sowing Experiments conducted in major sorghum growing areas during 1968 to 1973 showed that the most optimum sowing time for grain sorghum in the kharif season is immediately after the first monsoon shower There is progressive reduction in grain yield, depending on the period for which it is delayed In rabi, early sowing gave better yields and sowing after middle of September generally resulted in reduced yields

Plant population and spacing Under rainfed conditions the optimum plant population for high-yielding hybrids and varieties has been found to be about 1,80,000 to 2,00,000 plants/ha. For maintaining this population the seed rate required will be 10 to 12 kg/ha. In rabi season the optimum population varied from 90,000 to 1,35,000 plants/ha.

Though at some locations there were no significant differences between the row spacings of 45, 60 and 90 cm, 45 cm was found to be appropriate at all the locations Similarly 10 to 15 cm distance between the plants has given better yields.

Fertilization The response of high yielding sorghums to nitrogen has been studied in details. It has been found that response in terms of kg grain/kg N is much higher in the new cultivars than locals. Based on these trials it has been recommended that in addition to compost and farmyard manure 30 to 40 kg N and 30-40 kg P_2O_5 should be applied. Thus may give 3 times the yield in the hybrids and improved varieties as compared to locals. N may have to be applied in two split doses in light-textured soils In trials conducted at various locations optimum response of N has been found even up to 80 to 100 kg/ha.

Weed control. Weeds can significantly affect seedling growth, especially in the kharif season.

This paper is based on a more extensive research bulletin compiled by Dr N G.P. Rao. The condensation was done by Dr. M.G. Jotwani, Sr. Scientist, Division of Entomology, I.A.R.I., New Delhi

Limited trials conducted have shown that by weed control alone the yield can be increased by 60 per cent. Pre-emergence application of Atrazine or Propazine at 0.5 kg a.i./ha followed by one late weeding can effectively control the weeds and result in appreciable increase in grain yield.

Intercropping. From the view point of risk coverage under unfavourable conditions, intercropping system for sorghum is highly desirable. Under normal climatic conditions also it can result in additional income. Various inter crops have been tested to find suitable crops which offer least competition to sorghum and should be also remunerative. Response of the inter crops has been found to be different at different locations, for example soybean and groundnut have been found to be suitable at Indore, castor and cluster bean at Hyderabad, cotton at Dharwar, green gram and sunflower at Navsari, soybean, black gram and green gram at Kanpur and pigeon pea at several locations. The inclusion of grain legumes, several of which have been found to be suitable, will not only enhance the income of the sorghum growers, but will also provide them with the essential proteins in their cereal diets as well as enrich the soil fertility.

Entomological Research

The new high-yielding hybrids and varieties proved to be highly susceptible to insect pests. Over a dozen insects damage this crop but fortunately there are only four namely shoot fly, stem borer, midge and earhead bug, which are of major economic importance.

Keeping in view the economic status of the sorghum growers and marginal conditions under which this crop is grown, the major thrust of the entomological programme has been to develop different methods of control with the ultimate objective of recommending an integrated control strategy which should be effective, economical, non-hazardous and easy in application. Greater attention has been paid to methods by which monetary inputs can be avoided or considerably reduced.

Cultural and mechanical methods. Detailed investigations have been conducted on the biology, habits, nature of damage, alternate host plants, off-season carry-over and seasonal population fluctuations of the major pests. Based on the data on seasonal incidence, it has been found that in kharif crop, the shoot fly damage can be avoided by sowing the crop within 10 to 12 days after first monsoon shower. Use of higher seed rate of 12 kg/ha followed by removing and destroying damaged seedlings within two weeks after germination can effectively check the shoot fly population build-up, provided the operation is taken up as an organised campaign in large areas.

It has been found that carry-over of the stem borer from one season to other mainly occurs through the stubbles and stems stored for use as fodder. Proper disposal of these sources of infestation before the normal sowing season can check the borer damage considerably.

For protection against midge damage a suitable cultural-cum-varietal strategy has been developed which aims at avoiding the continuous and prolonged availability of flowering earheads in the field. This involves fixing a sowing period for a particular zone, coupled with selecting varieties and hybrids of the same maturity period. The destruction of earhead residues after threshing, which are the main sources of off-season carry-over, the initial population of the midge can be considerably reduced.

Insect resistance in sorghum. Extensive work has been carried out to identify the sources of resistance to major pests. Nearly 12,000 lines available in the world germplasm collection were screened under natural and artificial infestation conditions and several highly promising sources showing resistance to shoot fly and stem borer were selected. The selected lines also exhibited resistance to shoot fly when tested in Thailand, Uganda, Nigeria and Israel.

The suitable resistant lines were incorporated in the breeding programme and the recently released hybrids 'CSH-7R' and 'CSH-8R' and varieties 'CSV-3', 'CSV-4', 'CSV-5', 'CSV-6', 'CSV-7' and 'CSV-8' possess low to moderate levels of resistance contributed by one of the resistant parents. A number of other advanced derivatives, possessing higher levels of resistance namely 'P-37', 'P-151', 'E-302', 'E-303', 'E-444' are in advanced stage of testing. A few lines possessing multiple resistance have also been identified.

Basic studies have also been conducted to determine the mechanisms of resistance in shoot fly and stem borer.

Chemical control. Under certain circumstances use of chemicals to control insect pests becomes unavoidable. The major thrust of the programme on this aspect has been to test safe and easily available insecticides for their efficacy and to develop techniques by which the cost of application can be substantially reduced.

The outstanding achievement in this field has been the development of 'Carbofuran seed treatment' for the control of shoot fly. This method has proved to be most effective and economical. The cost involved is only one-third as compared to other effective method of soil application of granular systemic insecticides like phorate and disulfoton. The method has gained popularity in Maharashtra and is used in substantial quantities as indicated by the data given in Table 2.

In the case of stem borer control also, 'leaf whorl application technique' has been developed by which the doses of recommended insecticides like 4 per cent endosulfan or 4 per cent carbaryl or 2 per cent

TABLE 2. CARBOFURAN SEED TREATMENT ON SORGHUM (MAHARASHTRA STATE)

Year	*Quantity of seed treated (in quintals)*	*Area (in hectares)*
1974-75	814	[illegible]
1975-76	5142	[illegible]
1976-77	3076	41013
1977-78	2492	31045
1978-79	3000	40000

lindane or 5 per cent malathion dust can be reduced by about fifty per cent.

Pathological research. Though a number of diseases have been recorded on sorghum, none has so far proved to be a major limitation affecting sorghum yields. Some of the diseases which have received attention of the Sorghum Pathologists under the Project are downy mildew, leaf rust, zonate leaf spot, rough leaf spot, grey leaf spot, kernel smuts, leaf blight and charcoal rot.

A part of the available world germplasm collection has been screened, mostly under natural field conditions and the lines showing resistance have been identified. Successful methods have been developed for creating artificial epiphytotics and sick plots in field and standardising evaluation procedures. By conducting extensive surveys data have been collected on occurrence and intensity of different diseases. The hot spots for different diseases have been identified for intensive screening and control trials.

In general, it has been found that hybrids are superior to locals in respect of susceptibility to diseases. Most of the released hybrids and the varieties 'CSV-4' and 'CSV-5' are resistant to downy mildew. 'CSV-5' is also resistant to most leaf spots and striga. 'CSH-5', 'CSH-6' and 'CSV-4' have shown some resistance to head moulds and grain deterioration when caught in rains during grain formation.

The Impact and the Future Strategies

There is no doubt that the spread and consequently the impact of the high yielding sorghums on our food production has been rather slow, especially when compared to wheat or to some extent rice. This can partly be attributed to sorghum being mainly a dryland risk-prone crop and partly due to lack of adequate organisational framework affecting timely mobilisation of inputs.

With the slow but steady progress, the impact can now be clearly seen from the area and production figures given below:

YEAR AND SEASON KHARIF (K) RABI (R)

	1976-77		1977-78		1978-79	
	K	R	K	R	K	R
Area (1000 ha)	10,087.2	5,686.3	10,393.8	5,924.2	10,106.6	6,018.3
Production (1000 tonnes)	7,358.0	3,166.1	8,890.3	3,174.0	8,157.3	3,406.1

The production reached the record level of over 12 million tonnes in 1977-'78. The impact is clearly discernible in the yields from the State of Maharashtra where about 50 per cent area is now covered by the high-yielding hybrids in kharif season. With the expected increase in area under high yielding cultivars in the states of Madhya Pradesh, Andhra Pradesh, Tamilnadu and Karnataka and more coverage in rabi season, the production level of sorghum is bound to show considerable increase in the near future. This may create problems like adequate price support to farmers and developing diversified uses of grain for which plans may have to be prepared in advance.

The achievements of the sorghum project so far have been highly satisfactory, however, much remains to be done and in the current programme special attention is being paid to the following aspects:

1. To develop cultivars having the yield level of 6,000-7,000 kg/ha and possessing resistance to major pests and disease. Special attention is to be paid to identify and utilise sources having higher levels of multiple resistance.
2. To develop technology for satisfactory performance under low levels of management.
3. Improve grain quality in respect of size, luster, resistance to moulds in rainy weather, nutritional quality and *bhakri* making attributes.
4. Breeding early maturing hybrids and varieties with a capacity to produce good ratoon crop and its proper management.
5. Better hybrids and varieties for rabi area with appropriate production and protection technology.
6. Further studies on relay, multiple and inter-cropping systems.
7. To develop integrate method for pest control by further investigations on various components, especially ecological, cultural and biological methods.
8. Continuous survey and surveillance for disease and to develop appropriate methods for forecasting and control.

GENOTYPE × INPUT-MANAGEMENT INTERACTIONS IN SORGHUM*

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IT has frequently been stated that the performance of high yielding hybrids and varieties is satisfactory only under optimal input and management and that their yields may not be satisfactory under lower levels of input and management. If true, this will have implications on the conditions to which the breeding material should be subjected during the process of selection. An attempt was, therefore, made to elucidate answers to these questions by growing high yielding hybrids and varieties of sorghums of exotic and Indian parentage under two management levels at different locations over a three-year period. The results are presented in this paper.

MATERIALS AND METHODS

Yield trials involving hybrids and varieties were grown under two management levels at each of the locations, Parbhani (Maharashtra), Dharwar (Karnataka), Coimbatore (Tamilnadu), Navsari (Gujarat), Vallabhnagar (Rajasthan) and Indore (Madhya Pradesh). The experiments were conducted during *kharif* 1974, 1975 and 1977. There were in all five experiments. All the experiments were in randomized block design with three replications with a net plot size of 7·5 m × 1·8 m. The high management treatment consisted of 80 kg N, 40 kg P_2O_5 and 40 kg K_2O per hectare and full plant protection and good management. The low management consisted of 40 kg N, 30 kg P_2O_5 and 0–20 kg K_2O per hectare, no plant protection and normal management practices. The spacing adopted was 45 cm between row and 15 cm between plants. Each year two trials were grown at each of the locations, one under high management and the other under low management. The date of planting was the same, at best with a day's difference, and the soil and rainfall conditions were similar since they were conducted in adjacent plots side by side. All the trials were grown under rainfed conditions.

Data obtained over locations and years were subject to standard methods of statistical analysis. The parameters, H (Heritability relative to the test environment), and expected gain E ($\triangle \overline{Y}$) were computed according to the procedures developed by Allen, Comstock and Rasmusson (1978).

RESULTS

The analysis of variance for grain yields pertaining to the various trials conducted over locations under high and low management situations during different years is presented in Table 1. The mean grain yield of released hybrids and varieties is summarised in Table 2.

An examination of the means reveals that hybrids are generally superior to varieties and among top ranking hybrids as well as varieties, the superiority is maintained at both levels of management (Table 2).

*Part XXIII of the series 'Genetic analysis of some exotic × Indian crosses in sorghum' Part XXII appeared in Indian J. Genet. 40.

TABLE 1

Analysis of variance for individual trials (mean squares)

Trial		Replications Management	Genotypes (G)	Managements (M)	G × M	Error
Parbhani	1974 AVT/AHT)	714.13 (4)	286.07**(27)	4689.83**(1)	51.01 (27)	42.32 (108)
	1975 (AVT)	40.59 (4)	269.41**(21)	1493.03**(1)	14.81 (21)	18.67 (84)
	1975 (AHT)	140.44 (4)	259.56**(19)	1229.63**(1)	51.56 (19)	23.04 (76)
	1977 (Early)	488.17 (4)	44.27 (13)	17340.43**(1)	30.86 (13)	27.27 (52)
	1974 (Mid)	214.20 (4)	106.56**(21)	25875.16**(1)	35.52 (21)	24.18 (84)
Dharwad	1974 (AVT/AHT)	57.36 (4)	754.29**(27)	119.14**(1)	64.95 (27)	16.28 (108)
	1973 (AVT)	221.37 (4)	594.73**(21)	1230.65**(1)	69.53 (21)	28.85 (84)
	1977 (Early)	105.33 (4)	1483.11**(12)	20.30 (1)	30.74 (12)	19.19 (48)
	1977 (Mid)	225.48 (4)	825.78**(20)	1.10 (1)	16.44 (20)	19.78 (80)
Coimbatore	1974 (AVT/AHT)	1093.37 (4)	1351.75**(27)	7619.88**(1)	63.65 (27)	44.64 (108)
	1975 (AVT)	66.47 (4)	371.44**(21)	8787.13**(1)	100.68**(21)	43.66 (84)
	1975 (AHT)	8.58 (4)	337.23**(19)	17716.76**(1)	122.51**(19)	36.06 (76)
	1977 (Mid)	275.10 (4)	148.15**(21)	2392.18**(1)	131.28**(21)	46.50 (84)
Navsari	1974 (AVT/AHT)	17.59 (4)	99.03**(27)	946.94**(1)	41.16**(27)	14.17 (108)
	1977 (Early)	24.67 (4)	93.85**(13)	3328.37**(1)	36.74**(13)	6.00 (52)
	1977 (Mid)	12.59 (4)	52.15**(23)	9918.21**(1)	31.85**(23)	10.44 (92)
Vallabh-nagar	1974 (AVT/AHT)	210.05 (4)	224.63**(27)	1592.44**(1)	55.09**(27)	30.00 (108)
	1975 (AVT)	158.00 (4)	300.15**(21)	3389.85**(1)	36.74* (21)	17.50 (84)
	1975 (AHT)	105.93 (4)	228.81**(19)	4423.55**(1)	30.74 (19)	36.74 (76)
	1977 (Mid)	120.32 (4)	254.44**(21)	1970.24**(1)	20.16 (21)	40.32 (84)
Indore	1977 (Mid)	39.15 (4)	133.33**(20)	4136.80**(1)	38.45**(20)	8.25 (80)

Figures in parentheses indicate the d.f. on which the mean sum of squares are based. *Significant at 5% level; **Significant at 1% level.

Plot yields have been converted into q/ha before carrying out the analysis of variance owing to lack of uniformity in plot size over the locations and years.

AVT=Advanced Varietal Trial; AHT=Advanced Hybrid Trial; Early=Early duration trial; Mid=Medium duration trial.

TABLE 2

Mean yields (kg/ha) of some released hybrids and varieties under high and low managements during kharif *seasons of* 1974, 1975 *and* 1977

Genotypes	1974		1975		1977		Overall mean	
	HM	LM	HM	LM	HM	LM	HM	LM
				Hybrids				
CSH-1	3311 (4)	2012 (4)	3679 (5)	2790 (4)	3716 (4)	2603 (4)	3569 (4)	2468 (4)
CSH-5	4627 (1)	3032 (1)	4958 (1)	3902 (1)	3957 (3)	2621 (3)	4514 (1)	3185 (2)
CSH-6	3906 (3)	2728 (2)	3883 (4)	3696 (2)	4686 (1)	3615 (1)	4125 (3)	3346 (1)
SPH-1	3874 (2)	2538 (3)	4929 (2)	3523 (3)	5997 (2)	3032 (2)	4267 (2)	3048 (3)
				Varieties				
CSV-3	2638 (6)	1772 (6)	3953 (3)	2215 (5)	3011 (5)	1923 (5)	3200 (5)	1970 (5)
CSV-5	2819 (5)	1895 (5)	2380 (6)	1891 (6)	2667 (6)	1616 (6)	2622 (6)	1701 (6)

Figures in parentheses indicate the overall ranks. HM=High Management. LM=Low Management.

From the analysis of variance, it is clear that the differences due to genotypes and managements are highly significant in a number of cases while the genotype × management interaction is significant in relatively less number of cases studied. Even with regard to the experiments where genotype × management interaction is significant, the magnitude of the mean squares is much lower compared to mean squares pertaining to genotypes or managements indicating that such interactions may not be serious. Even this is attributable to the inclusion of a large number of unadapted genotypes.

The overall rank correlations between high and low managements (Table 3) indicate very high significance. The relative ranks of the most promising released hybrids and varieties are quite consistent under both managements over years.

Estimates of H, $\sqrt{H}$ and E ($\Delta\bar{Y}$) are presented in Table 4. $\sqrt{H}$, which was the logical measure of the joint effect of σ_e^2 and σ_g^2 on the value of the test environments, showed only 4.43% grain under high management over low management. On the other hand, the advantage of high management over low management was exaggerated by the value of expected genetic gain by 33%.

TABLE 3

Overall rank correlations between high and low managements

Year	Trial	Coefficient of rank correlation
1974	Variety/Hybrid	0.9365**
1975	Varietal Trial	0.9085**
	Hybrid Trial	0.8481**
1977	Early Trial	0.8462**
	Mid-duration trial	0.8001**

**Significant at 1% level.

TABLE 4

Estimates of H, $\sqrt{H}$ and E ($\triangle \bar{Y}$) under high and low input managements
(Averaged over 21 locations)

	Type of environment		% increase over low management
	High management (HM)	Low management (LM)	
H	0.8445	0.7742	9.05
$\sqrt{H}$	0.9189	0.8799	4.43
E ($\triangle \bar{Y}$) (kg/ha)	759.49	569.19	33.43

DISCUSSION

The type of environment to be chosen for yield testing is not only important from the point of view of maximising testing efficiency, but it has also a bearing on environmental conditions under which selection should be practised. Examining this aspect at some length, Allen, Comstock and Rasmusson (1978) stated that if any class of environments is established as superior for testing purposes, it is because the correlation between Y (value of a genotype relative to a test environment) and $\bar{Y}$ (value of a genotype relative to the entire population of environments) is comparatively high for that class of environments.

There has been an impression that while the performance levels of high yielding hybrids and varieties is satisfactory under high input and optimal management, the locals may be preferable under low input and poor management.

That this is false, is clearly established in the present study. The top ranking hybrids and varieties maintain their relative ranks under both levels of management as reflected by mean yields and rank correlations. The genotype × input management interaction is significant only in a few cases and even here the magnitude of m.s. for the interaction is much lower compared to the m.s. due to genotypes or managements.

Also in this particular study, the correlation coefficient (r) between the values under test environment and the targeted population is close to 1·00. According to Allen *et al.*, 'r' value is equal to unity in the absence of genotype × environment interaction. In other words, 'r' values that are variable among potential test environments would not occur when there was no interaction between genotypes and environments.

It is evident from the analysis of variance that the mean square due to genotype × management interaction is much less when compared with the magnitudes of the mean sum of squares due to managements and genotypes. Further, the rank correlation between the yields under high and low managements were highly significant and close to one. Observations of Jinks and Connolly (1973) and Smart (1978) also favour selection in good environments.

Summary

Experiments involving hybrids and varieties were conducted each under high and low input-managements at six locations over a three-year period.

The top ranking hybrids and varieties maintained their relative ranks under both types of inputs and managements. The rank correlations were highly significant.

The genotype × input management interaction was significant only in a few cases. Even here, the magnitude of the m.s. for this interaction was the lowest compared to m.s. for genotype or management.

Estimates of H, $\sqrt{\overrightarrow{H}}$ and E ($\Delta\overleftarrow{Y}$) also revealed the advantages of selection under optimal environments.

Acknowledgement

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INTERNODAL PATTERNS AND THEIR SIGNIFICANCE IN SORGHUM BREEDING*

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ABSTRACT

Internodal patterns in exotic, Indian, hybrid and cross deritatives of sorghum have been investigated by fitting first, second and third degree polynomial curves. The behaviour of various groups and their comparison with high yielding hybrids indicate that the linear pattern may have an adaptive advantage. Besides alteration of plant type through recombination breeding for duration, dry matter production and distribution, the temperate-tropical crosses of sorghum also enable manipulation of internodal patterns.

THE contribution of short statured varieties to cereal improvement is now well recognized. Genes influencing height frequently modify plant type resulting in altered canopy structure (Qualset, Fick, Constantin and Osborne 1970). The genetics of plant height and the use of height genes in sorghum improvement have received considerable attention (Quinby, 1975). The patterns of internodal elongation, which in turn reflect patterns of growth and development, together with duration, dry matter production and distribution are important attributes in determining proneness to risk and productivity under fluctuating rains. The present study is an attempt to characterize patterns of internodal elongation in traditional tropical sorghums, the dwarf temperate versions, their cross derivatives and some commercial hybrids.

MATERIALS AND METHODS

The genotypes used in this study were selected to represent a diversity of eco-geographic types of sorghum viz., dwarf temperate (IS 2031, CK 60B, 2219B, and 2077B), tall tropical (*Aispuri* from India, IS 9985 from Sudan, IS 11758 and IS 11167 from Ethiopia and Giza 114 from Egypt, commercial hybrids (CSH-1, CSH-5, SPH-20 and SPH-61) and 50 advanced generation derivatives obtained from temperate × tropical crosses with higher order yield levels and diversity for plant and panicle attributes.

The material was grown in three row plots at the National Research Centre for Sorghum during the 1978 monsoon (July-October) season, under optimal management. Internodal lengths from three random plants of the middle row of each entry were measured. Internodes were assigned numbers from 1 to n from base upwards with 1 as the lower most internode and n as the one immediately below the peduncle. An examination of the association between internode number and internode length indicated three (Type I, II and III) patterns. In order to characterize these patterns, first, second and third order polynomial regressions were fitted for each entry. A coefficient of determination (R^2) of 0·75 was chosen as the minimum for a satisfactory curve fitting and classification of genotypes into appropriate groups.

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*Part XXIV of Genetic analysis of some extoict Indian cross in Sorghum, Part XXIII appeared in Indian J. Genet., **41.**

Results

Data presented in Table 1 bring out established contrasting differences for height, maturity and mean internodal length between exotic (temperate) and Indian (tropical) groups of sorghum. The high yielding hybrid group follows temperate types but reflect some increase in mean internodal length. Compared to the parental forms, the cross derivatives are intermediate for most attributes. The hybrids are the highest yielding followed by the derivatives selected from temperate × tropical crosses. The first, second and third degree polynomial curves with observed and expected values are illustrated in Fig. 1.

Table 1

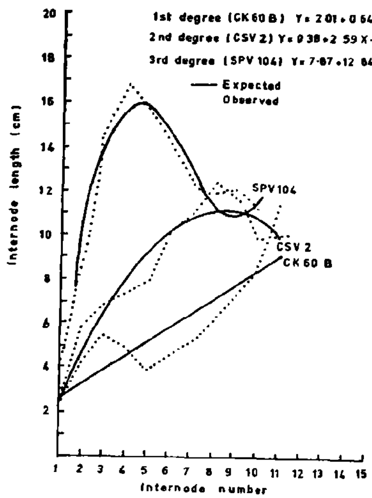
Internode and yield related attributes for tropical, temperate types and their derivatives

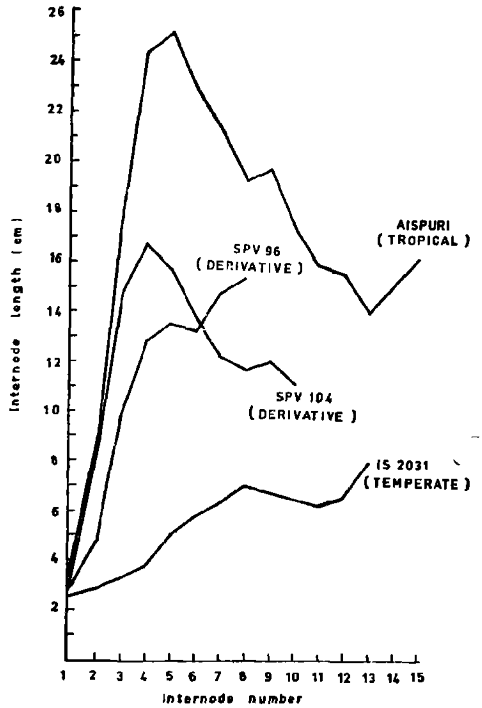
Group		Plant height (cm)	No. of inter-nodes	Average internode length (cm)	Days to flower	Grain yield (g/pl)
Temperate	(*4)	127.8	11.25	5.03	67.25	30.45
Tropical	(5)	290.4	14.40	17.56	83.20	40.10
Hybrids	(5)	175.4	11.40	8.54	67.66	84.88
Derivatives	(50)					
1. Type I	(15)	158.1	10.93	8.61	72.41	73.30
2. Type II	(20)	179.8	11.30	10.42	71.70	84.73
3. Type III	(15)	175.3	11.53	10.53	73.49	70.83
Mean		178.7	11.51	10.10	72.59	71.93
SED		9.2	0.75	1.42	1.30	13.65

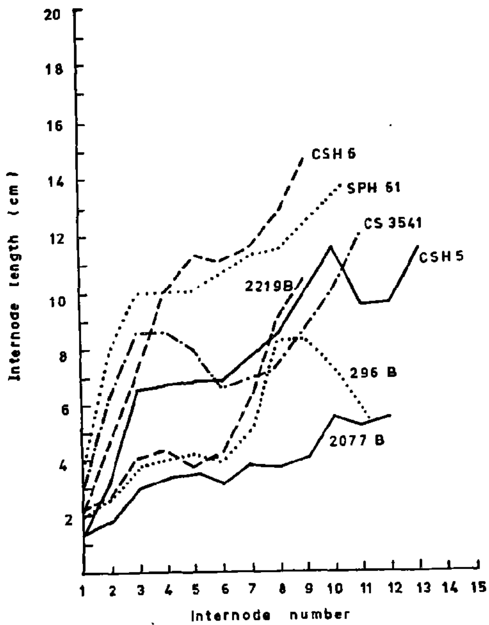
*Number in parentheses indicate number of entries studied in each group.

Data from Table 1 reveal that all temperate types and commercial hybrids follow a linear pattern of internodal elongation and fit the first degree curve. On the other hand, a third degree polynomial was required with regard to the tall tropical forms; IS 9985 exhibiting a second degree polvnomial was a relatively shorter tropical type. In case of the cross derivatives all the three types of curves were possible, the first degree types being relatively shorter. The parental extremes and the behaviour of derivatives are represented in Fig. 2 which indicate recombination and transmissibility of patterns of internodal elongation.

The internodal patterns of parents and hybrids are presented in Fig. 3. In case of all the commercial hybrids, the male parent is common and the females differ-2077A, 2219A and 296A for CSH-5, CSH-6 and SPH-61 (CSH-9) respectively. All the female parents and hybrids fit the first degree polynomial.







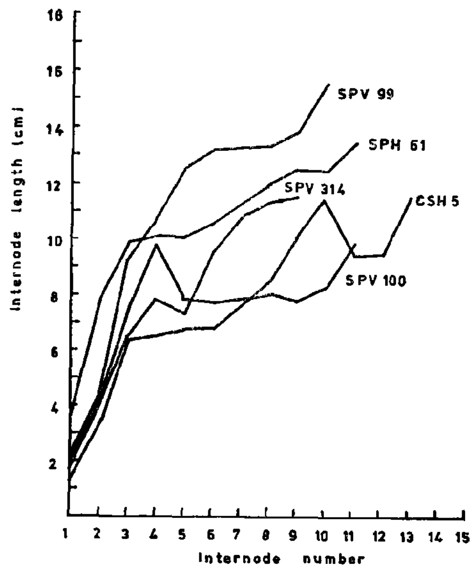


FIG. 1. Expected and observed internodal patterns in sorghums of diverse origin.
FIG. 2. Comparison of internodal patterns in some tropical and temperate sorghums and some derived types. FIG. 3. Internodal patterns of hybrids and their parents
FIG. 4. Internodal patterns of some high yielding hybrids and varieties.

Third order fitting is feasible with CS 3541, the common male parent. Plant to plant variability was also noticed in this genotype. Tallness is usually dominant, but the present study furnished information on heterosis for internodal length as well. CSH-9, which is the highest yielding and most stable hybrid, recently recommended for release on all India basis, conformed to a linear pattern of internodal elongation, all internodes being longer compared to both parents.

Comparative internodal patterns of three high yielding derivatives, SPV-99, SPV-100, and SPV-314 together with CSH-5 and SPH-61 are illustrated in Fig. 4 and all of them conform to the linear pattern.

Discussion

The major factors which contribute to productivity and stability of production, particularly under rainfed culture are duration of crop growth period and total dry matter production and its distribution (Rao *et al.*, 1975). Plant height being related to growth, is an essential component of growth analysis. Cassady(1967) recorded that the *Dw3* mutant height gene did not influence node number and hence maturity, but did affect other attributes. Brooks (1967) and Schertz (1970) observed that elongation is not uniform at all internodes in isogenic mutants. What is of significance is, whether any particular pattern of elongation from base upwards could be of selective value.

Longer internodes at the base in tropical sorghums do reflect a quicker rate of growth and consequently an advantage to stand above weeds. But the consequent low leaf number at the base does not provide adequate cover to smother weed growth. In the dwarf temperate sorghums, while the basal leaf number is high, their initial growth rate is slow. What is, therefore, needed is a recombination between the two and the commercial hybrids seem to satisfy this to some extent. Consequently, in handling temperate-tropical crosses, an appropriate recombination of internode number and length could be an essential criterion for selection.

The commercial hybrids conformed to the linear pattern of internodal elongation. Apart from the adaptive advantages of heterozygosity (Singhania and Rao, 1976), the linear pattern of elongation may cause a lesser set-back to growth under environmental stress. The derivatives of temperate × tropical crosses chosen in the study were all high yielding and were grown under optimal conditions and hence it is not possible to relate internodal pattern to yield under stress. But it may be inferred from experience and superior performance of hybrids under stress that a linear pattern of appropriate internodal lengths may be advantageous. Such a pattern has to be combined with duration as well as optimal dry matter production and distribution. Intermediate derivatives from temperate tropical crosses furnish such an opportunity. That an intermediate plant type may furnish phenotypic optimum was put forth by Rao *et al.*, (1973). Thus, besides providing opportunities to select for altered duration, dry matter production and distribution (Anantharaman *et al.*, 1978), the temperate-tropical crosses enable alteration of internodal patterns which could be of further selective value in breeding for higher yields and stability of performance.

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NEW HYBRIDS AND VARIETIES OF SORGHUM AND THEIR PERFORMANCE[1]

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ABSTRACT

The performance of some of the recently developed hybrids and varieties during the *kharif* season in India over a three year period has been examined. The recently released hybrid SPH-61 (CSH-9) was consistently superior and the most stable in yield performance. Hybrids were generally superior in performance and stability compared to improved varieties, but the latter do reflect significant improvement over local cultivars and could supplement hybrids to accomplish greater coverage.

SORGHUM breeding programmes in India continue to lay emphasis on the development of high yielding varieties and hybrids. There is also emphasis on similar maturity of hybrids and varieties so that earhead pest problems like midge resulting from growing cultivars of dissimilar maturities in a given tract are not accentuated (Rao and Jotwani, 1974). The present study attempts to analyse the three-year performance of some promising hybrids and varieties which reflect recent improvements in the development of hybrids and varieties.

MATERIALS AND METHODS

The experimental material for the present study comprised four early maturing varieties (SPV-35, SPV-96, SPV-99, and CSV-3) and two hybrids (CSH-1 and CSH-6) grown in the early maturity trial at a number of locations. A second All-India trial included medium maturity varieties (SPV-97, SPV-102, SPV-104, SPV-105, SPV-106 and SPV-107) and two hybrids (CSH-5 and SPH-61). Data on both trials was available over the three year period, 1976, 1977 and 1978. The total number of test locations over this period were III for hybrids, 113 for early maturing varieties and 118 for medium duration varieties. All the varieties were derived from tropical × temperate crosses. In case of CSH-1, CSH-5 and CSH-6 there is some tropical 'blood' in the male parents while in case of SPH-61 both parents have tropical × temperate parentage. The early hybrids and varieties matured in 90–100 days while the medium ones took 105–115 days to mature. Replicated trials were grown under rainfed conditions in the different agroclimatic regions of the country with standard cultural practices. The net plot size was 13·5 sq. metres. Stability analyses were done separately for each entry following Eberhart and Russell (1966).

RESULTS

YIELD POTENTIAL OF IMPROVED HYBRIDS AND VARIETIES

The comparative yields of the experimental hybrid, SPH-61 (now recommended for release as CSH-9), released hybrids and some of the new promising varieties are presented in Table 1. SPH-61 yielded 3379 kg to 4718 kg grain per

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TABLE 1

Average grain yield performance of hybrids and varieties (kharif 1976–78) *over* 111 *to* 118 *locactions all over India*

Hybrid/Variety		GRAIN YIELD (kg/ha) Maha-rashtra	Karna-taka	Tamil-nadu	Andhra Pradesh	Madhya Pradesh	Gujarat	Rajasthan	Average
A. Hybrids									
CSH-1	Av.	3960.5	3852.6	3729.2	2892.9	2627.5	2249.3	3077.0	3357.6
	% CSH-5	112.5	102.8	95.0	87.5	78.7	79.9	102.9	92.6
CSH-6	Av.	4193.0	4429.3	4180.4	3246.8	2974.0	2621.2	3591.1	3711.1
	% CSH-5	119.1	118.1	106.4	98.2	89.1	93.1	120.1	102.4
CSH-5	Av.	3519.5	3749.3	3927.3	3305.2	3338.1	2816.7	2988.7	3624.4
SPH-61	Av.	4717.7	4509.9	4250.4	3379.4	3563.5	3763.7	4454.6	4232.2
(CSH-9)	% CSH-5	134.0	120.3	108.2	102.2	106.7	133.6	149.0	116.8
B. Varieties (Early Maturing)									
SPV-35	Av.	3605.5	3747.4	2773.7	2550.3	2287.3	1976.2	2539.1	3007.0
	% Local	166.3	194.6	150.5	136.3	115.7	83.8	211.4	151.4
SPV-96	Av.	3088.6	2797.0	2120.5	2248.9	2156.0	1567.5	2442.8	2530.8
	% Local	142.4	145.2	115.1	120.2	109.0	66.5	203.3	127.5
SPV-99	Av.	2931.1	2924.9	2145.0	2329.3	1936.6	2078.5	2325.2	2529.5
	% Local	135.2	151.9	116.4	124.5	97.9	88.1	193.5	127.4
CSV-3	Av.	3470.7	2968.5	2595.8	2168.4	2900.2	2336.0	2691.9	2894.5
	% Local	160.1	154.1	140.9	115.9	146.7	99.0	224.1	145.8
C. Varieties (Medium Duration)									
SPV-102	Av.	3260.2	2804.3	2367.3	1941.1	2029.7	2431.8	2270.3	2639.0
	% Local	150.4	145.6	128.5	103.7	102.6	103.1	189.0	132.9
SPV-104	Av.	3186.5	2937.8	2322.9	2050.9	2080.0	2421.2	2917.7	2699.7
	% Local	146.9	152.5	126.1	109.6	105.2	102.7	242.9	136.0
SPV-107	Av.	3453.2	3014.5	2324.5	2350.5	2450.7	2511.3	3593.9	2979.5
	% Local	159.3	156.5	126.2	125.6	123.9	106.5	299.1	150.1
Local	Av.	2168.3	1926.1	1842.6	1871.1	1977.6	2358.7	1201.4	1985·7

hectare and excelled all the released hybrids in each State. It showed an average superiority of 17% over CSH-5, 14% over CSH-6 and 26% over CSH-1.

Experimental varieties SPV nos. 102, 104 and 107 produced 33 to 50% more grain yield than local cultivars. SPV-102 and SPV-104 were particularly superior in Maharashtra, Karnataka, Tamilnadu and Rajasthan States but SPV-107 was consistently superior in all the States.

Early maturing varieties, CSV-3, SPV-35, SPV-96 and SPV-99 were 27–51% high yielding than locals. CSV-3 and SPV-35 were the highest yielders among them. Greater advantage of improved early and mid-late varieties was observed in Rajasthan followed by Karnataka and Maharashtra. However, only mid-late hybrids/varieties appeared to be advantageous in Gujarat and Madhya Pradesh.

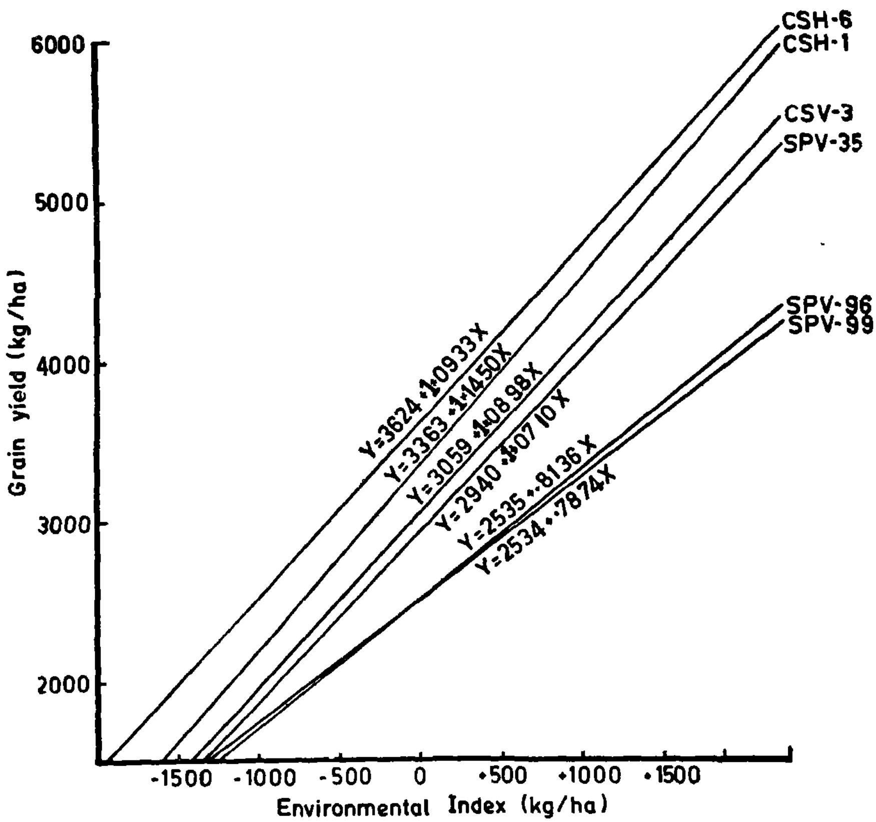

FIG. 1. Stability of early hybrids and varieties

Comparative yield performance of B lines (counter parts of females of hybrids used in the study) showed that 296B, the female parent of SPH-61 out-yielded all the female parents of released hybrids. Averaged over the three year period and over 25–27 locations, the grain yields of B lines were 296B (3074 kg/ha), 2077B (1897 kg/ha), 2219B (2686 kg/ha), and CK60B (2757 kg/ha). Since the male parent of CSH-5, CSH-6 and SPH-61 was the same, grain yield superiority of SPH-61 was mainly attributed to high yielding potential of its female parent and its combining ability with CS 3541.

STABILITY OF PERFORMANCE OF HYBRIDS AND VARIETIES

Among the early entries, CSH-6 was the highest yielding hybrid with slope slightly above unity (Fig. 1). CSH-1 was the next best in stability of performance. CSV-3 and SPV-35 showed average stability while SPV-96 and SPV-99 were relatively low yielding in this group but less sensitive to stress or improvement in environment.

Stability anlaysis of medium duration hybrids and varieties indicated that SPH-61 was superior to CSH-5 and other hybrids/varieties with respect to yield

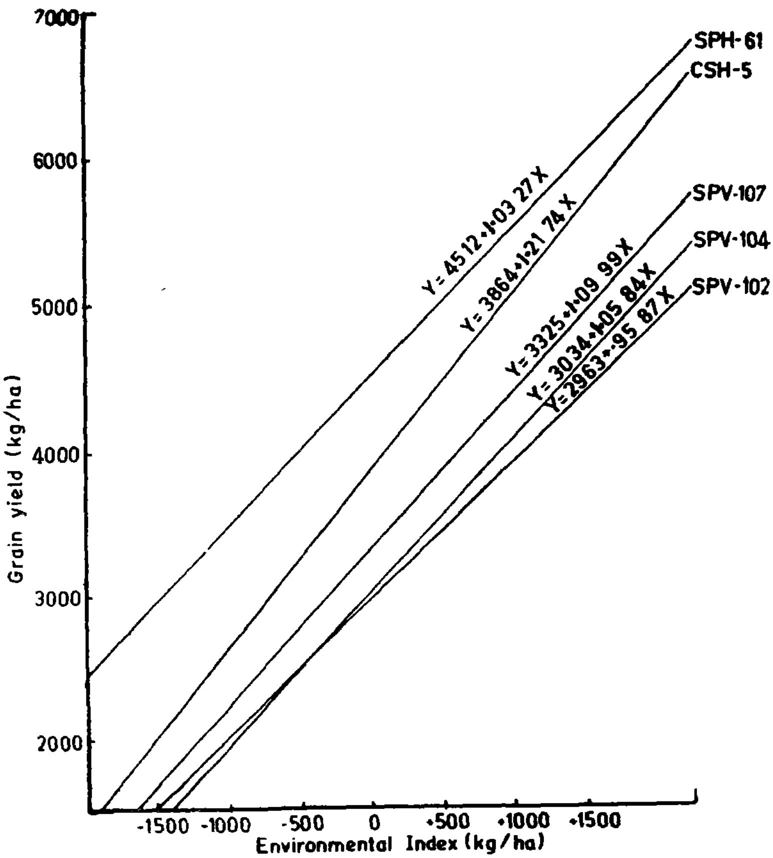

FIG. 2. Stability of medium duration hybrids and varieties

levels as well as stability both in poor and advantageous environmental conditions (Fig. 2). Yield of early hybrids, CSH-1 and CSH-6 was comparatively lower than mid-late hybrids. Deviations from linearity were particularly low in case of CSH-6. Among varieties, SPV-107, SPV-104, SPV-102 and SPV-101 were high yielding with slopes close to 1·0 (Fig. 2). Deviations from linearity were considerably low in case of SPV-104 and SPV-107. SPH-61 was the most widely adaptable hybrid. It was characterised by highest mean yield and low C.V. computed over all the locations during three years period (Fig. 3). CSH-5 and CSH-6 were the next best in their adaptability. CSV-3, CSH-1 and SPV-107 were intermediate in yield performance but reasonably good in their adaptability. Improved varieties such as CSV-4, SPV-102 and SPV-104 were intermediate in yield potential and adaptability. The performance of locals was characterised by low mean and high C.V. suggesting their poor and unstable performance.

Comparative performance of hybrids vs varieties

Average grain yields and stability parameters of promising varieties and hybrids grown in the same trials are presented in Table 2. Difference between yield performance of early varieties *vs.* hybrids was highly significant, hybrids being more productive than varieties and more adaptable ($b > 1\cdot1$). Similarly, mid-late hybrids possessed much higher yield potential over mid-late varieties, however, stability parameters were similar ($b = 1\cdot0$).

Table 2

Average grain yields (kg/ha) and stability of performance of some promising hybrids and varieties

Group	VARIETY		HYBRID		
	Mean	b	Mean	% over var.	b
Early	2767	0.9404	3493.5	26.12	1.1192
Mid	2822	1.0072	3994.5	41.62	0.9677

Significant at 1%; M.S. (Var. × Hyb.) Early group=37.2; Mid group 4.1**.

Advantage of mid-late hybrids over varieties of corresponding maturity was more (41·6%) than the advantage of early hybrids over early varieties. Comparison between the two maturity groups indicated that mid-late varieties were not appreciably superior in yield and stability over early varieties. Delayed maturity in hybrids conferred 14·3% advantage in grain yield over early duration hybrids.

Discussion

Development of high yielding hybrids and varieties of sorghum has made rapid strides in India during the recent past. The development of parents for new hybrids and vaiieties involved the use of exotic × Indian (temperate × tropical) crosses.

Both male and female parents of SPH-61 (CSH-9), the recently released hybrid are of exotic × Indian parentage and apparently the female improvement was responsible for its superiority since the male parent was common to CSH-5, CSH-6 and CSH-9. The results also indicate that superior yields and stability of performance seem to go together in most cases, since SPH-61 (CSH-9) was not only the highest yielder but most stable among all hybrids. That hybrids continue to be still superior to improved varieties with respect to performance and stability, as observed before (Rao and Harinarayana, 1968; Singhania and Rao, 1976) is also borne out in the present study. Amongst the varieties, the performance of SPV-35 among earlies and SPV-102, SPV-104 and SPV-107 among medium duration types is encouraging. Since their maturity is similar to the hybrids of the respective groups, and they are superior to locals, they could supplement hybrids to accomplish greater coverages and minimise damage due to earhead pests like midge occurring on late locals. The hybrids have higher yield levels and low C.V. compared to the improved varieties but the latter do reflect significant improvement over the local cultivars (Fig. 3).

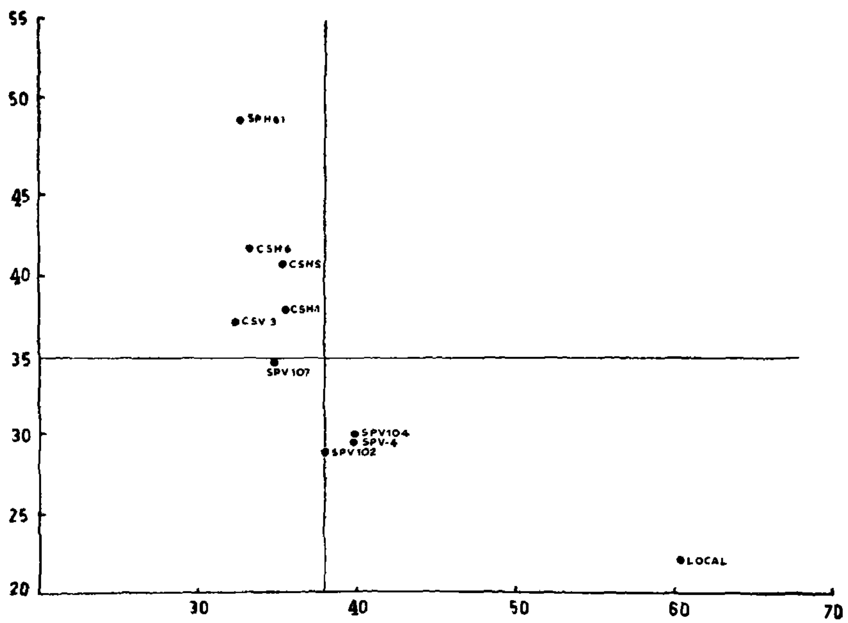

Fig. 3. Adaptability of promising sorghum hybrids and varieties; X—axis= Coefficient of variability and Y—axis=Grain yield (Q/ha).

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THE USE OF RISK AVERSION IN PLANT BREEDING; CONCEPT AND APPLICATION

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INDEX WORDS

Sorghun bicolor, sorghum, risk aversion, semi-arid-tropics, yield risk.

SUMMARY

Variance analysis is used to measure stability (inter-temporal) and adaptability (over space) components of variance with multilocation-multiyear sorghum yield data from India. Adaptability and stability were highly correlated. Only the stability component is relevant for farmers in their adoption decision. Measures of farmer's risk aversion are used to rank genotypes according to preferences which take account both of yield and stability. Since yield differences were large and risk aversion moderate, preference based rankings did not differ markedly from yield based rankings.

INTRODUCTION

The Indian Sorghum Improvement Program has aimed at developing short duration, high yielding, and widely adapted hybrids and varieties from temperate × tropical varietal crosses. Such hybrids and varieties are expected to withstand location-specific environmental fluctuations and still give high yield at a given location since genotype × year interaction was observed to be smaller than genotype × location interaction.

The question is pursued here more formally. The concept of stability is used exclusively in its temporal connotation and is the converse of low levels of risk. Adaptability is restricted to its location dimension and is defined as low fluctuations of (average over years) yields across location. This distinction is due to EVENSON et al. (1978). Stability (or conversely risk) and adaptability are measured by using a simple analysis of variance technique. The decision-theoretic concept of risk aversion is then used to establish a genotype ranking which is based on farmers preferences and takes account of both average yield and stability. The following questions are then pursued:

(i) Do hybrids outperform varieties when the preference-based ranking is used rather than a simple yield ranking?
(ii) Do yield and preference-based rankings deviate strongly from each other?
(iii) Are measured adaptability and (temporal) stability highly related?
(iv) How well can single-year data predict stability or adaptability?

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MATERIALS AND METHODS

A balanced set of five hybrids (CSH 1, CSH 2, CSH 4, CSH 5, and CSH 6) and six varieties (Swarna, 148, 302, 555, 604, and local) was chosen out of a total of 103 hybrids and varieties tested at 82 locations in the All-India coordinated trials. Those chosen were tested over 18 common locations from 1971 to 1974. The trials were conducted during the monsoon season and virtually all were under rainfed conditions. A uniform fertilizer dose of 80 kg N + 40 kg P_2O_5 and 40 kg K_2O per hectare was adopted with minor variations at some locations. The soil type was dissimilar from region to region, but deep black soils were prevalent in the major sorghum-growing belt. Trials were conducted in a complete randomized block design, entries replicated three times with a net plot size of 22.5 m^2. The plantings were done at a spacing of 45 cm between the rows and 15 cm between the plants. Early sowing and other plant protection measures were used.

Measures of risk and adaptability. The stability-relevant and adaptability-relevant components of variation are measured on the basis of the following linear model with random effects:

$$Y_{i\ell t} = \mu_i + \lambda_{i\ell} + \tau_{i\ell t} \qquad (1)$$

$Y_{i\ell t}$ is the yield of genotype i ($i = 1,\ldots,V$) at location ℓ ($\ell = 1,\ldots,L$) and in year t ($t = 1,\ldots,T$). The genotype mean is μ_i, $\lambda_{i\ell}$ is the effect of location ℓ on genotype i and $\tau_{i\ell t}$ is the location by year interaction. For analysis of variance purposes $\tau_{i\ell t}$ has to be further split up into $\tau_{i\ell t} = \upsilon_{it} + \eta_{i\ell t}$ where υ_{it} is the year effect on genotype i and $\eta_{i\ell t}$ is the residual location by year interaction. The following two subsections are a sharply condensed version of portions of BINSWANGER & BARAH (1980) to which the reader is referred for fuller details.

Replications are neglected in the analysis, although an extension to include their effect is straightforward. The variance of genotype i yield then is

$$\sigma^2_i = \sigma^2_{i\lambda} + \sigma^2_{i\tau} \qquad (2)$$

The 'adaptability component' of the variance is $\sigma^2_{i\lambda}$ (estimated by $S^2_{i\lambda}$) while the 'stability component' is $\sigma^2_{i\tau}$, measured by $S^2_{i\tau}$. (Formally this component is again broken up as $\sigma^2_{i\tau} = \sigma^2_{i\upsilon} + \sigma^2_{i\eta}$.) A farmer at any given location only experiences the stability component $\sigma^2_{i\tau}$ as his level of risk. Unlike the breeder, he is not interested in the (average) performance of the genotype at other locations; i.e., the adaptability component $\sigma^2_{i\lambda}$ is irrelevant for him.

From the mean squares (MS) of analysis of variance tables of each genotype yield across years and locations (and neglecting replications), these components are estimated as

$$S^2_{i\tau} = S^2_{i\upsilon} + S^2_{i\eta} = \frac{MS_{years} - MS_{residual}}{L} + MS_{residual}$$
$$= \frac{MS_{years} + (L-1)MS_{residual}}{L} \qquad (3)$$

$$S^2_{i\lambda} = \frac{MS_{location} - MS_{residual}}{T} \qquad (4)$$

For reasons explained in the next section and because of the one-to-one relationship of rankings based on variance and standard deviation, square roots of these components are used as estimates of stability- and adaptability-relevant standard deviations.

Decisions under risk and a measure of risk aversion. Ranking of genotypes by average yield and risk, as measured here by stability-relevant standard deviation will usually not coincide. A unique ranking for choosing among these genotypes can only be established by using decision theory under risk as developed by statisticians and economists. For an exposition of these theories see ANDERSON et al. (1977). The simplest of such a framework is Expected Returns-Variance analysis (E-V analysis). Before proceeding, however, note the following about this choice-theoretic framework: One can neglect the issues of subjective probabilities or perceptions of farmers because the analysis here is prescriptive, i.e., it addresses the question of what should be recommended to farmers. E-V analysis also assumes that yields are normally distributed over time (which cannot be tested with only 4 years of data); if there are sharp divergences from normality, more complex models are required. This is because measuring risk by variance or standard deviation is only appropriate for normal distribution (see ROUMASSET, 1979 on the problems of appropriate measures of risk). The use of the measure of risk aversion used below, (the tradeoff between yield and standard deviation) has a similar requirement. Note also that E-V analysis is usually performed with profits rather than yields. Since, in the trial considered, the cost of production is the same for all genotypes and we have no information about their output price differences, profit or yield leads to identical rankings. Where data sets have different characteristics the same analysis can be done by replacing yield $Y_{i/t}$ by profit $P_{i/t}$ where profit is computed as yield × price minus cost of production. If sufficient data on price variability over time is available one can then extend the model to take price risk into account as well.

In E-V analysis the farmer is assumed to have a utility function which measures his level of satisfaction taking into account both average yield and stability, i.e.

$$U = f(\mu_i, \sigma^2_{i\tau}) \qquad (5)$$

Problems associated with measuring such functions have been the focus of much research in economics and experimental psychology and cannot be reviewed here. What is important is that different combinations of expected return and stability can lead to the same level of satisfaction, i.e., one can solve equation (5) for iso-utility curves.

$$\mu_i \mid U = g(\sigma^2_{i\tau}) \qquad (6)$$

Because of the one-to-one correspondence of σ and σ^2, we can write this in the expected return-standard deviation space as

$$\mu_i \mid U = h(\sigma_{i\tau}).$$

Such iso-utility curves are given in Fig. 1 as lines AD, BD, or CD. The steeper the lines, the less risk-averse is an individual. The slope of the line $\Delta S/\Delta\bar{Y}$ is the tradeoff an

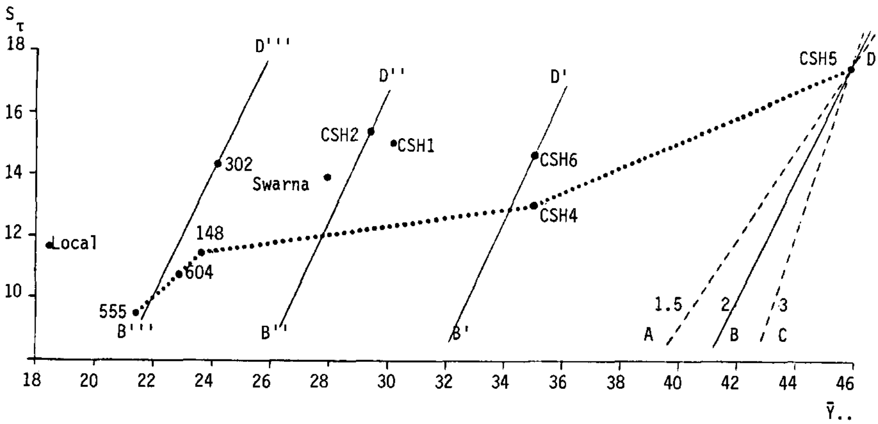

Fig. 1. Ranking according to risk preference.

individual is willing to accept between expected yield and standard deviation. Individuals with a given slope of these lines will choose the genotype which lies on the line farthest to the right in the graph because lower standard deviation and higher yield lead to higher utility.

BINSWANGER (1980) has measured the slope $\Delta S/\Delta Y$ of these iso-utility curves for the semi-arid tropical farmers in the Indian sorghum-growing belt. He finds that it lies in the fairly narrow range of 1.5 to 3.0 with a mean value of 2.0. This mean value will be used for the preference-based ranking.

RESULTS

The stability-relevant standard deviation S_τ plotted (vertical axis) against the mean yield of each genotype across all locations and over years (horizontal axis) shows that the genotypes fall into two distinct groups (Fig. 1). The hybrid groups have average yields ranging from 29.5 to 46.8 q/ha while the local check and the varieties have yields from 19 to 28.1 q/ha. Hybrids thus dominate all varieties from the yield point of view. However, the hybrids as a group tend to have slightly higher stability-relevant standard deviations than the varieties-cum-local groups. The most popular hybrids such as CSH-5 and CSH-6, therefore, are highest yielders, as well as higher in S_τ. By and large, higher yields must be 'paid for' by higher stability-relevant standard deviations. (They may, however, have lower coefficients of variation (CV) of yields. But CV cannot be used in this type of analysis because (a) no decision theoretic framework exists relating CV to yield or profits and (b) unlike S_τ, rankings by CVs of profits will not be identical to rankings by CVs of yields, even if output price and input levels do not differ by genotypes.)

Five genotypes 555, 604, 148, CSH-4 and CSH-5 are stability- or risk-efficient since no other genotype exists which has both higher (or equal) yield and lower (or equal) standard deviation. No risk-averse decision maker, regardless of his level of risk aversion, would choose a genotype which is not stability-efficient in this sense. Even without knowledge of the level of risk aversion of a decision maker one can thus classify genotypes into two sets. (This type of analysis can be extended to nonnormally

Table 1. Ranking of sorghum genotypes according to different device criteria and in different years.

Genotype	4 years average yield (q/ha)	Ranking		Stability efficient set	Stability standard deviation	Adaptability standard deviation	Adaptability efficient set	Individual year ranking			
		yield	risk preference					1971	1972	1973	1974
CSH 5	46.80	1	1	*	17.65	10.90	*	1*	1*	1*	1*
CSH 4	35.18	2	2	*	13.07	7.88	*	3	4	3*	2*
CSH 6	35.16	3	3		14.64	11.27		2	2	2*	4
CSH 1	30.29	4	4		14.95	9.96		4	3	4	10
CSH 2	29.54	5	5		15.34	11.93		5	6	5	5
Swarna	28.12	6	6		13.90	7.00	*	7	5*	6	3
302	24.18	7	9		14.27	7.34		9	7	7	9
148	23.77	8	7	*	11.40	6.08	*	6	9	8	7
604	23.09	9	8	*	10.83	5.90	*	8*	8*	9	6
555	21.51	10	10	*	9.48	6.52		11	10*	10*	8
Local	18.52	11	11		11.74	4.95		10	11	11	11

*The genotype is in the respective stability-efficient, adaptability-efficient, or variability-efficient set.

distributed yields where the concept of stochastic dominance is used (ANDERSON, 1974).) But such efficiency analysis does not lead to unique rankings. Therefore, to choose the 'preferred' genotype from the risk-efficient set requires the knowledge of the extent of risk aversion.

For this particular data set and for all three levels of risk aversion (1.5, 2, 3) the preferred genotype is also the highest-yielding CSH 5. In fact, the ranking based on risk-preference divides the genotypes into the same two groups as a yield-based ranking, namely, the hybrid and the varieties groups (Table 1). This answers the first question in the introduction in the affirmative. Furthermore the yield-based ranking and the preference-based ranking not only coincide across these groups but are very close within each group as well. The only rank reversal is the one between 302, 148, and 604. These genotypes have very similar yields but substantially different standard deviations causing reversal in rankings. Where yields differ widely such reversals do not happen. For this data set the second question in the introduction is also answered negatively.

The adaptability-relevant standard deviation is plotted against average yield in Fig. 2. In the absence of a choice-theoretic criterion for trading off yield against adaptability variance (BINSWANGER & BARAH, 1980) one can only infer that a genotype dominates the other in the adaptability sense if it has equal or higher yields and equal or lower adaptability variance (standard deviation). CSH-5 dominates CSH-2 and CSH-6; and CSH-4 dominates CSH-1, CSH-2, and CSH-6. Variety 148 dominates only 555. This dominance criterion can be used to define an adaptability-efficient set of genotypes as that set of genotypes which is not dominated by any other genotype in the adaptability sense. The adaptability-efficient set consists of 604, 148, Swarna, CSH-4 and CSH-5. The local check is also adaptability efficient. Since the local check differs from location to location, interpreting its adaptability-relevant standard deviation is not very meaningful.

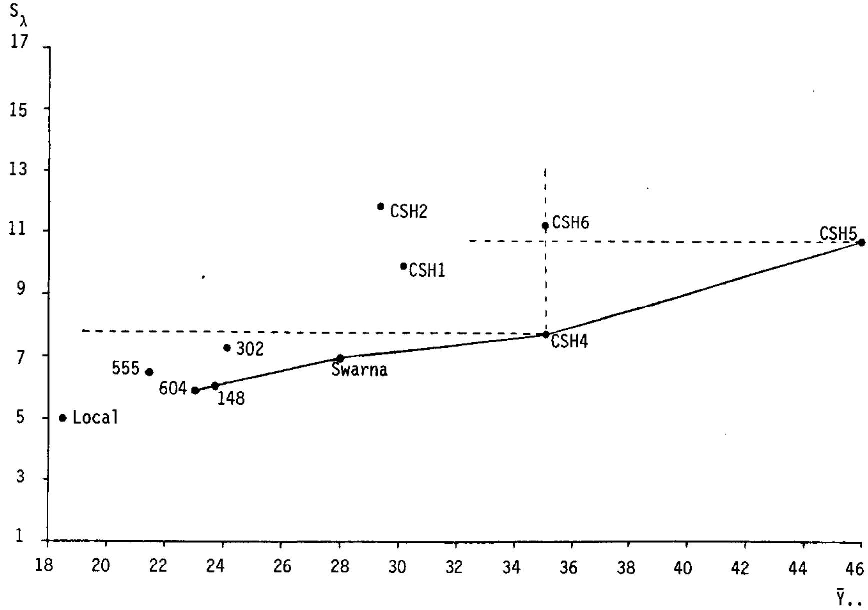

Fig. 2. Adaptability efficiency.

However, the adaptability-efficient set contains largely the same genotypes as the stability-efficient set (Table 1). Swarna is contained in the adaptability-efficient set but not in the stability-efficient one while the reverse is true of 555. In particular, CSH-5 and CSH-4 rank highest by yield and by risk preference and are also adaptability-efficient. Varieties 148 and 604 are among the lowest yielding but highest in their stability and adaptability.

The correlation coefficient between stability-relevant and adaptability-relevant standard deviation is also high at $r = 0.80$ which is significant at the 0.01 level of probability. Thus the third question in the introduction is answered affirmatively.

With single-year multilocation data, the total SD confounds stability and adaptability variance components and is thus neither a measure of stability nor of adaptability. It is larger than either one individually. However, one can define variability-efficient sets just as before for stability and adaptability. A genotype is variability-efficient if no other genotype has both higher (or equal) yield as well as lower (or equal) total standard deviation.

Comparing single-year yield rankings with the yield rankings over all 4 years and with the risk-preference rankings, the individual year rankings coincide fairly well with the overall yield and preference rankings where ultimate yield differences are large. CSH-5 always occupies first rank and local is last in 3 out of 4 years. On the other hand, Swarna does better than some of the hybrids in 2 out of 4 years. This leads to the conclusion that large yield differences in a single year are good predictors of yield differences over several years and of risk preference based rankings, but smaller differences must be confirmed in several years of trials. The fourth question of the introduction, therefore, receives the answer 'fairly well'.

Table 2. Annual yields, their standard deviations, and variability-efficient sets.

Genotype	1971	1972	1973	1974
CSH-5	57.76*	40.57	45.15*	43.71*
	(25.92)	(16.47)	(19.35)	(15.38)
CSH-4	35.30	32.15	37.17*	36.12*
	(18.18)	(16.44)	(15.51)	(9.36)
CSH-6	38.18	36.76	40.22*	25.48
	(19.99)	(20.57)	(16.57)	(11.52)
CSH-1	31.39	33.22	35.91	20.66
	(17.92)	(19.15)	(18.20)	(11.63)
CSH-2	30.28	30.15	32.34	25.41
	(19.19)	(18.86)	(22.25)	(17.58)
Swarna	24.81	31.16*	24.48	32.02
	(18.24)	(13.90)	(14.13)	(14.85)
302	22.34	29.26	20.56	24.59
	(17.16)	(18.58)	(10. 2)	(16.16)
148	26.40	24.48	19.	25.09
	(15.19)	(11.65)	(12.00)	(12.02)
604	23.35*	24.74*	18.95	25.34
	(12.48)	(10.48)	(12.79)	(13.10)
555	21.29	22.10*	17.94*	24.74
	(12.96)	(8.66	(8.65)	(14.11)
Local	21.95	18.33	17.16	16.68
	(13.43)	(19.22)	(16.20)	(10.50)

*Genotype is in variability-efficient set, i.e., there exists no other genotype which has equal or higher yield and equal or lower standard deviation.

DISCUSSION

It is our contention that the use of the joint regression technique of stability analysis is an inappropriate technique for analyzing stability in its risk connotation, although we do not dispute its usefulness in other contexts (Yates & Cochran, 1938; Finlay & Wilkinson, 1963; Eberhart & Russell, 1966; Perkins & Jinks, 1968; Freeman, 1973). First, the concept of stability used there coincides with stability as absence of risk only if it is used in a (usually nonexistent) data set for a single location over many years. It does not properly distinguish between a location and temporal dimension of variability, except in its extension by Evenson et al. (1978). Secondly, its measures of stability (regression coefficients and sometimes the residual variances around regression lines) have not been related to any choice-theoretic criteria for choice under risk. The neglect of a proper choice-theoretic framework is in our view the major reason for the continuing confusion about what are proper measures of 'stability' of genotypes, whether the discussion revolves around risk or adaptability as defined here.

The technique proposed here overcomes these shortcomings in the risk dimension. (But further work is required to develop a choice-theoretic framework of the adaptability issue.) It is simple and can be easily used with multilocation yield trials. It does require corresponding measures of risk aversion but such measures will increasingly become available for other farmer populations than the one studied here.

One limitation of the techniques is that the results are fairly specific to the agroclimatic region within which the experiments have been conducted, a problem shared by the joint regression approach as well. The preference-based rankings of these 11 genotypes may not be the same if tested in a similar way in Africa, for example. As discussed in BINSWANGER & BARAH (1980) or HARDWICK & WOOD (1972) such region-specificity can only be overcome by using regression techniques on plant-independent variables.

The results of the specific application are comforting to sorghum breeders in India and perhaps elsewhere as well. Yield and risk-preference-based rankings are very closely related, although further analysis is required to see whether this is also the case at lower fertilizer or plant protection levels. Furthermore, adaptability and stability are highly related, supporting a multilocation breeding and testing approach in the pursuit of both low risk and high yields.

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THEORETICAL AND APPLIED GENETICS

Amino Acids in Anthers of *Milo* and in Cytoplasmic Genetic Male Sterile Sorghums (*Sorghum bicolor* L. Moench) of Indian Origin

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Summary. Amino acid composition of proteins from anthers of *milo* and Indian origin male steriles were determined. Comparison of amino acid between A and B lines showed lower contents of histidine, threonine, glutamic acid, glycine, leucine and phenylalanine and higher contents of alanine, serine, proline and tyrosine in line A compared to line B. Alanine content in anthers of A lines was more than two fold higher than that in the anthers from B lines. Marked differences in amino acid composition of anthers of A and B lines are suggestive of their involvement in male sterility. Cytoplasmic male steriles of Indian origin M35-1A and M31-2A showed greater similarity but differed from *milo*, VZM2A and B.

Key words: Amino acid – Male sterility – Cytoplasmic male sterile – *Sorghum bicolor* L. Moench – Maintainer – Apomict

Introduction

All commercial hybrids of sorghum developed to date are based on *milo* cytoplasmic male sterility. However, there is a need to identify and utilize alternate sources to safeguard against possible hazards.

Rao (1962), Hussaini and Rao (1964) and Nagur and Menon (1974) reported the occurrence of cytoplasmic-genic male steriles from India. Compared to the *milo-kafir* system, fertility restoration in Indian steriles was difficult and it was, therefore, inferred that these sterility, inducing cytoplasm may be different. Several workers have studied male sterile lines and fertile lines in maize (Fukasawa 1954, Duvik 1965), cotton (Sarvella and Stojanovic 1968) and sorghum (Brooks 1962, Atkins 1970, Atkins and Kern 1972) for such chemical constituents as amino acids, carbohydrates, etc. At both meiosis and after the vegetative division of the microspores (Fukasawa 1954) proline was present in lesser amounts in the anthers of Texas cytoplasm plants than in the anthers of normal cytoplasm plants.

In cotton, Sarvella and Stojanovic (1968) observed higher aspartic acid arginine content in male sterile lines where *hirsutum* genomes were incorporated into *anomalum* and arboreum cytoplasm than the *hirsutum* type itself. Atkins (1970) and Atkins and Kern (1972) observed higher amino acid content in fertile lines. However, the precise difference between different cytoplasmic genetic male steriles from Indian and that of *milo* has not yet been characterised. In the present study the amino acid composition of anther from the *milo* and India origin male steriles has been studied.

Materials and Methods

Diverse male steriles, their maintainers and a apomictic line were included in this study. Seeds of CK60B, VZM-2A, VZM-2B, M35-1A, M35-1B, M31-2A and R473, provided by the All India Coordinated Sorghum Improvement Project (AICSIP), Hyderabad, were grown on IARI farms. Mature anthers were collected before bursting and either stored in liquid nitrogen or analysed immediately.

Protein Hydrolysis and Amino Acid Estimation

Weighed anthers (100 mg in B lines and 300 mg from A lines) were placed into hydrolysis tubes and 6 ml of 6N redistilled HCl was added. The tubes were then evacuated, sealed and hydrolysis was carried out by keeping tubes at 110°C for 24 hours. The hydrolysate was filtered and then freed of acid by repeated flash evaporation at 40°C. The residue was finally dissolved in a small volume 0.1 M sodium citrate buffer, pH 2.0, and amino acid analyses was done employing a TSM amino acid analyzer.

Results

The amino acid (g amino acid per 100 g protein) composition of proteins from anthers of male sterile and main-

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Table 1. Amino acid composition (g amino acid/100 g protein) of protein from anthers of male sterile, maintainer and apomictic sorghum lines

S. No.	Amino acid	CK60B	VZM 2A	VZM 2B	N35–1A	M35–1B	M31–2A	R473
1.	Lysine	7.25	5.90	8.00	6.70	5.90	6.70	9.20
2.	Histidine	1.70	0.90	1.70	–	2.40	1.80	1.80
3.	Argnine	6.78	4.00	4.20	5.90	6.00	6.00	7.00
4.	Aspartic acid	8.56	6.10	9.40	7.60	7.60	7.60	9.20
5.	Threonine	4.68	2.40	3.70	2.80	6.80	2.80	4.10
6.	Serine	5.02	6.90	5.40	8.40	4.80	7.20	6.00
7.	Glutamic acid	9.66	7.00	10.10	8.80	10.10	8.40	11.80
8.	Proline	10.76	13.30	11.10	13.20	11.90	13.20	11.90
9.	Glycine	4.56	4.80	5.30	4.30	5.20	5.20	4.30
10.	Alanine	6.93	16.20	7.40	19.40	7.20	18.40	9.20
11.	Cystine	Trace	Trace	Trace	–	Trace	Trace	–
12.	Valine	4.93	5.10	5.00	6.70	5.40	6.70	6.70
13.	Methionine	2.02	1.50	1.70	1.70	3.40	1.70	3.40
14.	Iso-leucine	4.31	4.10	4.30	4.50	4.50	4.50	6.00
15.	Leucine	6.65	5.40	7.50	6.00	7.50	7.50	9.00
16.	Tyrosine	4.53	5.90	4.20	6.20	4.20	6.20	6.20
17.	Phenylalanine	6.60	2.90	4.20	3.80	5.70	3.80	5.70
18.	Ammonia	3.41	4.30	4.30	3.00	4.50	2.40	2.80

tainer lines is shown in Table 1. Marked differences in the amino-acid composition of anthers from male sterile lines and their maintainers were observed. Comparison of amino acids between sterile and maintainer lines showed higher content of histidine, threonine, glutamic acid, glycine, leucine and phenylalanine and a lower content of serine, proline, alanine and tyrosine in the maintainer lines than in the male steriles. VZM-2B had higher aspartic acid compared to its male sterile VZM-2A while M35-1B had higher methionine and lower valine content than M35-1A anthers. All the A lines were characterized by very high levels of alanine. Alanine concentration was more than two fold higher in sterile lines than in their maintainer lines. Arginine, valine, methionine, isoleucine and ammonia did not show many differences between VZM-2A and VZM-2B. Also, in the case of M35-1A and M35-1B no differences were observed in the levels of arginine, aspartic acid and isoleucine. M35-1A had the highest level of alanine while CK60B had the lowest content. Comparison of the amino acid content of all sterile lines, i.e. VZM-2A, M35-1A, M31-2A, showed the common features of higher alanine, proline and serine content compared to their respective maintainers. Alanine and proline together accounted for 29-32 percent of the total amino acids present in A lines while in the cases of VZM-2B and M35-1B these two amino acids accounted for only 18-19%. Anthers from M35-1A and M31-2A had similar contents of lysine, arginine, aspartic acid, threonine, glutamic acid, proline, valine, methionine, isoleucine, tyrosine and phenyl alanine (Table 1). These results, therefore, indicate that the amino acid composition of M31-2A is very much similar to that found in the anthers of M35-1A. The amino acid composition of M35-1A and M31-2A differed from that of VZM-2A anthers. Both M35-1A, M31-2A anthers had higher contents of lysine, threonine, glutamic acid, alanine, valine, leucine and phenylalanine and lower contents of ammonia, as compared to that found in VZM-2A. This increased concentration of ammonia indicates the presence of higher levels of amides, either asparagine or glutamine, in VZM-2A than in M35-1A, M31-2A. Amino acid composition of anthers of VZM-2B and M35-1B also differed markedly. Lysine, aspartic acid and serine contents were higher while histidine, arginine, threonine, proline, valine, methionine and phenylalanine contents were lower in anthers of VZM-2B as compared to anthers from M35-1B. Methionine content in VZM-2B anthers was half that found in M35-1B anthers. Threonine content in VZM-2B was also nearly half that found in M35-1B anthers. There was not much difference in glycine, alanine, isoleucine, leucine, tyrosine and ammonia levels between M35-1B and VZM-2B anthers. The contents of arginine, threonine, methionine, tyrosine and phenylalanine were higher, while that of lysine, aspartic acid, serine, glutamic acid, glycine, alanine and leucine were lower, in anthers of CK60B than in VZM-2B anthers. Lysine, arginine, aspartic acid and phenylalanine contents were higher and that of histidine, threonine, glutamic acid, proline, glycine, valine, methionine, leucine and ammonia were lower in CK60B anthers than in M35-1B anthers. The amino acid composition of the apomictic line R 473 also differed from other anthers with respect to many amino acids. Lysine, aspartic acid, serine, glutamic acid, proline, alanine, valine, methionine, isoleucine, leucine were higher and threonine, phenylalanine and ammonia lower in R 473 anthers than in anthers of CK60B. Aromatic amino acid contents, including leucine

Table 2. Amino acid content (mg/g anther) from sorghum male steriles

S. No.	Amino acid	CK60B	VZM 2A	VZM 2B	M35–1A	M35–1B	M31–2A	R473
1.	Lysine	3.639	2.352	3.083	2.148	2.841	2.290	3.745
2.	Histidine	0.862	0.358	0.648	Trace	0.965	0.598	0.706
3.	Argnine	3.407	1.595	1.592	1.641	2.812	2.059	3.013
4.	Asparctic acid	4.308	2.430	3.563	2.471	3.389	2.476	3.470
5.	Threonine	2.369	0.981	1.427	1.009	1.392	0.964	1.673
6.	Serine	2.546	2.782	2.106	2.883	2.361	2.682	2.497
7.	Glutamic acid	4.875	2.778	3.924	3.136	4.644	2.740	4.549
8.	Proline	5.400	5.400	4.293	4.652	5.686	4.719	4.974
9.	Glycine	2.277	1.922	2.068	1.504	2.112	1.752	1.614
10.	Alanine	3.468	6.577	2.844	6.861	3.280	6.724	3.827
11.	Cystine	Trace	Trace	Trace	–	Trace	Trace	–
12.	Valine	2.465	2.039	1.885	2.160	2.342	2.429	2.632
13.	Methionine	1.009	0.598	0.634	0.628	1.321	0.653	1.038
14.	Iso-leucine	2.140	1.619	1.688	1.631	2.215	1.698	2.265
15.	Leucine	3.362	2.200	2.920	2.152	3.582	2.420	3.813
16.	Tyrosine	2.304	2.364	1.617	2.054	1.819	2.057	1.944
17.	Phenylalanine	3.321	1.134	1.593	1.161	1.928	1.118	1.959
18.	Ammonia	1.712	0.900	1.648	1.030	2.149	0.818	1.143

and isoleucine, in the apomictic line were comparatively higher than those found in other anthers. Lysine content was highest in R-473 anthers. Amino acid content per unit weight of anthers (mg/g anther) is shown in Table 2 for anthers of male steriles, maintainers and apomictic line, R 473. Amino acid content per unit weight of anther gives an idea of total abundance or lack of amino acid in anthers. A general comparison indicated a greater proportion of amino acids in CK60B, M35-1B and apomictic line, R-473, when compared to male steriles VZM-2A, M35-1A, M31-2A as well as VZM-2B. A comparison of A vs B lines indicated higher contents of lysine, histidine, aspartic acid, threonine, glutamic acid, leucine, phenylalanine and ammonia and lower contents of serine and alanine. Amino acid content in M35-1A had greater similarity to that found in M31-2A whereas that of VZM-2A differed from that of M35-1A and M31-2A with respect to proline, glycine, alanine, valine and tyrosine. CK60B also showed differences with the other maintainer lines VZM-2B, M35-1B as well as with R-473.

Discussion

Cytoplasmic male-sterility in *Sorghum* is fundamentally an aspect of the problem of gene action and nuclear cytoplasmic interaction. In order to find out if the cytoplasmic genetic male sterility could presumably be the result of a relatively simple course involving a deficiency of one or more compounds, amino acid analysis was done. The deficiency might reflect the known functioning of an enzyme system and result in subsequent accumulation of certain metabolites.

Upon compairing amino acids (g/100 g protein) from anthers of A and B lines, lower concentrations of histidine, threonine, glutamic acid, glycine, leucine and phenylalanine and higher concentrations of serine, proline, alanine and tyrosine were observed in A. However, proline and glycine did not show consistent results when amino acids were expressed on anther weight basis. Alanine contents in maintainer lines were less than 50% of that present in sterile lines. Khoo and Stinson (1959) have also observed accumulation of alanine in certain sterile lines of maize. Brooks (1962) also reported higher glycine levels in anthers of sorghum male steriles. However, in the present study male steriles had low glycine contents. The exact role of alanine is not known in inducing male sterility. Because of the predominance of alanine in anthers of sterile lines, it would be interesting to examine the involvement of either alanine or one of its intermediates in determining male sterility. Consistent differences in A and B lines are suggestive of changes in the pattern of amino acid metabolism in sterile anthers, relative to that of fertiles. In general, the amino acid composition of M35-1A anthers had greater similarity to that found in M31-2A anthers. These results further support the similarity observed in M35-1A and M31-2A using isoenzyme pattern mapping (Tripathi 1979).

The amino acid composition from anthers of apomictic line differed considerably from that of sterile and maintainer lines with respect to lysine, aspartic acid, glutamic acid, alanine, isoleucine, leucine, etc. The contents of lysine, leucine, isoleucine, glutamic acid and aspartic acid were higher in anthers of R-473 as compared to anthers of A and B lines. The differences in amino acid composition of sterile and maintainer line and anthers of different cytoplasmic background are suggestive of basic differences in protein quality and quantity.

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SOLUBLE PROTEIN AND ISOENZYMES FROM ANTHERS OF DIVERSE MALE STERILES IN SORGHUM*

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FOLLOWING the vulnerability of corn hybrids to leaf blights, primarily attributable to the T cytopasm, great attention is being bestowed on diversification of cytoplasmic sources of male sterility. All commercial hybrids of sorghum developed so far are based on milo cytoplasmic male sterility and there is a clear need to identify and utilize alternate sources. Compared to the *milo-kafir* system, fertility restoration on Indian steriles was difficult and it was, therefore, inferred that these sterility inducing cytoplasm may be different. The precise differences among male steriles of Indian-origin and *milo* are not known. Theoretically, proteins which are the primary products of genes, probably provide a direct measure of gene homology. Various workers (Alam and Sandal, 1969; Schwartz, 1966; Siddiq *et al*, 1972) have tried to study genome relationship by studying soluble protein and isoenzyme patterns. In the present study, soluble protein and isoenzyme pattern in anthers of sorghum (*Sorghum bicolor* Moench.) strains with diverse cytoplasmic and nuclear factors have been studied.

MATERIALS AND METHODS

The seeds of six male steriles, 'Ck 60 A', 'Nagpur A', 'GIA', 'VZM 2A', 'M 35–1A' and 'M 31–2A' and their maintainers were grown on IARI farm. Mature but unburst anthers were collected in the morning hours and stored in liquid nitrogen before use.

Soluble protein extraction: Anthers were ground in chilled pestle and mortar with 50 mM Tris-Cl buffer (pH 7·6) (1:2·5 W/V) containing 50 mM β-mercaptoethanol and 5 mM EDTA for soluble protein and isoenzymes of esterases. For peroxidase, 50 mM Tris-Cl buffer, pH 7·6 (1 : 2·5 W/V) was used. All operations were carried at 4°C. The suspension was then centrifuged at 15,000 g for 30 minutes at 0°C. The supernatant obtained was used immediately for gel electrophoresis.

Separation of proteins: Polyacrylamide gel electrophoresis was used to separate soluble proteins and various isoenzymes. Anionic system of Davis (1964) and Ornstein (1964) was adopted. Samples containing 200–225 μg protein were layered above the spacer gel. Electrophoresis was conducted in cold (about 4°C) by applying initially 2 mA and then 3 mA current per gel tube untill tracking dye (bromophenol blue) entered the running gel. After completion of electrophoresis, which was indicated by the movement of trackling dye to the bottom of gels, the gels were stained for 30 minutes in 0·1% amido black (in 7% acetic acid) and destained by diffusing out excess stain in 7% acetic acid. Esterases were detected by incubating gels in 50 ml phosphate buffer (0·05 M pH 6·0) containing 1 ml of 1% α-naphthylacetate in 60% acetone and 25 mg fast blue RR at room temperature for 10–30 minutes. For peroxidase, the gels were incubated for 30 minutes in 0·5% O-dianisidine HCl 1 ml, 0·6 M sodium acetate buffer (pH 5·4)

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3 ml. and distilled water 26 ml. Then the gels were incubated in 0·1 M H_2O_2 until the visible bands developed and photographed immediately. For each group of the enzymes duplicate runs were made.

The relative migration (R_m) of each band and the similarity index values calculated as given by Siddiq *et al.* (1972).

Results

The amount of soluble protein extracted from anthers of sterile lines was considerably less as compared to the anther of maintainer lines. The anthers from 'CK 60 A and' 'Nagpur A' were more or less completely devoid of soluble proteins as no staining appeared on gel even after loading extra amount of extract.

R_m values of different bands is shown in Table 1. The soluble protein pattern from anthers of different lines showed characteristic differences (Fig. 1). Protein patterns of 'G1A' and 'G1B' anthers differed considerably from that

TABLE 1

R_m value of soluble protein bands on polyacrylamide gel electrophoresis from anthers of different sorghum strains

R_m	CK60B	NagpurB	G1A	G1B	VZM2A	VZM2B	M35–1A	M35–1B	M31–2A	M31–2B
0·04	+	—	—	—	+	—	—	—	+	—
0·06	+	F	—	—	+	—	+	—	+	—
0·08	—	+	—	F	+	—	+	—	+	+
0·18	F	+	—	—	—	+	—	+	—	+
0·22	—	—	—	—	—	—	—	—	—	+
0·24	+	—	—	F	—	+	—	—	F	—
0·28	—	—	—	+	—	—	—	+	—	+
0·30	—	+	—	—	—	+	F	+	—	—
0·32	—	—	—	—	—	—	—	+	—	—
0.34	+	F	—	—	+	F	—	—	+	+
0·40	—	+	—	—	+	—	F	+	—	—
0·44	—	—	+	—	—	+	—	—	—	+
0·46	—	+	—	—	—	F	—	—	—	—
0·48	—	—	—	+	—	—	—	+	+	+
0·52	+	+	—	+	—	+	F	+	—	—
0·58	—	—	—	—	—	—	+	—	—	+
0·60	+	+	+	—	—	+	—	—	—	—
0·64	—	—	—	F	—	—	—	+	—	+
0·68	—	+	—	—	F	F	—	+	—	—
0·70	+	+	—	—	—	—	—	—	—	—
0·72	—	+	F	—	—	F	—	—	—	—
0·84	—	—	+	—	—	—	—	—	—	—
0·92	—	+	—	+	+	—	—	—	+	—
0·96	—	—	—	—	—	—	+	+	—	+
Total	8	13	4	7	7	10	7	10	7	10

+ Band present; — Band absent; F—Faint band.

of other anthers. The similarity index values, which give an idea of gene homology between male sterile *vs* maintainer lines of different cytoplasmic origin,

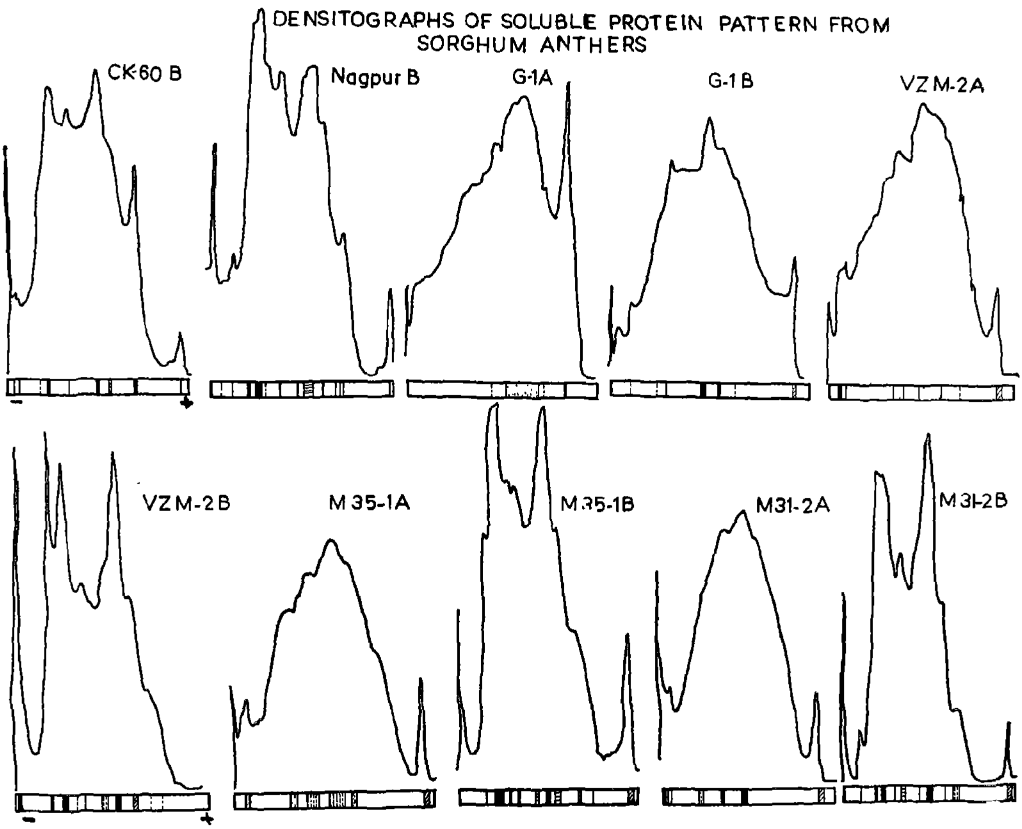

Fig. 1.

are shown in Table 2. Based on these similarity index values, 'CK 60 B' had considerable homology only with. 'Nagpur B'. 'Nagpur B' anthers showed greater homology with 'VZM2A' and 'VZM2B' than with others. Even A and B lines of same origin did not show greater homology.

Esterase isoenzyme: Esterase isoenzyme patterns from anthers are shown in Fig. 2 and the R_m values of the isoenzyme are given in Table 3. Qualitative and quantitative differences were noticed not only between male sterile and the corresponding maintainer line but also between lines of different cytoplasmic background. The pattern of 'Ck 60 B' had greater resemblance with 'Nagpur B' as compared to that of other lines. The patterns from 'G1A' and 'G1B' were quite distinct compared to other sterile and maintainer lines. Intensity of esterase isoenzyme bands was greater in male steriles than in the corresponding B lines. In general, band pattern of 'M 35-1A' and 'M 35-1B' had great

TABLE 2

Similarity index for soluble protein from anthers of different male steriles and their maintainer

S. No.		Nagpur B	G1A	G1B	VZM2A	VZM2B	M35–1A	M35–1B	M31–2A	M31–2B
1	CK60B	60	10	17	25	38	15	13	40	13
2	Nagpur B		14	18	47	53	33	28	11	15
3	GI A			0	0	30	0	0	0	8
4	GI B				17	13	17	31	30	31
5	VZM 2A					14	27	13	44	13
6	VZM 2B						13	25	14	18
7	M 35–1A							31	8	21
8	M 35–1B								7	33
9	M 31–2A									14

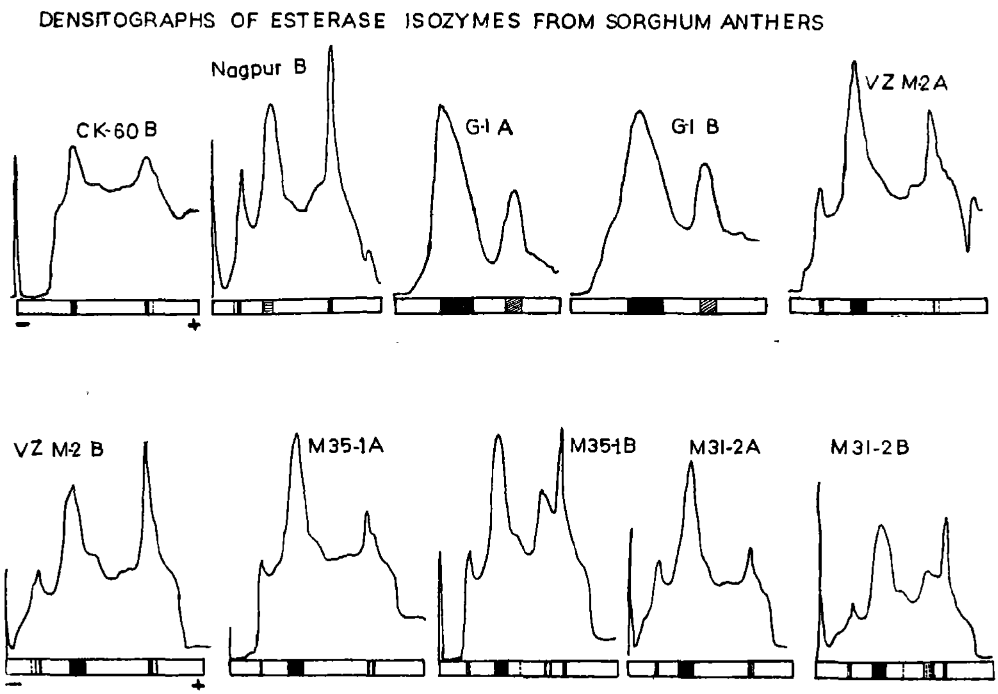

FIG. 2.

TABLE 3

R_m value along with their intensity of esterase isoenzyme bands on polyacrylamide gel electrophoresis from anthers of different sorghum strains

R_m	CK60B	Nagpur B	G1A	G1B	VZM2A	VZM2B	M35–1A	M35–1B	M31–2A	M31–2B
0.13	—	+	—	—	—	F	—	—	—	—
0.15	—	++	—	—	+	+	—	+	—	—
0.17	—	—	—	—	—	+	+	+	+	F
0.19	—	—	—	—	—	—	—	—	—	+
0.35	++	+++	+++	—	+++	+	++++	+	++++	++
0.39	—	—	—	+	—	—	—	—	—	—
0.45	—	—	—	—	—	—	—	F	—	—
0.49	—	—	—	—	—	—	—	—	—	F
0.59	—	—	—	—	—	—	—	+	—	—
0.61	—	—	—	—	—	—	—	F	—	F
0.71	+	++++	—	—	—	—	+	++	+	++
0.73	—	—	+	+	++	++	+	—	+	—
0.75	F	—	—	—	F	+	—	—	—	—
Total	3	4	2	2	4	6	4	7	4	6

+ Band present; — Band absent; F—Faint band.
NB: Increasing no. of plus indicate the higher intensity.

resemblance with respectively 'M 31–2A' and 'M 31–2B' esterase isoenzyme patterns. Esterase pattern from 'G1A' and 'G1B' differed qualitatively from that of 'VZM 2A' and 'VZM 2B' anthers.

Peroxidase isoenzyme: Peroxidase isoenzyme pattern was studied due to its known involvement in growth and development. Peroxidase isoenzyme patterns obtained from anthers of diverse sorghum A and B lines are shown in

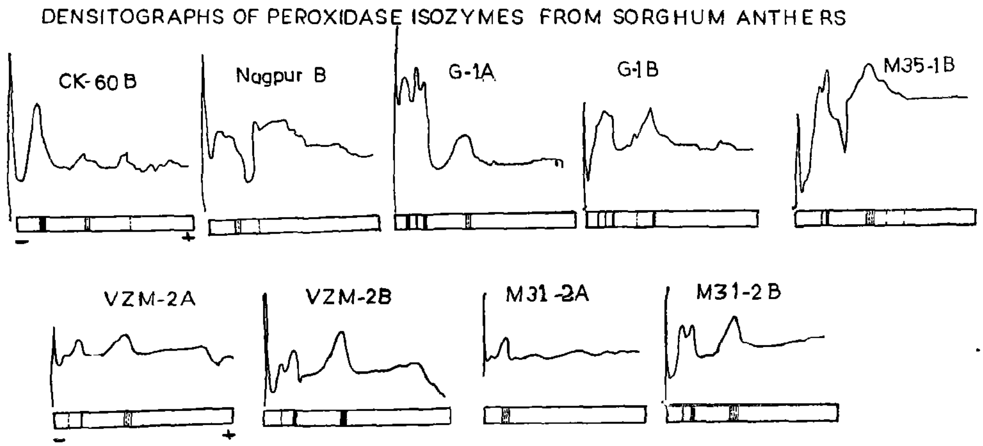

FIG. 3.

TABLE 4

R_m value of peroxidase isoenzyme bands on polyacrylamide gel electrophoresis from anthers of different sorghum strains

R_m	CK60B	NagpurB	G1A	G1B	VZM2A	VZM2B	M35–1A	M35–1B	M31–2A	M31–2B
0·07	—	—	+	+	+	+	—	—	—	—
0·11	—	—	+	+	—	—	—	+	+	+
0·15	+	F	+	+	+	+	—	+	—	+
0·31	—	F	—	F	—	—	—	—	—	—
0·39	+	—	F	+	F	+	—	F	—	F
0·51	—	—	—	—	—	—	—	F	—	—
0·61	—	—	—	—	—	—	—	F	—	—
0·65	F	—	—	—	—	—	—	—	—	—
Total	3	2	4	5	3	3	0	5	1	3

+ Band present; — Band absent; F—Faint band.

Fig. 3, and the R_m values of different isoenzymes in Table 4. Peroxidase isoenzyme bands from anthers of maintainer lines were very clear while those from all sterile lines except 'G1A', were very faint. Peroxidase intensity in 'G1A' was greater compared to any other A line. The pattern of 'M 35–1B' was similar to G1B'. 'VZM2A' and 'VZM2B' were also similar quantitatively but differed qualitatively. Peroxidase band at R_m 0·15 was common to all the maintainer lines while the band at R_m 0·07 was common to 'G1A' and 'G1B' and 'VZM2A' and 'VZM2B' lines. The number of peroxidase bands varied markedly in the male steriles and their maintainers. Only one band was present in 'M 31–2A' while a maximum of five bands were present in 'G1B' and 'M 35–1B'. 'M 35–1A' did not show the presence of any peroxidase.

Discussion

Comparison of anther soluble protein patterns indicated quantitative and qualitative differences among different cytoplasmic backgrounds. Soluble protein pattern from anthers of *milo* based steriles showed greater homology among themselves. Protein band pattern of 'G1B' and 'VZM 2B' differed considerably from anthers of other lines. Decreased number as well as decrease in intensity of the protein bands from anthers of sterile lines is indicative of reduced protein accumulation in these anthers. These results have been further confirmed by electron scanning microscopy where pollen from sterile lines were found to be devoid of much of the contents (Tripathi *et al.*, 1981). Alam and Sandal (1969) reported differences in protein pattern from male sterile and fertile lines of sudan grass.

Based on esterase band pattern in anthers, diverse male steriles can be grouped into three groups (i) Ck 60 B, Nagpur B, (ii) M 35–1A and M 31–2A, (iii) G1A and VZM 2A.

The intensity of peroxidase isoenzymes from anthers was less in all male steriles (except G1A) than in their maintainers. Peroxidase isoenzyme pattern of 'M 35–1B' and 'M 31–2B were similar. This further confirmed the observation that these belong to the same group. However, peroxidase isoenzyme pattern could not group the diverse male steriles distinctly.

Summary

Soluble protein, esterase and peroxidase isoenzyme pattern were studied in anthers of diverse sorghum male steriles and their maintainers. Soluble protein pattern of sterile and corresponding maintainer line showed qualitative and quantitative differences. Based on esterase isoenzyme pattern the diverse male steriles and maintainers could be classified in three groups. Peroxidase pattern also showed characteristic but not so clearcut differences.

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INHERITANCE OF HOST PLANT RESISTANCE TO THE SORGHUM SHOOTFLY

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Abstract—The behaviour of shootfly resistance is examined over the F1, F2, F3 and advanced generations. The F1 is almost intermediate between two parents with an added heterotic advantage of a lower 'dead-heart' percentage. Resistance shows partial dominance under low to moderate shootfly infestation but this relationship may shift under heavy infestation conditions.

The resistance is polygenic in nature and governed by additive genes. In the absence of host immunity, gradual accumulation of favourable genes is possible by line breeding from R × I and I × I crosses by selecting 1 SD below the population mean. Selection for multiple characters limits the genetic advance for shootfly resistance—resulting in 0–5% selection intensity and relatively less resistant but high yielding desirable progenies. Multilocation tests enable the selection of varieties stable for shootfly resistance.

Key Words: Shootfly, resistance, inheritance, varieties, progenies, selection, crosses, generations, susceptible

INTRODUCTION

Sorghum in the tropics being a low-input crop necessitates a greater awareness for the development and growing of resistant varieties to reduce the cost of cultivation and to improve and stabilize the productivity. The release of varieties susceptible to insect attack may accentuate the problem. The primary objective of sorghum breeding, therefore, involves combining productivity, insect and disease resistance in a suitable plant type background.

NATURE AND STABILITY OF RESISTANCE

The primary mechanism of shootfly resistance is reported to be ovipositional non-preference (Soto, 1972; Jotwani *et al.*, 1971; Rao *et al.*, 1978) involving a low level of antibiosis (Soto, 1974). Egg laying and 'dead-heart' formation are genotypically correlated, though at least one egg per plant can be laid even on resistant varieties and crosses between them (Sharma *et al.*, 1977). Resistance to the shootfly, therefore, appears to be the cumulative effect of non-preference, antibiosis and some morphological factors earlier reported by Ponnaiya (1951) and Blum (1968).

Rana *et al.* (1975) examined the tropical and temperate parental stocks and their derivatives. Based on group differences, gradation among varieties and the continuous range of variation, it was concluded that host immunity is absent and that non-preference is a primary mechanism of resistance which is quantitative in nature. The varieties differ in their 'dead-heart' percentage under different levels of infestation but non-preference appears to be a stable mechanism at all levels of infestation over time and space (Singh *et al.*, 1978). IS Nos 1054, 5469 and 5490 are fairly stable varieties and furnish a dependable source of resistance for a breeding programme.

BEHAVIOUR OF SHOOTFLY RESISTANCE IN DIFFERENT GENERATIONS AND THEIR INTERRELATIONSHIP

When susceptible (S) and moderately resistant (I) temperate tropical derivatives are involved in crosses, the average heterosis in a series of crosses varies from −40.2 to 8.7% (Table 1). In general, the S × I, I × I and S × S F1s show lower 'dead-heart' percentages than mid-parent values indicating the partial dominance of resistance, with overall heterosis being −18.8% (Table 2). The relationship may change when resistant (R) parents are crossed with moderately resistant parents and screened under high shootfly infestation. The susceptibility shows a partial dominance in I × R crosses, heterosis being 17.2%.

The 'dead-heart' percentage increases proportionately as the parental susceptibility increases in crosses (Table 3). The linear fashion in which 'dead-heart' percentage decreases from 56 to 23% in order of resistance is due to a gradual accumulation of desirable alleles rather than to a few major genes. The susceptibility level of the S × S and S × R crosses decreased in F2 as compared to the respective parents while for the S × I and I × I crosses the level increased (Table 3). The F2 mean and increase over the mid-parent value for the 'dead-heart' percentage in F2 is minimal for the I × R and R × R crosses. The behaviour of I × R crosses is desirable since gene transfer from R parents is convenient through the derivatives of temperate × tropical crosses in the improved genetic background.

The 'dead-heart' percentage of F1 is positively associated with parental performance. Therefore, paren-

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Table 1. Average heterosis over respective parents in a series of crosses

S. No.	Parent	Heterosis (%)	S. No.	Parent	Heterosis (%)
1	36A	−15.9	10	221	−23.7
2	173A	−31.6	11	252	−27.8
3	418A	−40.2	12	434	1.3
4	648A	−11.4	13	512	−25.3
5	1220A	−23.9	14	R-24	−5.1
6	1219A	−29.2	15	FR493	8.7
7	2947A	−15.5	16	IS 84	−16.3
8	148	−24.8	17	CS3541	−13.5
9	165	−22.6	18	Swarna	−13.7

Parents 1–7 are male sterile lines—8–18 are restorer lines.

Table 2. Heterosis for the 'dead-heart' percentage in crosses involving resistant (R), moderately resistant (I) and susceptible (S) parents

S. No.	F1 hybrid	Heterosis over mid parent (%)	Shootfly infestation
1	S × S	−16.9	Moderate
2	S × I	−11.8	Moderate
3	I × I	−34.9	Moderate
4	I × R	17.2	High
5	R × R	3.9	High

Table 3. F2 performance for the 'dead-heart' percentage in relation to parents

S. No.	Cross	$\bar{F}2$	Proportioned to R × R	$(\bar{F}2 - \bar{P})/\bar{P}$ (%)
1	S × S	56.3	2.40	−12.6
2	S × I	47.9	2.05	24.4
3	S × R	37.7	1.61	−13.3
4	I × I	32.2	1.37	40.6
5	I × R	25.0	1.07	9.6
6	R × R	23.4	1.00	4.0

S = Susceptible, I = moderately resistant, R = resistant.

tal performance *per se* can be used to predict the hybrid performance (RAO *et al.*, 1974). Similarly, F2 and F1 performance is also positively correlated with the 'dead-heart' percentage as well as with egg laying per infected plant (SHARMA *et al.*, 1977). Another study involving parents, F1 , F2, BC1 and BC2 generations of an I × S cross revealed the dose effect in back crosses (BALAKOTAIAH *et al.*, 1975). The reciprocal differences were not significant, though generation differences were quite perceptible.

The behaviour of the parental, F2 and F3 generations of the I × R and I × I crosses was further examined by RANA *et al.* (1975). The means of different generations were almost the same. Variations among different F2 were not significant but the difference within and between F3 progenies were highly significant. Selection can conveniently sort out resistant progenies of superior crosses in F3.

The estimates of combining ability are presented in Table 4. The general combining ability is considerably high in F1 and F2 generations indicating a heritable nature for shootfly resistance. The significant positive relationship between the F1 and parental performance, and between the F1 and F2 generations for 'dead-heart' percentage, provide further evidence that resistance to shootfly is governed by additive genes which are polygenic in nature. Gene effects estimated over various generations indicate the predominance of additive and additive × additive interactions (BALAKOTAIAH *et al.*, 1975).

Table 4. Estimates of the combining ability variance for the 'dead-heart' percentage

S. No.	Parameter	Generation F1	F2*
1	$\hat{\sigma}^2$gca	35.68	36.18
2	$\hat{\sigma}^2$sca	15.77	5.57
3	$\hat{\sigma}^2$gca/$\hat{\sigma}^2$sca	2.26	6.50
4	Heritability (%)	43.93	61.55

*BALAKOTAIAH *et al.* (1975).

Table 5. F2 frequencies (%) of plants surviving shootfly damage

Type	Cross	Survival (%)	Grain yield (g/plant) <20	21–40	41–60	61–80	81–100
R × R	IS 4664 × IS 2312	82	28.0	54.0			
R × I	IS 4664 × SPV-97	55	14.6	35.3	5.3		
I × I	E302 × SPV-97	41	4.7	20.7	12.6	1.3	1.3
	E302 × SPV-103 dw	40	2.7	10.0	14.7	6.7	6.0
	SPV-97 × SPV-103 dw	38	1.9	6.9	8.1	10.0	11.2
I × S	E302 × CS3541	34	1.3	19.3	9.3	2.7	1.3
	SPV-97 × CS3541	40	0.7	8.7	14.7	9.3	6.7
	SPV-103 dw × CS3541	35		9.3	14.0	6.0	5.3
R × S	IS 4664 × CS3541	31	8.0	17.3	5.3		
			Plant height (cm) <100	101–150	151–200	201–250	>250
R × R	IS 4664 × IS 2312	82				38.0	44.0
R × I	IS 4664 × SPV-97	55			10.7	41.3	3.3
I × I	E302 × SPV-97	41		0.7	10.0	28.7	1.3
	E302 × SPV-103 dw	40	2.0	5.3	11.3	13.3	8.0
	SPV-97 × SPV-103 dw	38	2.5	14.4	20.6	0.6	
I × S	E302 × CS3541	34	2.7	8.0	12.0	10.7	0.7
	SPV-97 × CS3541	40	2.7	15.3	17.3	4.7	
	SPV-103 dw × CS3541	35	4.0	24.0	6.0	0.7	
R × S	IS 4664 × CS3541	31	1.3	3.3	3.3	16.0	6.6

LIMITS TO SELECTION

Various F2 and F3 progenies show a continuity of variation for the 'dead-heart' percentage (Balakotaiah *et al.*, 1975; Rana *et al.*, 1975) When the frequency distribution was examined, the parents and F2 progenies fit a normal distribution with a mean of 36.7 ± 1.19 mortality (%) and a range of variation from 22.5 to 64.4%. The frequency distribution of F3 progenies for the 'dead-heart' percentage also closely fits the normal curve with a population mortality range between 6.7 and 67%. This clearly indicates the limitation of choosing for absolute resistance. Under such circumstances, progenies exhibiting mortality percentages 1 SD below the mean (<20%) could be considered resistant to the shootfly.

Selection for multiple characters imposes further restrictions. The F2 segregation of approximately 300 plants per R × R, R × I, R × S, I × I and I × S progeny for 'dead-heart' percentage, grain yield, plant height and rust resistance is presented in Table 5. The surviving plants of the R × R and R × I crosses are low yielding, tall, susceptible to leaf disease and unsuitable for selection. On the other hand, in spite of the high mortalities of the I × I and I × S crosses, the surviving plants offer the opportunity for selecting the high yielding, dwarf to medium tall plants resistant to leaf diseases and head moulds (Table 6). The selection intensity is fairly high, ranging from 0.7 to 5%.

BREEDING FOR SHOOTFLY RESISTANCE

It is well established that the Indian tropical winter varieties furnish the source of shootfly resistance in the whole world germ plasm collection but they are in no way immune to fly attack when the preferred host is removed. Sources of resistance are documented by Singh *et al.* (1968), Young (1972) and Rao *et al.* (1978). Since these varieties are poor in productivity due to a physiologically inefficient plant type, the initial breeding programme should aim to transfer their resistance to an improved agronomical background. The Indian resistant lines do not differ in gene frequencies and, therefore, the building up of an absolute resistance through R × R crosses is not feasible.

Based on the findings that host immunity is absent and inheritance of shootfly resistance is quantitative (polygenic) in nature governed by additive genes, the resistance can gradually be built up by conventional

Table 6. No. of plants selected from survivals on the basis of plant type, grain yield and disease resistance

Type	F2	Grain yield (g/plant) 41–60	61–80	81–100	Total plants	Selection intensity (%)
I × I	SPV-97 × SPV103 dw	1	5	10	16	5.0
I × S	E302 × CS3541	0	2	0	2	0.7
I × S	SPV-97 × CS3541	1	3	6	10	3.3
I × S	SPV-103 dw × CS3541	2	5	3	10	3.3

None of the plants were suitable for selection from the R × R, R × I and R × S crosses.

Table 7. Shootfly reaction of some promising derivatives of temperature × tropical crosses*

	Entry	'Dead-heart' percentage Timely planting	Delayed planting	Average	Difference
Variety	SPV-97	28.9	54.1	41.5	25.2
	SPV-99	26.5	51.2	38.8	24.7
	SPV-101	30.2	50.0	40.0	19.8
	SPV-104	28.4	44.7	36.6	16.3
	SPV-105	31.6	42.7	37.2	11.1
	SPV-108	28.2	49.9	39.1	21.7
	SPV-115	24.5	49.1	36.8	24.6
	SPV-175	29.6	42.6	36.1	13.0
	SPV-192	31.3	51.9	41.3	20.6
	SPV-220	29.1	47.1	38.1	18.0
	SPV-233	27.4	44.8	36.1	17.4
	SPV-258	30.0	52.7	41.3	22.7
Hybrid	CSH-1	41.4	75.0	58.2	33.6
	CSH-5	48.9	72.8	60.9	23.9
	CSH-6	38.7	53.0	45.8	14.3
	CSH-9	43.2	55.1	49.1	11.9
Resistant check	E303	24.1	37.3	30.7	13.2
	IS1054	23.9	27.2	25.5	3.3
	μ	35.6	56.5	46.1	20.9
	S.E. ±	1.1	1.5	1.3	0.91

*Fifty entries tested over seven locations.

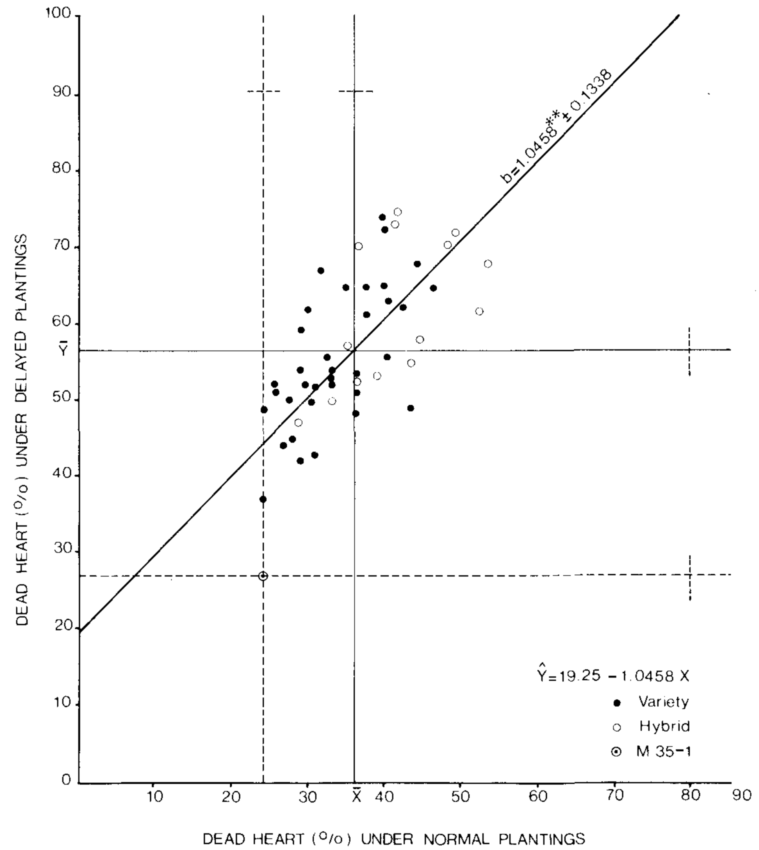

Fig. 1.

breeding methods through accumulation of desirable alleles. The selection of 1 SD below the population mean for the 'dead-heart' percentage in segregating generations may alleviate the level of resistance in resulting progenies. This procedure enables one to identify potential crosses in F2 and differentiate between susceptible and relatively resistant progenies in F3 under a reasonable level of shootfly infestation. While the resistant progenies get established by F3, subsequent within-progeny selection could result in further improvement and stabilization of resistance as has been achieved in some of the advanced-generation progenies (Fig. 1 and Table 7). Thirteen promising varieties show a mortality of less than the population mean under normal (35.6%) and delayed plantings (56.5%). Hybrids are relatively more susceptible than varieties although the average mortality under normal planting data over various locations is positively related ($r = 0.75$) to the 'dead-heart' percentage under delayed plantings. Multilocation testing is desirable to choose varieties stable in resistance.

Estimates of heritability and additive gene action may vary according to the initial frequencies of resistant genes in parental material, the selection intensity, the generation and the level of shootfly infestation. The heritability of the I × R and I × I F3 crosses is estimated to be 25% (RANA *et al.*, 1975). In F3, selection of 1 SD below the population mean operates with 10% intensity and helps to pick up progenies of below 20% mortality. Since a further increase in the selection pressure from 10 to 5% does not change the expected F4 mean substantially, it is useful to operate at the moderate level and allow the elimination of progenies at the score of other agronomical characters.

The choice of multiple characters usually results from a 0–5% selection intensity (Table 6) and picking up relatively less resistant progenies rather than the most resistant ones. Several derivatives of temperate × tropical crosses, therefore, could combine only moderate shootfly resistance with high yield and multiple disease resistance. CSV-5, CSV-6, CSV-7R, CSV-8R and CSH-7R among them have been released for general cultivation. These moderately resistant varieties furnished the new set of parental material to continue the next cycle of resistant breeding programmes resulting in a new set of promising varieties (Table 7).

The resistance is almost intermediate between two parents with a slight heterotic advantage under low to moderate shootfly infestation. Both male sterile and restorer parents of a commercial hybrid should, therefore, be reasonably resistant to shootfly.

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Induced Mutations in Sorghum Improvement*

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Recent advances in sorghum improvement are mainly due to spontaneous mutations followed by selection and hybridization. Induced mutations received relatively limited attention. A critical review of different aspects of mutagen sensitivity, considering the importance of such factors as genotypic constitution of the material, pre- and post-treatment modifications, type of mutagen and dose, techniques of handling the material and treatment procedures to maximize the induction of mutations together with the scope of induced mutations in sorghum improvement constitute the subject matter of this paper.

Hydrazine was found to be a more effective and efficient mutagen for inducing chlorophyll and viable mutations in sorghum than ethyl methanesulphonate, methyl methanesulphonate or γ-rays. Ethyl methanesulphonate among the alkylating agents and nitroso methyl urea was among nitroso compounds were the most potent mutagens. The efficient radiation dose was within the 20-35 kr range, whereas 0.015M was the effective dosage for hydrazine and ethylmethane sulphonate. The combination treatments of various physical and chemical mutagens failed to yield significant increase in the recovery of mutations, while cysteine post-treatments of γ-irradiated and hydrazine-treated material reduced seedling injury, seed sterility and increased the recovery of viable mutations compared to single treatments. There is scope for induced mutations in solving some of the current problems of sorghum improvement such as, increasing the recombination potential of tropical × temperate crosses, improving the nutritional quality of grain and forage sorghums, diversification of male sterile cytoplasmic sources, better understanding of mechanism of apomixis and augmenting the levels of resistance to sorghum insects, pests and diseases.

Key Words: Sorghum mutations, Gamma rays, Mutation, Breeding, Sorghum improvement, Hydrazine, Cysteine, Post-treatments

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Introduction

Cultivated sorghums originated about 5000–7000 years ago or earlier in North East Africa, probably in Ethiopia or Sudan. After domestication these moved to other parts of Africa, India, China and Europe. Sorghum were introduced into the Western hemisphere during the 17th and 18th centuries.

Recessive mutations at the height and maturity loci of cultivated sorghums, which took place in the tropics, resulted in the evolution of dwarf, early and photo-insensitive forms. Intensive selection and isolation of such forms, however, took place in the USA. Superimposed on the dwarf and early stature were the recessive male sterility genes (msc_1 and msc_2) which, interacting with *milo* cytoplasm resulted in cytoplasmic-genetic male sterility that laid the foundation for the development of commercial hybrid sorghums, a source of major yield advance.

Thus, while spontaneous mutations in cultivated sorghum furnished the basis for the recent advances in sorghum improvement, the work on induced mutations has not been generally rewarding. This paper presents a comprehensive review of the work on induced mutations in sorghum, identifies some of the current problems in sorghum improvement and discusses the possible role of induced mutations in providing solutions.

Mutational Studies in Sorghum—Present Status

As early as 1934, Ayyangar and Rao treated pollen grains of sorghum with X-rays. By 1942, Quinby and Karper reported several deleterious mutations from seeds exposed to X-rays and inferred that improvement of sorghum through induced favourable mutations may not be promising. Since then, there have been several studies on induced mutations in sorghum, but not with measurable success.

Several investigators have employed various physical agents such as X-rays, γ-rays, thermal neutrons and chemical mutagens such as methyl methanesulphonate (MMS), ethyl methanesulphonate (EMS), diethyl sulphate (DES), 1:2, 3:4 diepoxybutane (DEB), ethyleneimine (EI), 1-4 bisdiazo-acetylbutane (BDB), 1-methyl-3-nitrosoguanidine (NG), N-methyl-N-nitrosourea (NEU), hydrazine (HZ) and colchicine in their attempts to induce mutations in sorghum. Also various combinations of these physical and chemical mutagens and pre- and post-treatments with cysteine (CS) of γ-irradiated and hydrazine-treated material have been used to increase the mutation frequency and to attain an altered mutation spectrum in sorghum.

Mutagenic effects in M_1 generation

(a) *Plant injury and sterility:* Para-sorghum species were found to be more sensitive to γ-rays and X-rays than Eu-sorghum species. For Eu-sorghum species LD_{50} based on seed germination in the laboratory was 63.68 Kr for X-rays and 65.16 for γ-rays, while for Para-sorghum species the corresponding values were 16 Kr and 26.06 Kr respectively (Nirula 1963). Critical doses of γ-rays based on 50% sterility in M_1 generation were between 20 and 30 Kr for Redalan-60 sorghum variety and between 40 and 50 Kr for *Shallu* (Harris et al. 1965). Reddy (1977) found LD_{50} value of γ-rays in Texas-414, as 63.4 Kr in vitro and 38.6 Kr in vivo (21 days after the treatment). This could be attributed to the fact that many seeds which meet the criteria of germination in the laboratory i.e., extrusion of radical and plumule, may be damaged too severely to sustain growth required from soil emergence.

X-rays showed greater effects on stigmas than on pollen germination (Ayyangar & Rao 1934). Nirula (1963, 1964) found X-rays to be more effective than γ-rays in causing reduction in survival, however the latter were more potent as regards seedling growth reduction, on the other hand, Sree Ramulu (1970a) reported X-rays as less effective in causing reduction not only in survival and seedling growth, but also in fertility compared to γ-ray treatments in *Sorghum durra* and *S. subglabrescens*. The relative biological efficiency of different radiations varies according to linear energy transfer of radiations.

MMS caused higher toxic effects on seed germination, survival and seedling growth than EMS, DES and NEU (Sharma 1965, Sree Ramulu 1970a, Reddy 1977). This agrees with the view that among alkylating agents, methyl groups are relatively more toxic than other chemicals, since they rapidly methylate the phosphate and purine bases and cause deploymerisation of DNA. Hydrazine showed low toxic effects (based on low seedling injury and sterility in M_1 generation) than EMS (table 1). Sree Ramulu (1971c) found DEB as more effective in reducing the percentage seed germination, survival, growth of root, coleoptile and seedlings than NMU and NG.

The combination treatments of γ-rays, EMS, MMS and DES caused less than additive effects in the reduction of survival or seedling growth or seed fertility (Sree Ramulu 1973). Reddy (1977) found that combined treatments of γ-rays, HZ and EMS reduced seed germination more than additively, while less than additive effects were observed in reducing the length of primary root, coleoptile and seedling height in M_1 generation. Fertility reduction and survival was more than additive in combination treatments of HZ and EMS, and less than additive in all combination treatments of γ-ray and hydrazine (table 1).

Cysteine by itself had no toxic effects on either seed germination or seedling injury (table 2). Post-treatments with cysteine reduced seedling injury and sterility caused by γ-irradiation of sorghum seeds (Reddy & Smith 1978a, 1978b). In HZ-treated sorghum, post-treatment with cysteine reduced seedling injury, while both pre- and post-treatments reduced seed sterility in M_1 generation (table 3). The most probable mode of action of cysteine on HZ-treated material of sorghum seed could be attributed to the scavenging of excess of mutagen when given as pre- or post-treatment. Cysteine reacts with the excess of mutagens resulting in different reaction byproducts, which by themselves are generally devoid of any biological activity (Reddy & Smith 1979). Also cystine post-treatments may reduce the effects of diplontic selection by scavenging out free radicles produced by γ-rays and HZ, which cause cellular death, thus reducing the seedling injury and sterility in HZ and γ-ray treatments.

(b) *Cytological effects:* X-rays and thermal neutrons were reported to induce chromosome breaks in root tip cells and bridges and fragments in PMC's of *S. bicolor* (Kaukis & Webster 1956). Treatments of Eu- and Para-sorghum species with thermal neutrons induced one quadrivalent per PMC.

Table 1 *Mutagenic effectiveness and effieciency of Hydrazine (HZ), Ethyl methanesulphonate (EMS) γ-rays and their combinations in grain sorghum*

Mutagenic Treatments	Injury (I) %	Sterility (S) %	No. of M_1 Panicles analysed	No. of M_2 seedlings analysed	Mutation events: 100 M_1 Panicles Msp	Mutation events: 100 M_2 Seedlings Msd	Mutagenic effectiveness Msp/tC(Kr)	Mutagenic efficiency Msp/I	Mutagenic efficiency Msp/S
Borate buffer	—	—	114	5,700	—	—	—	—	—
0.005M HZ	21.59	7.83	159	7,950	20.13	1.37	1.68	0.93	2.57
0.010M HZ	32.57	8.02	93	4,650	25.81	1.91	1.07	0.79	3.22
0.015M HZ	39.01	9.33	75	3,750	37.33	3.44	1.04	0.96	4.00
0.020M HZ	51.51	15.99	87	4,350	33.33	3.50	0.69	0.65	2.08
0.030M HZ	58.71	22.15	19	950	26.31	2.21	0.36	0.45	1.19
Water (Control)	—	—	449	22,450	—	—	—	—	—
0.005M EMS	17.64	14.45	52	2,600	15.38	1.73	1.28	0.87	1.06
0.010M EMS	29.94	20.37	131	6,500	18.32	2.15	0.76	0.61	0.90
0.015M EMS	44.92	32.11	83	4,150	24.10	2.77	0.67	0.54	0.75
0.020M EMS	49.73	51.03	25	1,250	20.00	2.24	0.42	0.40	0.40
0.030M EMS*	67.91	—	0	0	—	—	—	—	—
0.005M HZ+0.005 M EMS	3.79	88.26	62	3,100	20.97	1.45	0.87	5.53	0.24
0.005M EMS+0.005 M HZ	20.83	78.85	90	4,500	23.33	1.80	0.97	1.12	0.30
0.010M HZ+0.010 M EMS	34.09	93.33	4	200	25.00	2.50	0.52	0.73	0.27
0.010M EMS+0.010 M HZ	50.00	94.17	14	700	28.57	2.86	0.60	0.57	0.30
20 Kr TX—414	30.97	31.24	428	21,400	18.46	0.97	0.92	0.60	0.59
35 Kr	38.36	59.81	258	12,900	22.87	1.43	0-65	0.60	0.38
50 Kr	56.82	79.64	117	5,850	25.64	2.03	0.51	0.45	0.32
20 Kr+0.005 M HZ	28.79	23.40	122	6,100	20.49	1.14	0.08	0.71	0.88
20 Kr+0.010 M HZ	51.89	27.73	127	6,350	23.62	1.38	0 05	0.45	0.85
35 Kr+0.005 M HZ	47.35	48.54	54	2,700	23.63	1.85	0.06	0.60	0.49
35 Kr+0.010 M HZ	62.00	57.54	35	1,750	25.71	2.51	0.03	0.41	0.45
20 Kr NM—31	51.00	44.95	253	12,650	22.53	1.68	1.13	0.44	0.50
35 Kr	60.60	67.39	184	9,200	25.00	2.30	0.71	0.41	0.37
50 Kr	70.53	87.10	55	2,750	29.09	2.98	0.58	0.41	0.33

*None of the treated plants survived in the field until maturity at this concentration

I = % Seedling height reduction (% of control)

S = % Reduction in seed set (% of control)

TC = The product of treatment time × initial concentration of the mutagen

Kr = γ-radiation dose in kilorads

Table 2 *Effects of cysteine (CS) on seed germination and seedling growth in the M_1 generation of sorghum*

Treatments	Seed germination %	Length of primary root (cms) Mean ± S.E.	Length of coleoptile (cms) Mean ± S.E.	Seedling height (cms) Mean ± S.E.
Phosphate buffer (control)	100	3.14±0.09 a*	2.13±0.08 a	3.06±0.17 a
0.005 M CS	101	3.23±0.09 a	2.04±0.05 ab	3.41±0.06 a
0.010 M CS	100	3.23±0.07 a	1.91±0.07 b	3.32±0.09 a

* Means followed by the same letter are not significantly different by Duncan's Multiple Range test at the 5% level of probability

Trivalents, univalents, B-chromosomes and binucleate microsporocytes were observed in Para-sorghum species and tripolar spindles in Eu-sorghum species (Nirula 1963, 1964). In γ- and X-irradiated material of *S. durra* and *S. subglabrescens* a higher frequency of translocations and univalents was observed than in treatments with EMS and DES.

X-rays also induced a higher frequency of laggards, bridges, tripolar spindles than chemical mutagens (Sree Ramulu 1971a). Spraying of atrazine induced chromosome abnormalities in Redlan, K–33 and Martin (Liang & Liang 1972). Reddy and Bhaskar Rao (1975) isolated γ-ray induced interchange heterozygotes in sorghum varieties, IS 3941 and IS 2566. They found that translocation breakpoints were fairly well spread out in several of the chromosomes both in heterochromatin and euchromatic regions. Among the reverted diploids of the irradiated tetraploid sorghum variety, IS 3949, Bhaskar Rao and Reddy (1975b) found chimeral plants in which some spikelets showed normal meiotic behaviour while others showed rings or chains of four chromosomes at diakinesis and reduction in the chiasma frequencies.

Mutagenic effects in M_2 generation

(a) *Chlorophyll mutations:* In sorghum, chlorophyll-deficient mutants have been observed spontaneously and their spectrum was similar to that found in barley and maize (Karper & Conner 1931). Most of the chlorophyll mutants are recessives and may be lethal. These mutants are often used for the assessment of mutagenic efficiency of various agents. Chlorophyll mutants such as *albino*, *pinkish-albino viridis*, *xantha*, *Chlorina*, *albo-viridis*, *albo-xantha*, and *zebra* or *striata* types have been observed in M_2 following various mutagenic treatments (Goud et al. 1970, Harris et al. 1965, Kaukis & Reitz 1955, Nirula 1963, 1964, Reddy & Smith 1976, Reddy 1977, Sharma 1965, Sree Ramulu 1970a, 1970e). Kaukis and Reitz (1955) found a higher frequency of *albino* mutants with thermal neutrons than with X-rays. However, Haensel (1960) and Ross et al. (1961) did not obtain any chlorophyll mutants in sorghum variety Experimental-3 by EI and γ-radiation treatments. Varietal differences in the induction of chlorophyll mutations have been observed with γ-rays (Goud et al. 1970, Harris et al. 1965, Reddy & Smith 1975, Reddy 1977, Sree Ramulu 1970e). A wider spectrum of

Table 3 *Mutagenic effectiveness and efficiency of hydrazine (HZ) following cysteine (CS) pre- and post-treatments in grain sorghum*

Mutagenic treatments	Injury (I) %	Sterility (S) %	No. of M_1 panicles analysed	No. of M_2 seedlings analysed	Mutation events/ 100 M_1 panicles Msp	Mutation events/ 100 M_2 seedlings Msd	Mutagenic effectiveness Msp/tC	Mutagenic efficiency Msp/I	Mutagenic efficiency Msp/S
0.01M CS	—	—	171	8,550	—	—	—	—	—
0.01M HZ	32.57	8.02	93	4,650	25.81	1.91	1.07	0.79	3.22
0.01M HZ+0.01 M CS	7.21	4.41	125	6,250	22.40	1.95	0.93	3.20	5.08
0.01M CS+0.01 M HZ	39.67	6.17	211	10,550	28.40	2.08	1.18	0.70	4.61
0.02M HZ	51.51	15.99	87	4,350	33.33	3.50	0.69	0.65	2.08
0.02M HZ+0.01 M CS	36.07	8.41	222	11,100	24.77	2.16	0.69	0.69	2.94
0.01M HZ+0.02 M HZ	57.38	13.08	178	8,900	28.09	2.54	0.49	0.49	2.14
0.03M HZ	58.71	22.15	19	950	26.31	2.21	0.36	0.45	1.19
0.03M HZ+0.01 M CS	59.67	9.75	123	6,150	30.89	2.02	0.52	0.52	3.16
0.01M CS+0.03 M HZ	70.16	10.08	31	1,550	32.26	2.58	0.46	0.46	3.20

I = % Seedling height reduction (% of control)
S = % Reduction in seed set (% of control)
tC = The product of treatment time × initial concentration of the mutagen

chlorophyll mutations was observed in M 35–1 than in GM–2–3–1 with γ-radiation (Goud et al. 1970). Reddy (1977) found a wider spectrum of chlorophyll mutants and a higher frequency of *albino* mutants in NM–31 than in TX–414 with γ-rays.

EMS was found to be the most potent mutagen and induced the highest frequency of chlorophyll mutations followed by DES, γ-rays, MMS and NEU on M_2 plant basis when comparisons were made at LD_{25} for survival. The low potency of MMS and NEU was due to their higher toxicity (Sree Ramulu 1970a). NMU was more efficient in inducing a higher and broader spectrum of chlorophyll mutations than NG in *S. subglabrescens* (Sree Ramulu 1972).

We have observed hydrazine to be more efficient in inducing higher frequency and broader spectrum of chlorophyll mutations than γ-rays and EMS (table 1). *Albo-viridis* and *striata* types were observed only in HZ treatments, whereas *albino viridis*, *xantha* and *chlorina* types were induced by both chemicals and γ-rays (table 4.) various studies show that the *viridis* type occurs more frequently in all the mutagen treatments. The relative frequency of *albino* mutants was highest in EMS followed by HZ and γ-rays in that order, while *xantha* and *chlorina* types were more frequent in HZ than in EMS or γ-treatments (table 4).

In the combination treatments of γ+HZ, HZ+EMS or EMS+HZ, the chlorophyll mutation frequencies were less than additive (table 1). Similarly γ+MMS and γ+DES produced less than additive mutation frequencies but γ+EMS treatments induced an additive mutation frequency (Sree Ramulu 1973). Recurrent treatments with NMU induced a higher frequency and wider spectrum of chlorophyll mutations than single treatments (Sree Ramulu 1971c).

No chlorophyll mutations were observed in treatments with cysteine alone (Reddy & Smith 1978b). Broader spectrum of chlorophyll mutations was observed in CS pre- and post-treatments of HZ-treated and γ-irradiated material (table 4). *Striata* and *albo-viridis* mutants were observed in CS post-treatments of γ-irradiated material while they were not observed in γ-ray treatments alone. *Albo-xantha* was observed only in CS pre- and post-treatments of HZ-treated material. The relative proportions of *albino*, *xantha* and *chlorina* were increased in CS post-treatments of γ-irradiated material and that of *viridis* type decreased compared to γ-ray treatments alone.

(b) *Morphological mutations:* Viable mutations reported so far include those affecting plant height, maturity, panicle type, midrib colour, presence of awn, grain colour, grain size, grain type, spikelet type and tillering (Chanchal Kapoor 1967, Goud et al. 1970, Gurusiddaradhya & Goud 1977, Harris et al. 1965, Nirula 1964, Quinby & Karper 1942, Rao et al. 1969, Reddy & Smith 1976, Reddy 1977, Sree Ramulu 1975). The mutants tolerant or resistant to shootfly attack, drought-tolerant types (Goud et al. 1970, Usman & Goud 1972) and also mutants with high lysine and protein content (Mohan 1973) have been isolated in sorghum following various mutagenic treatments.

A higher frequency and broader spectrum of morphological mutants was recovered from HZ (2.14%) than EMS (0.81%) and γ (0.42%) treatments. The total viable mutation frequency was more than additive in γ+HZ (3.22%) while it was less than additive in sequential treatments of EMS+HZ (0.09%)

Table 4 *Relative proportions of different types of chlorophyll mutations recovered in M_2 generation of sorghum following various mutagenic treatments*

Mutagen treatment	Total no. of M_2 seedlings analysed	Total chlorophyll mutations %	Frequency of chlorophyll mutations (%)						
			albino	*viridis*	*xantha*	*chlorina*	*striata*	*albo-viridis*	*albo-xantha*
HZ	22,650	28.60*	10.33 (93)**	48.23 (232)	14.14 (63)	13.72 (63)	1.45 (7)	3.12 (15)	—
EMS	14,550	19.45	35.67 (117)	45.73 (180)	12.19 (40)	6.40 (21)	—	—	—
Gama rays	40,150	22.32	8.94 (44)	76.00 (377)	9.35 (46)	5.08 (25)	—	—	—
Gama + HZ	24,400	24.82	17.42 (73)	57.76 (242)	15.03 (63)	8.11 (34)	—	1.67 (7)	—
EMS + HZ	5,200	25.95	29.00 (29)	39.00 (33)	24.00 (24)	9.00 (9)	—	—	—
HZ + EMS	3,300	22.99	24.00 (12)	48.00 (24)	18.00 (9)	10.00 (5)	—	—	—
HZ + CS	23,500	26.02	15.29 (74)	59.30 (287)	25.50 (75)	5.16 (25)	—	—	4.75 (23)
CS + HZ	21,000	29.59	16.50 (79)	62.63 (300)	14.40 (69)	—	1.46 (7)	2.09 (10)	4.39 (21)
γ + CS	19,700	28.16	23.10 (76)	39.51 (130)	17.32 (57)	12.46 (41)	1.52 (5)	6.08 (20)	—

** Parenthetic numbers identify the number of independent mutations of each class which were recovered

* Chlorophyll mutations based on % M_1 segregating panicles. Mean percentage of Mutations of all treatments is given

and no mutation was observed in HZ+EMS treatments (table 5). With CS post-treatments of γ-irradiated material a higher frequency and broader spectrum of viable mutants (6.75%) were recovered compared to that of γ-rays alone (table 5). Similar observations were made with CS Pre- (7.4%) and post-treatments (3.12%) of HZ-treated material compared to HZ alone (Reddy & Smith 1976, Reddy 1977). Sree Ramulu (1970e) compared the potency of different mutagens for inducing viable mutations at LD_{25} for survival and found NEU to be the most potent, followed by EMS, MMS, DES, X-rays and γ-rays in that order.

In TX-414 a higher frequency and broader spectrum of viable mutants were recovered (0.42%) than in NM-31 (0.08%) with γ-ray treatments (Reddy 1977). Similarly Rao et al. (1969) observed that among a number of tall indigenous varieties with partly exposed internodes, only Ujjain-6 yielded mutants of brachytic dwarfs with varying maturities, while a number of medium tall Indian varieties with nodes enclosed by leaf sheaths yielded dwarf and early maturing mutants when treated with radiations and chemicals. Goud et al. (1970) found M 35–1 to be highly mutable than GM 2–3–1 both with regard to frequency as well as spectrum of viable mutations.

Reddy (1977) obtained a number of mutants simulating the characters of other species particularly those affecting the grain, spikelet and panicle types (table 5) The system proposed by Harlan and de Wet (1972) was used in classifying the spikelet type mutants. TX-414 possesses *durra* type spikelets while *caudatum*, *kafir*, *guinea* and wild types were isolated following various mutagenic treatments. Induced systematic mutants have been reported in rice (Siddiq & Swaminathan 1969) and sorghum (Chanchal Kapoor 1967, Sree Ramulu 1975, Reddy 1977). The recovery of high frequency of systematic mutants in the present study reflects the evolutionary process which has taken place in sorghum. According to Doggett (1964, 1965) cultivated sorghums seems to have developed from a single wild species through disruptive selection. The occurrence of high frequency of mutants resembling races of *S. bicolor* ssp. *bicolor*, other than that used in the present study suggest that racial differentiation proceeded through a series of independent mutations affecting grain and spikelet characteristics, either independently or stepwise in evolution of cultivated varieties of sorghum from wild to cultivated, brought together under the influence of disruptive selection.

(c) *Relationship between chlorophyll and viable mutations:* No relationship was observed between chlorophyll-deficient and morphological mutations in the present study. Though a higher frequency of chlolorophyll mutations could be recovered from all treatments, only certain agents induced a higher frequency of viable mutations (tables 4 & 5). A higher frequency of chlorophyll and low frequency of viable mutations were observed in NM–31, whereas reverse was the case in TX–414 (Reddy 1977). Similarly, Sree Ramulu (1970a) working with the cultivated varieties, C_0–11, C_0–12 and C_0–18 found that the frequency of chlorophyll mutations was highest in C_0–18, while C_0–11 showed the widest spectrum. The occurrence of chlorophyll and viable mutations are thus different events and are independent of each other (Gaul 1964).

Table 5 *Frequencies (number) of induced morphological mutations recovered in the M_2 generation of sorghum following various mutagenic treatments*

Mutagen treatments	Frequency of viable mutations (%)									Total viable mutations %	Ratio of viable/ chlorophyll mutations
	Grain mutations				Glume type	Panicle type	Awned	Tall	White Midrib		
	Color	Shape	Type	Size							
HZ	1.07 (12)*	0.67 (7)	—	0.45 (5)	—	—	—	—	—	2.14	0.07
EMS	0.36 (4)	—	—	0.27 (3)	0.18 (2)	—	—	—	—	0.81	0.04
γ rays	0.13 (8)	0.14 (8)	0.02 (1)	0.05 (3)	0.02 (1)	0.02 (1)	0.02 (1)	0.02 (1)	—	0.42	0.02
γ + HZ	0.88 (12)	0.74 (11)	0.45 (6)	0.15 (3)	0.60 (9)	0.15 (3)	0.10 (2)	0.05 (1)	0.10 (2)	3.22	0.13
EMS + HZ	0.09 (1)	—	—	—	—	—	—	—	—	0.09	0.13
HR + EMS	—	—	—	—	—	—	—	—	—	—	—
HZ + CS	1.03 (7)	0.30 (2)	0.15 (1)	0.15 (1)	0.59 (4)	0.30 (2)	0.30 (2)	0.15 (1)	0.15 (1)	3.12	0.12
CS + HZ	2.06 (14)	1.48 (10)	1.04 (7)	0.44 (3)	0.74 (5)	0.60 (4)	1.04 (7)	—	—	7.40	0.25
γ + HZ	2.25 (43)	1.45 (29)	1.40 (28)	0.25 (5)	0.60 (12)	0.35 (7)	0.30 (6)	0.10 (2)	0.05 (1)	6.75	0.24

* Parenthetic numbers identify the number of independent mutations of each class which were recovered

Factors affecting Recovery of Induced Mutations

Induction of mutations at the gene level and their subsequent recovery are two independent processes. The probability that an induced mutation will survive and give rise to a mutant at the level of organism is controlled by many factors, the important ones are listed below :

(*a*) *Genotypic constitution :* Differential genotypic response of sorghum varieties was reported following treatments with radiations and chemical mutagens (Goud et al. 1970, Harris et al. 1965, Nirula 1963, 1964, Reddy 1977, Sree Ramulu 1975). Para-sorghum species (2n=10) were more sensitive to radiations and chemicals than Eu-sorghum ones (2n=20) with respect to M_1 parameters (greater reduction in survival, seedling growth and seed fertility), but yielded low frequency of chlorophyll or morphological mutations (Nirula 1964, Sree Ramulu 1975). Para-sorghum species have relatively longer chromosomes than the Eu-sorghum ones. The plants with longer chromosomes and low diploid number are reported as more sensitive to mutagen treatments than those with higher number of smaller chromosomes (Sparrow et al. 1963). Cytogenetical investigations have pointed out that Para-sorghum section is distinctly different from Eu-sorghum with regard to speciation (Magoon et al. 1964).

Several studies indicate that differences in the quantity of the genetic material, nuclear volume, interphase chromosome volume, heterochromatin content, undefined differences in the constitution of genes or gene system and cytoplasm as well as several other factors may be responsible for inter-varietal differences to radiation sensitivity (Evans & Sparrow 1960, Sparrow & Chrinstensen 1953). The genome make-up and/or genetic constitution of the species is more important in realising the gene mutations following mutagenic treatment.

(*b*) *Type of mutagen and dose:* Effectiveness of a mutagen usually means the number of mutational events per unit of mutagen dose and the efficiency refers to the mutational rate in relation to the undesirable effects such as seedling injury and sterility.

Mutagenic effectiveness and efficiency of γ-rays decreased with increasing concentrations. (table 1). These were higher in NM-31 than in TX-414. Among the various treatments tried by us, the 20 Kr treatment was the most efficient as measured by mutation frequencies adjusted for seedling injury and seed fertility.

Mutation frequencies reached peak at 0.015M concentration and then on decreased with increasing concentrations of HZ and EMS (table 1). This phenomenon of saturation effect was also reported in comparisons of chlorophyll, viable, and total chlorophyll mutation frequencies of EMS, MMS, DES, NEU, γ-rays and X-rays (Sree Ramulu 1970e). Gradual inactivation of the repair system with increasing doses of mutagens thereby inducing high lethality and sterility could be responsible for this decreased tendency after the peak mutation rate was reached. Saturation effect was also attributed to the rigor of diplontic and haplontic selections in the biological material (Swaminathan 1961). The injurious effects at increasing concentrations increase at faster rates than gene mutations (Konzak et al. 1965).

Hydrazine was found to be more effective and efficient mutagen in inducing chlorophyll and morphological mutations in sorghum than EMS and γ-rays (Reddy 1977). HZ was also reported to be an efficient mutagen in rice (Reddy 1972, Reddy et al. 1973, 1974) and tomato (Jain et al. 1968). The differential action of HZ and EMS on DNA molecule may be responsible for the production of higher frequency and broader spectrum of Chlorophyll and morphological mutations with HZ than EMS. Toxic effects of HZ are due to peroxides and free radicles while the mutagenic action is due to its direct action on DNA, specifically with thymine or uracil (Freese 1963). The inhibitory effect of EMS on seedling growth depression has been attributed to its hydrolytic products namely, ethyl sulphuric acid and ethyl alcohol (Konzak et al. 1965), while the mutagenic action is due to its direct action on DNA molecule, specifically by the addition of an alkyl group to the purine, guanine (Freese 1963). It also acts indirectly by making sugar phosphate backbone sensitive to breakage which can lead to further genetic damage.

(c) Combination treatments: Mutation yield and efficiency of mutagenic treatments can be considerably increased by manipulating the secondary factors such as methods of pre- and post-treatments or by combining various mutagenic treatments. In sorghum, combination treatments of γ-rays, EMS, DES, MMS and HZ, in general, produced lower efficiency values as compared to the sum of these produced by mutagens individually (Reddy 1977, Sree Ramulu 1975). A synergistic effect was observed in the recovery of viable mutations with γ-rays+HZ treatments (table 5).

The synergistic effects would be produced following post-irradiation chemical mutagen treatment, when the chemical mutagen besides inducing potential lesions, may also render the repair enzymes non-functional (Roberts & Warwick 1957) thereby promoting the fixation of already induced pre-mutational changes or when the access of alkylating agents to vulnerable sites in DNA may be increased by denaturation of DNA at sites of reaction due to pre-irradiation.

The higher dose, interaction of mutagens in increasing the toxicity, inhibition of uptake of the mutagens, sequence of treatments as well as number of other factors are presumed to be responsible causes for less than additive effects observed in combination treatments in the present study. Also it is quite probable that high seed sterility and low survival of plants in combination treatments masked the recovery of mutations. The results suggest that it is the recovery of mutations rather than their induction that determines whether less than additive or additive or synergistic effects will be obtained from the combination treatments.

(d) Pre- and post-treatments with cysteine: An increase in the mutagenic effectiveness and efficiency based on seedling injury was resulted from CS post-treatments of γ-irradiated material (Reddy & Smith 1978b) compared to γ-rays alone. The mutagenic effectiveness was increased with CS post-treatments of HZ-treated material compared to HZ alone. Similarly, the mutagenic efficiency based on sterility (Msp/S) also increased with CS pre- and post-treatments of HZ-treated material compared to HZ alone (table 3).

The increased recovery of chlorophyll and viable mutations in CS pre- and post-treatments of HZ-treated and γ-irradiated material can be explained as follows. Two types of selections are known to intervene before a mutation induced in a seed is expressed in the M_2 generation. The first is the diplontic selection occurring in M_1 somatic tissues and the second is haplontic selection operating at gametic level (Swaminathan 1969). Only a mutation which passes through both somatic and gametic sieves will find phenotypic expression in the M_2 and subsequent generations. In γ-irradiated and HZ-treated populations, though a large number of mutations may be induced, relatively few pass through diplontic selection sieve because of intracellular death caused by free radicles. Thus, relatively few chlorophyll and viable mutations were recovered in the M_2 generation following γ-irradiation and HZ treatments. CS post-treatments reduce the effects of diplontic selection by scavenging free radicles which cause cellular death, as observed by reductions in the seedling injury and sterility. This would increase the probability of induced mutations to be transmitted and identified in the subsequent generations. If this presumed effect upon diplontic selection is correct, it suggests that the mutagenic efficiency of ionizing radiation and chemical mutagens can be greatly enhanced by post-treatment with radio-protective agents like cysteine.

Colchicine-induced Mutations

Polyploids have been induced in grain sorghum by colchicine treatments (Chin 1946, Murty et al. 1978, Schertz 1969). In general autotetraploid grain sorghums are characterised by slow growth, dark green foliage with wavy margins, short but stouter straw, larger grains, greater protein content and higher degrees of sterility. Another cytological feature of autotetraploid sorghum is the lower frequency of univalents and trivalents (Murty & Rao 1973). Low seed set in auto-tetraploids makes them of limited use in sorghum breeding. However, Doggett (1964) has shown that there is a scope for fertility improvement through crossing autotetraploids of different genotypes and also by repeated back crossing to *Sorghum almum* to incorporate its high seed setting. Differences in fertility between autotetraploids have been ascribed to variation in chromosome behaviour at meiosis and to genetic differences (Morrison & Rajathy 1960a). Rao and Murty (1972) have suggested that tetraploid sorghum from apomictic sorghum strains, may give better seed sets than sexual ones, since meiosis is circumvented in apomicts.

Murty et al. (1978) induced autotetraploids in apomictic grain sorghum R 473 by treating with colchicine, which had higher seed fertility than earlier reported ones (Chin 1946, Schertz 1962) with low percentage of univalents and quadrivalents. Absence of meiosis in the formation and development of embryo sac from diploid cells of nuclear origin, autonomous development of the endosperm and the diploid nature of the young endosperm accounts for high seed set (Murty et al. 1978). Also they explained that the genetically controlled regular segregation at A 1 and the increased chaisma frequency of the tetraploid may also be responsible for the regular disjunction of the chromosomes resulting in higher seed set.

In addition to polyploidizing effect following colchicine treatment, Franzke and Ross (1952) and Ross et al. (1954) found diploid mutants in *Sorghum bi-color*, variety Experimental-3, which bred true for many changed characters (height, stem diameter, leaf width, seed size and yield). They explained that colchicine treatment caused the formation of haploid chromosome complement by somatic reduction followed by doubling to restore the original diploid number. Simaental and Ross (1963) have taken the formation of 10 bivalents in F_1 between the haploid and diploid mutants, as well as the presence of unlinked mutated genes, as evidence that entire chromosome complement resulted from the reduction process. Sanders and Franzke (1962) and Chen and Ross (1963a) have shown somatic reduction involving all the chromosome pairs by the induction of diploid mutants following treatments of tetraploid seedlings of Experimental-3 with colchicine. Beraho and Olembo (1971) also reported the isolation of two diploid mutants from colchicine treatments—one was tall mutant and other chlorophyll-deficient mutant.

Diploid mutants from colchicine treatment do not occur always. Their production requires infra-red light, an optimum temperature and specific genotypes. Sanders and Franzke (1976) found 20°C as the optimal temperature for colchicine treatment and concluded that conditions favourable for survival of colchicine-treated plants should be used to obtain mutants rather than conditions resulting in most rapid growth.

Future Prospects of Mutation Breeding in Sorghum

Mutation studies of immediate utility are fewer in sorghum than in other major crops (Reddy 1977, Sree Ramulu 1975). They were mostly confined to determining the mutagenic sensitivity, effectiveness and efficiency of mutagens, increasing the efficiency of mutagens by pre- and post-treatment modifications, standardizing the techniques of handling the material and treatment procedures to maximize the induction of mutations. This basic information is, of course, essential for sorghum breeders.

Compared to conventional breeding methods mutation breeding was less widely used, probably because of the enormous amounts of variability already present in the germplasm. Some areas where mutation breeding appears useful in sorghum are: overcoming problems of tight linkage between height, maturity and yield in tropical and temperate crosses; improving nutritional quality through increasing essential amino acids such as lysine or elimination of toxic products; diversification of male sterile cytoplasmic sources; increasing the frequency of apomixis and further augmenting the levels of resistance to insect pests and diseases of sorghum.

(a) Improving recombination potential in tropical and temperate crosses: Yield is a complex polygenic character and can be rarely expected to be improved by mutations in single genes, though a number of mutant cultivars with increased yield have been released in many crops (Sigurb-jornsson & Micke 1974). Tall mutants with high yielding ability have been reported in sorghum (Bhaskar Rao & Reddy 1975, Hadley et al. 1965, Landi 1974). At least four recessive loci (dw_1, dw_2, dw_3, dw_4,) inherited independently affect height (Quinby & Martin 1954). The dw_3 is unstable in the recessive state and reverts spontaneously (4.48%) to dominant condition (Landi 1974). Analysis of 52 true breeding induced mutants in sorghum has revealed that all the four height (*Dw*) genes have mutated and the genes dw_1, dw_2, appear to affect the internode length, dw_3, affects the number of nodes

and dw_4 seem to affect the panicle length (Goud & Vasudev Rao 1977).

Economically useful dwarf and early maturing mutants were reported in sorghum (Goud et al. 1970, Gurusiddaradhya & Goud 1977, Rao et al. 1969). When used as parents in hybridization programme, dwarf mutants contributed to high yield (Gurusiddaradhya & Goud 1977). Indirect improvement of yielding ability, and promotion of distinct traits by means of changes, and making the plants more adapted are the main objectives of utilising induced mutations in sorghum.

Crosses between tropical and temperate sorghums have been receiving considerable attention in recent years, but on account of the tight linkages between height, maturity and yield, the recombination potential has been very low (Rao 1971).

Localised chaisma formation results in decreased or no recombination in large chromosome segments. In such cases, genes are inherited in blocks and cannot be separated by hybridization. In most cereals, atleast crossing-over is restricted to the region distant from the centromere. Thus the available potential for recombination is not fully realised in hybridization programmes. Release of genetic variability and independent assortment of linked loci can be expected if the recombination in F_1 can be enhanced. In eukaryotic cells, radiation treatments are known to enhance crossing-over. Irradiation of F_1 plants especially during pre-meiotic stages, is expected to further enhance the variability in the F_2 population.

Increased variability in F_2 M_2 for quantitative characters was reported in rice (Jalil Miah & Yamaguchi 1968). Similarly radiation as well as chemical mutagens are reported to increase somatic recombination in *Glycine max* (Vig 1973), which can also contribute to increased variability in the F_2. This phenomenon could be explored in sorghum for obtaining desirable recombinants in tropical × temperate crosses.

From mutational studies in tropical sorghums, Rao et al. (1969) felt that a complex or unusual locus may be involved in the transformation of tropical sorghums with exposed internodes to the temperate type with enclosed internodes which is a rare event. Such a change involves the alteration of the entire genotype and the spontaneous height and maturity mutants reported by Quinby and Martin (1954) operate only after this major change has taken place. This hypothesis, however, needs verification.

(*b*) *Protein content and quality:* Protein availability is limited in sorghum due to the presence of tanins in testa layer of the grain. Protein quality is also poor due to its low lysine content. Two high lysine lines of sorghum (IS 11167 and IS 11758) were collected from Ethiopia which have shrivelled grains and high photosensitivity. High lysine and shrivelledness are tightly linked. There is need to break this linkage by incorporating high lysine gene in plump background sorghum to elevate yield level. Mohan (1973) reported the isolation of high lysine mutants of sorghum by screening for opaque kernels following DES treatments. Of the 425 mutants identified, P721 was less shrivelled and promising for protein and lysine. The inheritance of this opaque mutant is controlled by single gene that expresses partial dominance in triploid sorghum endosperm.

(*c*) *Toxic substances*: Young sorghum has pronounced ability to produce hydrocyanic acid (HCN) or prussic acid. Poisoning by this substance is a problem when livestock are grazed on young sorghum plants, whose growth has been retarded by drought or low temperature. Mutants devoid of HCN content could be isolated by treating the sorghum seed with physical or chemical mutagens.

(*d*) *Cytoplasmic male sterility mutants:* In sorghum there is a need to diversify the male sterile cytoplasm since current hybrid sorghum programmes are based on *milo* cytoplasm. Hybrid seed production will be impaired if this cytoplasm becomes susceptible to disease as in the case of susceptibility of Texas male sterile cytoplasm of maize to southern corn leaf blight caused by *Helminthosporium maydis*, race T, and yellow leaf blight *Phyllastica zeae*. Also there is a need to diversify the nuclear genotypes to evolve new restorer lines which can restore alternate cytoplasm i.e., sources reported by Rao (1962).

The origin of cytoplasmic male sterility and fertility restoring genes are more important in higher plants. It has been postulated that some factors controlling male fertility reside in organelle DNA and their alteration causes cytoplasmic male sterility. The alteration might be a point mutation or an extensive loss of DNA and both types of events have been observed in organelle DNA of fungi and algae (Harvey et al. 1972).

There are reports of isolation of cytoplasmic male sterile mutants in barley (Favert & Ryan 1963), maize (Stoilov 1969) and Pearl Millet (Burton & Hanna 1976) following treatment with physical and chemical mutagens. In sorghum, isolation of cytoplasmic male sterile mutants by treating the seed with NMU, EI and 1, 4-bisdiazoacetyl butane is reported (Malinvosky et al. 1973).

Induction of cytoplasmic mutants through different mutagens is rather rare, but the results in various crops suggest that it may be possible.

(*e*) *Alternation of the reproductive system*: Apomixis, seed production without fertilization, occurs in sorghum (Rao & Murty 1972) and may be utilised as a system for fixing heterosis. It was first reported in a line (R 473) of sorghum derived in advanced generations from a cross between IS 2942 (a yellow endosperm *Kafir* line) and Aispuri (an Indian local variety). The frequency of apomixis could not be determined in R 473 through progeny tests because of its cross sterility. Mutagen treatments can be used to break cross sterility barriers and also to further enhance the frequency of apomixis. Attempts are being made to isolate plants with markers, either seedling marker such as chlorophyll mutant or simply inherited morphological character, from R 473, following treatments with γ-irradiation and hydrazine treatments, which can be used as pollen sources (Reddy & Rao 1979, Reddy et al. 1980).

(*f*) *Breeding for insect and disease resistance*: The primary mechanism of resistance to most sorghum pests such as shoot fly, stem borer and midge, is non-preference with low levels of antibiosis. Induced mutations could provide a means of augmenting the available sources of resistance to most sorghum pests.

Shoot fly is the most destructive insect of sorghum at the seedling stage. So far, absolute resistance is not known for shoot fly in cultivated varieties or in wild species. Attempts have been made to isolate shoot fly resistant mutants in sorghum. γ- or X-irradiation reduced the shoot fly attack in three sorghum varieties, but the resistance was only temporary and limited to initial stages of plant growth (Subba Rao et al. 1968). Isolation of 42 mutants which were 100% resistant to shoot fly attack was reported in varieties M 35–1 and GM 2–3–1 treated with γ-rays (Nayar et al. 1969). Later, only twelve of these showed tolerance to attack (Usman & Goud 1972).

Striga, a phaneogamic root parasite in sorghum can damage the crop up to 75%. Sorghum plants produce strigol which is essential for the survival of parasite. Hence, mutants incapable of producing strigol could be isolated through induced mutations which confer a high degree of resistance to *Striga*.

In sorghum, perconia root rot, caused by the fungus *Periconia circincta* causes serious losses. Resistant mutant plants were found spontaneously in farmer's fields that bred true. Resistance was found to be due to a single gene (Schertz & Tai 1969). Maize dwarf mosaic virus (MDMV) resistant mutants have been isolated from γ-irradiated sorghum (Pai 1977).

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CHARACTERIZATION OF DIVERSE SORGHUM MALE STERILE POLLEN GRAINS BY SCANNING ELECTRON MICROSCOPY*

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ABSTRACT

Pollen grain shape and size, exine sculpture and internal structure as revealed by scanning electron microscopy of pollen from diverse sorghum cytoplasmic-genetic male sterile and their maintainer lines showed distinct differences VZM2 pollen showed resemblence to GI pollen but differed from both CK 60 and M 35-1 pollen. CK60 pollen exine sculpture showed differences from that of M35-1 pollen. The pollen from make sterile exine lines were more or less devoid of protein and starch particles, The grouping of sorghum lines based on pollen structure corresonds to the grouping based on genetic and biochemical studies.

All commercial hybrids of sorghum developed todate are based on milo cytoplasmic male sterility. There is need to identify and characterize alternative sources of male sterility to safeguard against any possible disease hazards. Rao (1962), Hussaini and Rao (1964). and Nagur and Menon (1974) have reported the occurrence of cytoplasmic genctic malc steriles from India which are different from milo-kafir system.

Recent studies have shown characteristic diflerences in soluble protein and esterase isoenzyme patterns among different cytoplasmic-genetic male steriles of Indian origin (Tripathi, Mehta and Rao. 1981b,c). In addition, differences in amino acid composition of anther protein from diverse male steriles and their maintainers have been observed (Tripathi, Mehta and Rao, 1981a).

In the present study pollen from diverse cytoplaimic genetic male sterile lines of sorghum have been studied by scanning electron microscopy.

MATERIALS AND METHODS

Seeds of four male steriles (CK 60A, VZM 2A, GIA and M35-1A) and their maintainer lines were grown at IARI, New Delhi, during 1978. Mature anthers were collected and the pollen grains were fixed by tearing the anthers in 6.5% glutaldehyde solution in cacodylate buffer, pH 7.2, for 24 hours at 4°C.

To observe the internal structure of the pollen grains by SEM, the anthers were ground at 4°C to break the pollen grains. The material was later fixed for 24 hours at 4°C.

The samples after fixation were washed in cacodylate buffer for 15 min. and transferred in 1% osmium tetraoxide solution at 25°C in cacodylate buffer (pH 7.2). The material was post fixed for 4 hours and finally washed with buffer. The samples were dehydrated by usual procedure with a graded series of alcohol and later mounted on SEM stubs and room dried. The material was

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later vacuum coated with gold in a coating unit. The mounted stubs were rotated while being coated. The gold coated pollen grains were examined in Cambridge Stereoscan S 4-10 scanning electron microscope for their (i) shape and size (ii) exine ornamentation (iii) fractured pollen grain surface and interior, at 15-20 KV accelerating voltage in the secondary emission mode at large working distance.

RESULTS AND DISCUSSION

POLLEN SHAPE AND SIZE

The pollen grains of M 35-1A and M 35-1B were similar and oval in shape and largest in size ($15.0\mu \times 8.6\mu$). The pollen grains of GIA and GIB were the smallest and spheroidal in shape. On comparing A *vs*. B lines B pollen were larger in size ($13.4\mu \times 8.9\ \mu$) than A pollen ($11.1\ \mu \times 8.4\mu$) in GI. The pollen of VZM2 A and VZM2 B were also almost identical to GI A in their shape and size. CK 60 B pollen was intermediate in size ($12.7\ \mu \times 8.8\mu$) between M35-1 and GI. In VZM2 A, pollen were polyhedral and shrunken in shape (Fig. 1 E).

EXINE SCULPTURE

The exine organization of sorghum pollen grains are shown in Fig. 2. In CK 60A the exine distribution was completely irregular and a symmetrical but its maintainer line CK 60B showed very clear grouping in the exine. It had on an average 10.66 processes per aggregation (Table 1). The exine organisation in M 35-1A and M35-1B showed more or less uniform distribution. There was less aggregation of exines in M35-1A line than M35-1B. The density of exine processes was much more in VZM2 A as compared witn VZM2 B. In GI B line the grouping processes were having on an average 2.84 processes per aggregation. The aggregations were distinctly separate in CK 60B as compared to GIB.

INTERNAL STRUCTURE

In order to get information about the cytoplasmic material, apparently the starch granules and protein matrix in pollen grains, the broken fragment of the crushed pollen were studied. Internal structure of pollen from different lines is shown in Fig. 3. CK 60A pollen showed many cavities with more protein matrix and little amount of starch granules embeded in it. In CK 60B the cavities were few and large with very small protein material but much more aggregated starch granules which were spherical to oval in shape (Fig. 3B). The GIA and GIB pollen showed almost similar structure with much more protein matrix inside them. The amorphous protein material was covering the starch granules which appeared much smaller in size, than in CK 60B and M35-1B pollen. In M35-1A line the cavities were larger thanin CK 60A, but in M35-1B line there was no cavity and it was densly packed. The starch granules were more in number in M35-1B pollen as compared with all other pollens and were of bean and capsule shape. The protein material was less in it.

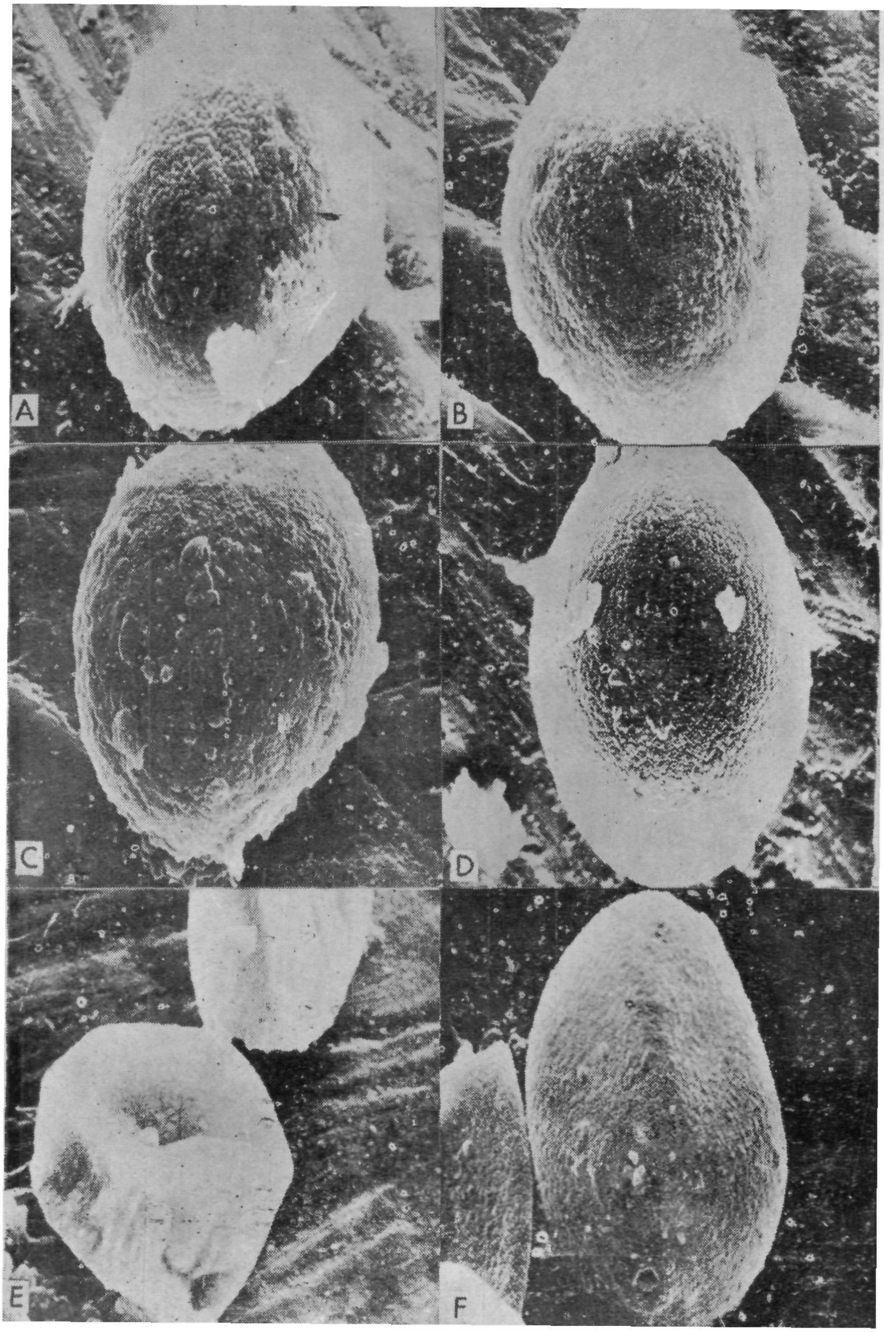

Fig. 1 Scanning electron micrograph showing pollen size and shape :
A. CK60 (× 5885) B. GIB (× 5885) C. VZM2B (× 5885)
D. M35-1B (× 5491) E. VZM2A (× 4634) F. M35-1A (× 5512)

TABLE 1

Pollen size and exine ornamentation in diverse male sterile of sorghum and their maintainer lines

Line	Pollen size (μ)		No. aggregation with X processes per aggregation where											Total No. Processes	Mean No. Processes per aggregation
	L	W	X=1	2	3	4	5	6	7	8	9	10	15		
CK 60A	—	—	5	3	1	—	—	—	—	—	—	—	—	14	1.55
CK 60B	12.7	8.8	—	—	—	—	—	—	1	—	—	1	1	32	10.66
M35-1A	15.0	8.6	18	1	—	—	—	—	—	—	—	—	—	20	1.05
M35-1B	14.7	9.2	19	2	2	—	—	—	—	—	—	—	—	29	1.26
VZM 2A	11.5	9.4	29	4	3	2	—	—	—	—	—	—	—	54	1.40
VZM 2B	13.1	9.1	11	2	—	2	1	1	1	—	—	—	—	41	2.27
G 1A	11.1	8.4	—	—	—	—	—	—	—	—	—	—	—	—	—
G 1B	13.4	8.9	7	—	2	2	—	—	—	2	—	—	—	37	2.84

L=Length
W=Width

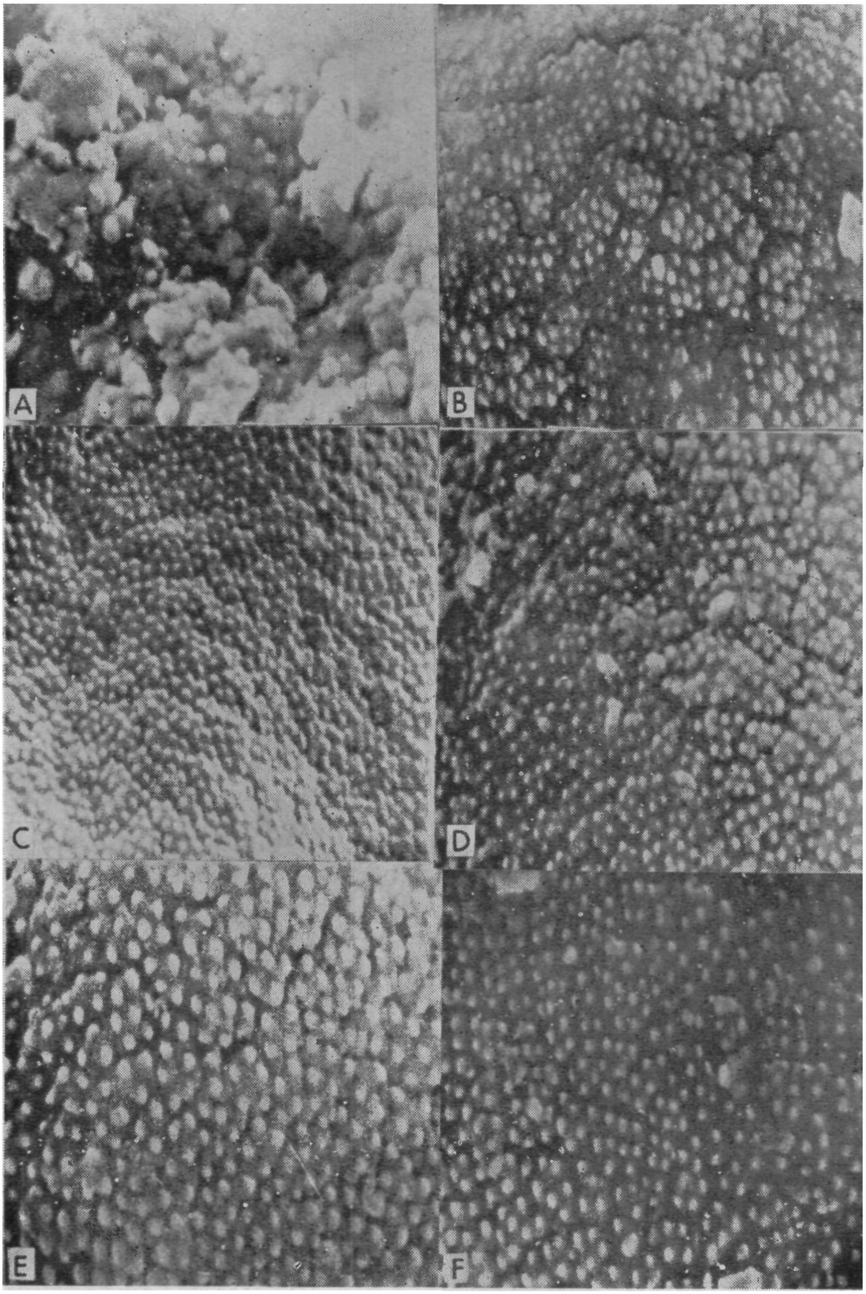

Fig. 2 Scanning electron micrograph showing exine sculpture:
A. CK60A (× 27584) B. CK60B (× 31264) C. V2M2A (× 28391)
D. V2M2B (× 27770) E. M35-1A (× 33862) F. M35-1B (× 31264)

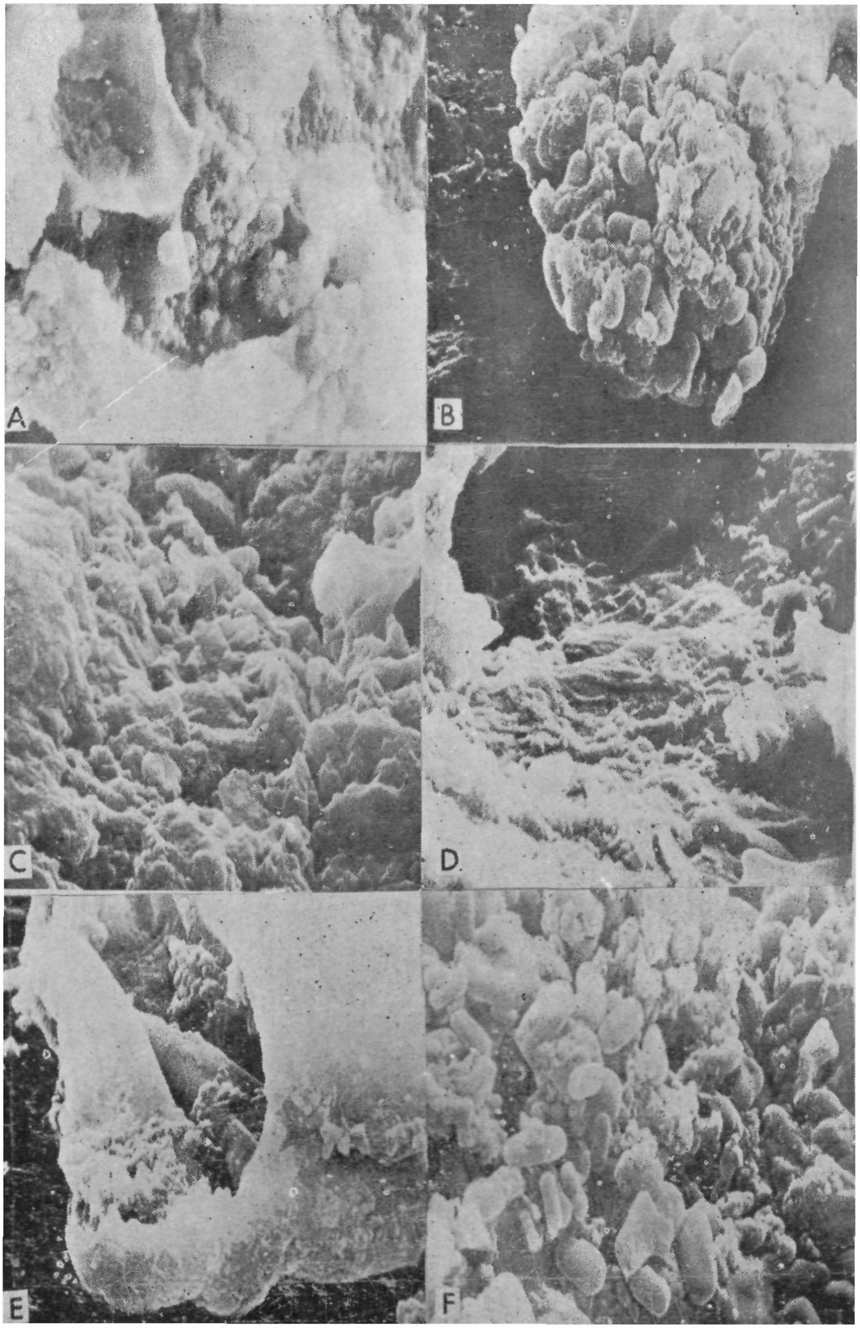

Fig. 3 Scanning electron micrograph showing internal structure of pollen grains :
A. CK60A (× 14130) B. CK60B (× 16805) C. G1A (× 17064)
D. G1B (× 14851) E. M35-1A (× 18966) F. M35-1B (× 16414)

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BASIS FOR FURTHER IMPROVEMENT OF PARENTAL LINES OF SORGHUM HYBRIDS[1]

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ABSTRACT

An attempt has been made to develop a basis for further improvement of male and female parents for future commercial sorgeum hybrides. With respect to female improvement, compared to B×B crosses, B×R crosses offered greater scope for improving yield, grain quality and resistance ot stem borer. The B×R and R×R crosses have been found to be generally superior to B×R indicating limited B variability among B lines.

Improvement of hybrid and varietal yield levels is a continuous process. While the first commercial hybrids of sorghum released in India were exotic×exotic combinations (Rao, 1972), subsequently developed hybrids as well as varieties were derived from temperate (exotic) ×tropical (Indian/African) cross combinations (Rao, Rana, Rao and Reddy 1981), The grain yield level of the presently released hybrids is high and future attempts at further elevating yield levels need a rational and scientific basis. The present paper is an attempt in this direction, with particular emphasis on development of female parents.

MATERIALS AND METHODS

Five restorer (R) lines derived from temperate×tropical crosses (CSV-4, CSV-5, SPV-104, SPV-232 and SPV-290) and four maintainer (B) lines (296B, 323B, 2077B and 2219B) were crossed in all possible combinations. The 9 parents and 36 F_1 hybrids were planted in single row plots of 3 metre during *kharif*, 1979 at National Research Centre for Sorghum, Hyderabad. Row to row distance was 60 cm. and plant to plant distance was 15 cm. A fertilizer dose of 80 kg. N, 40 kg. P_2O_5 and 40 kg. K_2O per hectare was applied. Half of nitrogen and whole quantity of other fertilizers was given as basal before planting. Another 40 kg. N was given as top dressing at a month of crop growth. Two irrigations were given, one at grand growth stage and second after flowering, since rainfall was scanty during crop growth period.

Data were recorded on five random plants per plot on six characters,*e .g.*, days to 50% flowering, plant height, panicle length, panicle weight, grain yield and percentage of stem borer tunnelling. Tunnelling was measured after vertically splitting the stalk and was expressed as percent of total plant height. Percentages were transformed to angles for computation. Statistical analysis was done according to fixed effects model of Griffing (1956), Method II Model I.

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[1] Part XXVI of Genetic analysis of some exotic×Indian crosses in sorghum. Part XXV was published in *Indian J. Genet.* 41 (1981).

RESULTS

A summary of the means is presented in Table 1 and analysis of variance in Table 2. For grain yield, the restorer parents as a group were superior to the maintainers and B×R crosses were the highest yielders followed by the R×R. The B×B combinations were the lowest yielding. Stem borer tunnelling was the highest in B×B combinations. Generally, the B×R and R×R combinations were superior for most economic attributes. Heterosis for grain yield in B×R combinations was highest compared to R×R combinations. The B×B group, which yielded less, exhibited high degree of heterosis. Analysis of variance also showed that for grain yield the differences within R×R and B×R combinations was more significant while the differences within B×B crosses were not statistically significant. The within group differences in B×R combinations were also significant for all characters except for stem borer tunnelling.

TABLE 1.

Group means and average heterosis (%) over mid-parent

	Days to 50% flowering	Plant height (cm)	Panicle length (cm)	Panicle weight (g)	Grain yield (g/pl)	% tunnelling (Angular Trans. values)
Parents	76.0	154.3	25.8	50.1	30.2	32.1
Restorers	76.5	155.0	23.3	53.7	33.7	30.9
Maintainers	75.4	153.3	28.8	45.6	25.9	33.6
Hybrids	75.9	192.6	29.9	96.1	63.4	27.8
R×R	76.9	175.7	26.7	94.2	62.2	27.8
B×B	74.2	179.4	33.2	92.6	58.8	31.1
B×R	75.8	204.9	30.5	98.1	65.4	26.7
Average Heterosis (%)	—0.17	24.8	15.8	91.8	109.9	—13.4
Heterosis (%) in R×R	0.6	13.3	14.4	75.4	84.4	—10.1
Heterosis (%) in B×B	—1.5	17.5	15.2	102.9	127.2	— 7.5
Heterosis (%) in R×B	—0.2	32.8	18.4	95.7	116.3	—16.9

Analysis of variance for combining ability revealed that the mean squares for *gca* and *sca* effects for yield are significant and of nearly equal magnitude; the estimates of variances establish that *sca* predominates over *gca* for several attributes. Only for days to flowering and panicle length, the estimates were of nearly equal magnitude.

The general combining ability effects (Table 2) established the superiority of SPV-104 in breeding for higher yields. This particular line combines resistance to several of sorghum insect pests and diseases with the exception of head moulds. SPV-232 and

TABLE 2

General Combining Ability Effects

Parents	Days to 50% flowering	Plant height (cm)	Panicle length (cm)	Panicle weight (g)	Grain yield (g)	% tunnelling (Angular values)
			Restorers			
SPV-290	—0.23	— 2.57	9.15**	1.15	1.00	–0.80
CSV-4	0.15	— 8.85**	1.52**	0.52	1.85	0.35
CSV-5	0.55	—13.62**	—2.95**	—8.47**	—7.27*	—0.86
SPV 104	0.52	19.78**	—2.58**	1.60**	10.65**	—1.83
SPV-232	0.34	— 2.19	—2.46**	1.66	2.06	0.94
			Maintainers			
323B	0.85*	21.61**	— 0.16	—3.03	—3.41	—2.35*
296B	0.74*	— 2.04	2.41**	5.88*	3.20	2.64
2219B	—2.51**	—16.73**	1.24**	—7.28**	—5.13*	0.15
2077B	—1.41**	4.61	3.43**	0.97	0.75	2.47*

**Significant at 1% ; *Significant at 5%.

296B are also desirable parents from the point of view of grain yields. The parent, 323B, contributed maximum for stem borer resistance. 2219B is particularly desirable for earliness and dwarfing.

DISCUSSION

Rao (1970) indicated that further improvement over the first commercial hybrids of sorghum, which were exotic×exotic combinations were likely to come from the utilization of tropical germplasm. The recently developed hybrids and varieties, which reflect marked improvement for yield and quality over first releases, resulted from the utilization of tropical (Indian and African) germplasm (Rao *et al.*, 1981). In the development of commercial hybrids, lack of adequate variability among the milo cytoplasmic steriles was brought out by Rana, Tripathi, Balakotiah and Rao(1974). The development of 296A, the female parent of CSH-9, derived form the exotic × Indian cross, IS 3922 × *Karad Local.* contributed substantially to yield improvement over CSH-5.

Most efforts at female improvement have been through development of B × B populations from which selections were made. The present analysis clearly establishes that the B×R crosses are of greater potential than B×B crosses for female improvement as well. In the present study, all the restorer lines are from temperate × Indian combinations and CS 3541 from temperate × African combination. Amongst B lines, 296 and 323 are from exotic × Indian cross combinations while the rest are of temperate origin but developed in India. This study has also established that for further yield improvement, lines derived from exotic × Indian crosses such as SPV-104, SPV-232, among restorer lines and 296B among females are most desirable. 2219B of temperate origin is still the earliest and shortest. Apart from yield several of the derived lines are superior with respect to grain quality as well as for attributes conferring greater levels of insect and disease resistance. Thus, further improvement of females in particular and line improvement in general is likely to come from the use of derived lines from the original tropical × temperate crosses. Such derived lines have already been corrected or excessive height and maturity of their tropical progenitors.

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BRIDGING THE GAP BETWEEN HYBRID AND VARIETAL PERFORMANCE IN SORGHUM[1]

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ABSTRACT

Growth analysis of several sorghum hybrids and improved cultivars was carried out to assess the progress made in varietal improvement. Compared to CSH-1, the first commercial hybrid, the performance of improved varieties like SPV-221 and SPV-314 was superior, but much headway needs to be made before attaining performance levels of CHS-5 or CSH-9. At comparable heights and maturities, improvement in total biomass production with out detriment to harvest index leads to higher order yields. There are indications that marked yield superiority and stability of performance may be positively related but mo re critical studies are needd to establish this.

The general superiority of the hybrids over varieties with respect to performance levels as well as stability has been demonstrated (Rao, Rana, Rao and Reddy, 1981). Yet, there have been instances where a few true breeding varieties were comparable in yield to hybrids under favourable environmental conditions (Rao and Harinarayana, 1969; Singhania and Rao, 1976). Whether sorghum varieties similar to hybrids in duration, dry matter production and performance levels together with stability and adaptability could be developed poses **a** challenging problem. This paper is an effort to compare some recently developed hybrids and varieties at different stages of growth so as to identify gaps in varietal improvement.

MATERIALS AND METHODS

Four released hybrids and sixteen recently developed varieties from tropical × temperate crosses were studied in a randomised complete block design with three replications. The material was sown on July 2, 1979 at the National Research Centre for Sorghum, Hyderabad. Normal doses of fertilizer and irrigation practices were followed. Five random plants per plot were cut to ground level and data recorded at five stages of growth, *viz.*, (1) 23 days, (2) 45 days, (3) flag leaf emergence, (4) 50% flowering and (5) maturity/harvest. The characters plant height, number of leaves, total dry matter, grain yield, harvest index, days to 50% flowering and stem girth were recorded.

RESULTS

Data on seven characters during different stages of growth are presented in Table 1. With the exception of *Aispuri*, a tall late local variety, most improved varieties are comparable to CSH-5 with respect to duration and plant height.

[1]Part XXVII of Genetic analysis of some exotic × Indian crosses. in sorghum. Part XXVI appears in this issue.

TABLE 1

Grain yield and related attributes of some hybrids and varieties of sorghum at various stages of growth

Hybrid/ Variety	Plant height (cm)				Number of leaves				Dry matter (g/plant)					Grain yield (g/pl.)	Harvest Index (%)	Days to 50% flower	Stem girth (mm)
	Stage				Stage				Stage								
	I	II	III	IV	I	II	III	IV	I	II	III	IV	V				
CSH-1	15.1	49.7	99.2	151.1	7.5	11.5	13.1	11.8	2.83	20.8	67.3	97	130	73.9	56.8	62.7	19.9
CSH-6	17.2	58.9	124.1	176.7	7.6	11.3	13.2	12.7	4.23	37.4	74.0	113	147	71.2	48.4	64.3	21.3
CSH-5	14.1	55.5	149.7	195.7	7.8	11.3	14.6	13.4	3.41	40.5	157.6	156	255	110.0	43.1	72.0	21.5
CSH-9	16.5	60.1	142.1	186.1	7.3	11.4	13.9	13.2	4.73	39.4	89.0	99	242	102.7	42.4	66.0	22.5
SPV-59B	14.6	53.9	120.5	170.8	6.9	9.8	11.4	10.9	3.42	29.6	74.0	110	150	71.2	47.4	72.0	22.7
SPV-107	16.7	62.1	158.3	196.5	6.6	9.1	11.8	12.3	3.63	27.0	138.3	131	222	70.9	31.9	72.0	19.6
SPV-221	13.0	53.7	133.3	186.3	6.8	9.3	12.0	11.6	3.41	28.0	69.0	106	179	82.6	46.1	66.0	20.8
SPV-232	14.5	44.3	110.3	142.7	6.5	10.2	13.0	12.5	2.83	26.6	91.0	120	163	71.0	43.5	75.0	19.9
SPV-269	13.0	43.2	129.4	166.0	6.7	9.7	12.7	11.5	2.56	25.4	88.0	92	191	55.1	28.8	75.0	17.7
SPV-290	13.5	46.4	119.2	150.0	7.3	8.8	12.0	11.8	2.71	24.4	101.3	122	168	62.8	37.3	75.0	18.1
SPV-291	12.7	44.2	111.3	145.0	7.1	9.7	12.8	11.3	2.49	24.3	146.6	111	173	59.4	34.3	75.0	21.5
SPV-257	13.6	57.5	167.7	210.3	6.3	9.2	11.8	11.9	2.97	24.3	92.3	146	173	64.0	36.9	72.0	17.7
SPV-304	14.1	60.3	143.3	211.4	6.5	9.4	12.6	11.4	2.67	26.4	86.6	93	189	69.6	36.8	69.0	20.6
SPV-305	14.8	49.6	157.0	196.7	6.9	9.1	11.5	11.7	3.00	29.0	92.6	109	189	68.6	36.2	75.0	18.1
SPV-308	12.0	53.2	189.0	213.9	6.7	9.3	11.5	10.7	1.98	20.6	96.3	85	204	73.4	35.9	72.0	15.4
SPV-310	13.7	53.2	146.0	170.0	6.5	9.7	12.5	12.7	1.87	27.4	112.6	136	167	78.8	47.1	75.0	17.9
SPV-314	15.7	46.7	114.8	145.1	7.0	9.5	11.0	11.9	3.97	33.0	125.3	109	173	86.0	49.7	66.0	17.2
SPV-315	13.1	50.7	126.3	168.7	6.6	9.3	12.0	11.7	2.55	30.7	117.0	121	162	78.4	48.3	75.0	18.7
SPV-316	14.2	41.6	124.5	144.0	6.7	9.4	12.6	13.1	2.88	29.0	95.6	90	163	72.0	44.1	72.0	17.1
Aispuri	15.3	84.5	274.8	310.3	7.1	9.5	15.6	16.1	3.33	37.4	171.6	249	481	81.6	16.9	93.0	18.9
Mean	14.4	53.6	142.1	181.7	6.9	9.8	12.6	12.2	3.07	29.6	104.3	120	196	75.1	38.3	72.2	19.4
SEm±	1.06	31.4	5.1	5.54	0.26	0.46	0.47	0.39	0.59	3.40	18.9	18.8	61.7	6.1	2.42	1.86	0.94

Sampling stages ; I=23 days ; II=45 days ; III=Flag leaf stage ; IV=50% flowering ; V=Harvest.

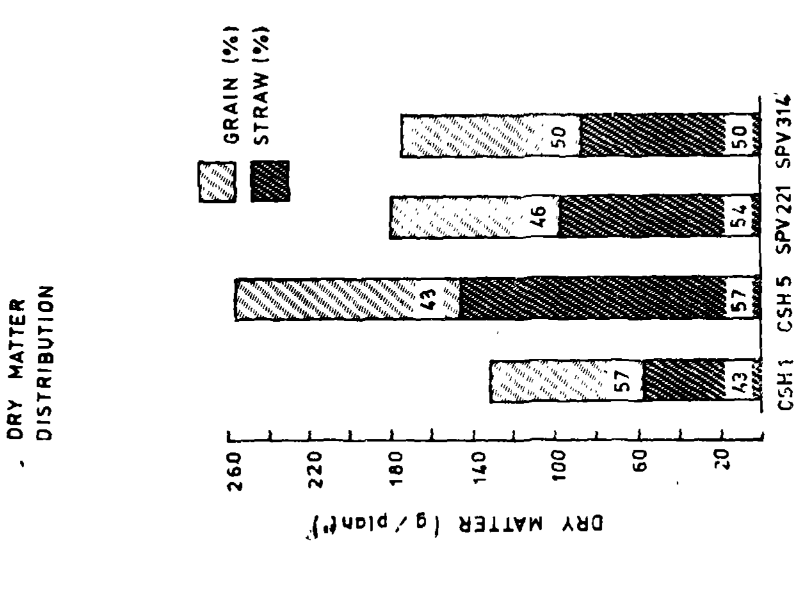
DRY MATTER DISTRIBUTION
GRAIN (%)
STRAW (%)
DRY MATTER (g / plant)
260
220
180
140
100
60
20
CSH 1
CSH 5
SPV 221
SPV 314
57
43
43
57
46
54
50
50

Fig. 1

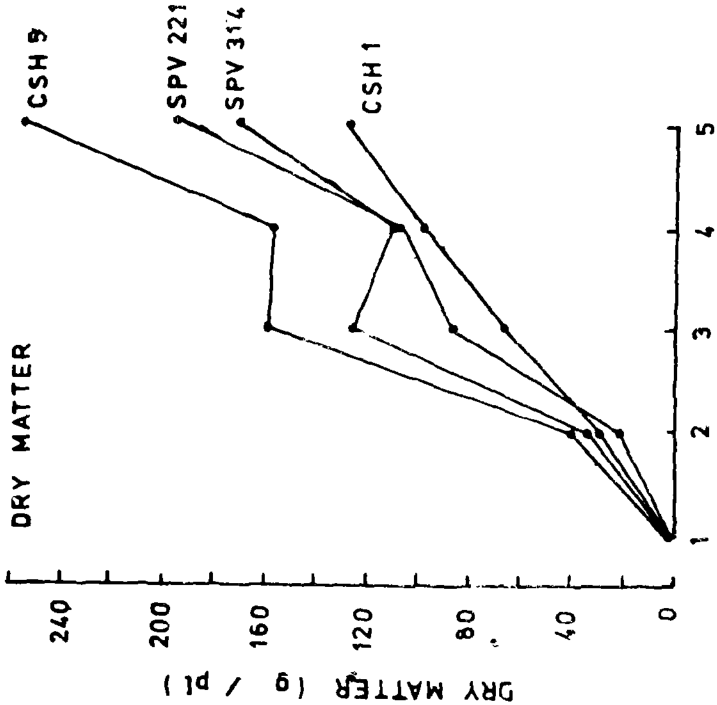
DRY MATTER
CSH 5
SPV 221
SPV 314
CSH 1
DRY MATTER (g / pl)
240
200
160
120
80
40
0
1
2
3
4
5
STAGE

Fig. 2

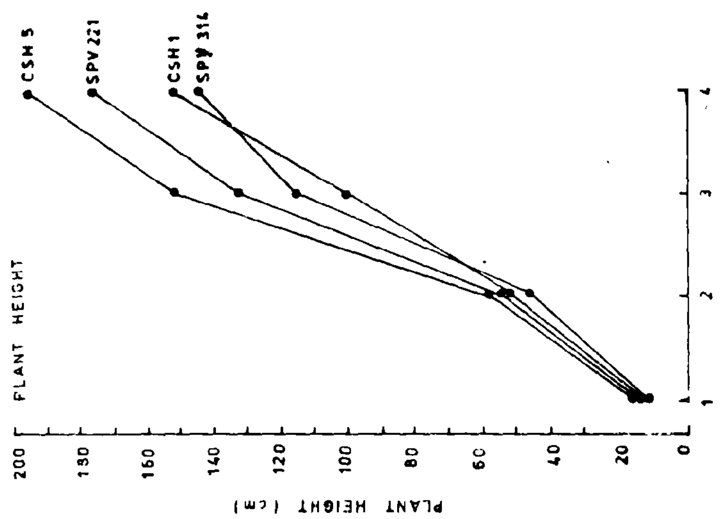
PLANT HEIGHT
PLANT HEIGHT (cm)
STAGE
CSH 5
SPV 221
CSH 1
SPV 314

Fig. 4

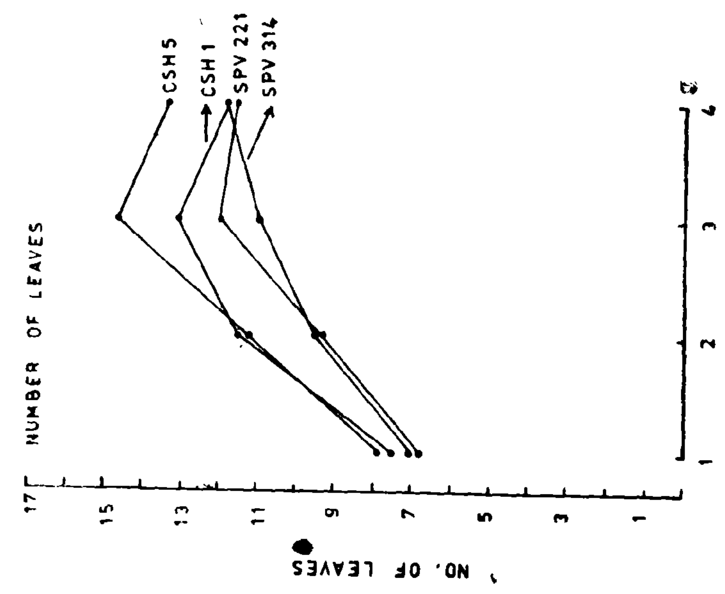
NUMBER OF LEAVES
NO. OF LEAVES
STAGE
CSH 5
CSH 1
SPV 221
SPV 314

Fig. 3

Yield-wise, SPV-314 and SPV-221 were the heighest yielding varieties, but their grain yields per plant are less compared to the hybrid, CSH-5. The growth attributes of these varieties in comparison with CSH-1 and CSH-5 are presented in Figs. 1 to 4. These improved varieties do reflect superiority over CSH-1 but not over CSH-5. Grain yield as well as harvest index of SPV-314 is particularly noteworthy. Plant height of SPV-221 is higher compared to CSH-1 but that of SPV-314 is comparable. Lea number of both varieties is less than that of CSH-1. SPV-314 remains green till harvest and hence the final leaf number approaches that of CSH-1. With respect to total dry matter also, the varieties are superior to CSH-1 but CSH-5 tops with respect to all the attributes studied.

Amongst the rest of the varieties under study, SPV-310 and SPV-315 are also superior to CSH-1.

DISCUSSION

That the superiority of recently developed hybrids and varieties was attributale to changes in duration, growth rhythms, dry matter production and distribution was brought out in the studies of Rao and Venkateswarlu (1971) and Anantharaman, Rao, Kandlikar and Rao (1978). Yet under environmental stress, the superiority of the hybrids over improved varieties was maintained (Rao and Harinarayana, 1969 and Singhania and Rao, 1976). The problem of further improving the varieties with respect to both yield and stability has been receiving attention. The present study which is in this direction clearly establishes that compared to the first commercial hybrid CSH-1, yield levels of improved varieties like SPV-221 and SPV-314 were certainly higher reflecting marked improvement. The superiority of SPV-221 with respect to yield levels and adaptability was further confirmed in All-India multilocation trails over a two year period (AICSIP Annual Reports, 1979 and 1980). Thus, varietal improvement todate has made rapid strides although yield levels of CSH-5 or CSH-9 are yet to be attained at varietal level.

We, therefore, attempted to study the growth behaviour of recent commercial hybrids and improved varieties. CSH-5 was superior at all stages of growth for dry matter production, plant height as well as number of leaves. The total dry matter of SPV-221 and SPV-314 was superior to that of CSH-1 at all stages of growth. SPV-314 tends to remain green at harvest as indicated by its leaf number. Although SPV-314 is slightly shorter than CSH-1, its dry weight and grain yield are higher. This is indicative that at comparable heights and maturities, yield increases are likely to come from an increase in the production of biomass without concommitant detrimental changes in the harvest index. That yield superiority and stability may go together is revealed by the performance of SPV-221 and SPV-314, two improved varieties, in all India trials. Further planned studies are needed to establish changes in adaptability of varieties brought about by genotypic improvement and to realise grain yields comparable to CSH-5 or CSH-9.

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INHERITANCE OF FIELD RESISTANCE TO SORGHUM DOWNY MILDEW*

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ABSTRACT

Inheritance of SDM resistance was studied in a set of resistant × susceptible crosses using both qualititative and quantitative genetic analysis techninues. Segregatiod ratios in the (R × S) crosses clearly indicated the presence of three gene pairs which exhibited both complementary and duplicatory types of gene interaction among them. Quantitive genetic analysis of this character indicated similar results. SDM resistance was observed to be quantitive threshold character.

Incidence of sorghum downy mildew (SDM), caused by *Perenosclerospora sorghi* (Weston and Uppal) Shaw, is frequent in the humid areas of Karnataka, Maharashtra and Tamil Nadu. The level of incidence varies from year to year. The local cultivars of sorghum are more susceptible compared to the recently released hybrids and varieties. Although considerable progress has been made in breeding resistant hybrids and varieties, the nature of inheritance of SDM resistance is yet to be fully understood. The present study is an attempt in this direction.

MATERIAL AND METHODS

Two released varieties, CS-3541 and 148 (CSV-5), known for SDM resistance (R) were crossed to 296 and 303, two susceptible (S) but otherwise desirable varieties resulting in four R × S crosses. Another cross was also made between the two resistant parents. Subsequently, back-crosses to both parents were attempted in all the five crosses. The five sets of parents, F_1's, back-crosses, F_2's and some F_3 progenies of each cross were raised in randomized complete block design with two replications at AICSIP, Regional Research Station, Dharwar during *kharif*, 1976 in a SDM sick-plot.

Data on systemically infected sorghum plants were recorded on 96 to 204 plants in parents, F_1's and individual F_3 progenies and on 435 to 633 plants in different F_2 populations. There were 12 to 40 different progenies in F_3 in different crosses. SDM susceptibility was expressed as the number of systemically infected plants and also as percent of total number of plants. Percentages so obtained were transformed to angles for statistical analysis.

Proportions of resistant and susceptible plants in a population allowed the study of SDM resistance in the form of a qualitative character. The frequency of SDM susceptible plants expressed as percentages of population, were used to study this trait as a quantitative character.

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* Part XXVIII of Genetic analysis of some exotic × Indian crosses in sorghum. Part XXVII appears in this issue.

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RESULTS

QUALITATIVE GENETICS OF SDM RESISTANCE

The resistant (R) parents were compeletely free from infection while susceptible (S) parents showed different levels of infection (Table 1). The infection levels in F_1's indicated that there was dominance of resistance over susceptibility in all the four crosses, though the levels of infection reached was not as much as the resistant parents. The F_2 ratios indicated that the two crosses involving 296 as one parent segregated into a 15 : 1 ratio of resistant and susceptible plants. In the other two crosses involving 303 as one parent, a segregation ratio of 57 : 7 was observed. It was interesting to note that the F_2 of the cross between the two resistant parents gave two susceptible plants out of 494 F_2 plants.

TABLE 1

Frequency of resistant (R) and susceptible (S) plants in different generations

Generation	Disease Reaction	Cross: CS-3541 × 296	148 × 296	CS-3541 × 303	148 × 303	CS-3541 × 148
P_1	R	153	184	153	184	184
	S	0	0	0	0	0
P_2	R	145	145	96	96	153
	S	34	34	65	65	0
F_1	R	148	105	—	99	88
	S	5	7	—	6	0
F_2	R	414	563	528	566	492
	S	21	39	60	67	2
	ER	15:1	15:1	57:7	57:7	α:0
	χ^2	1.50	0.05	0.33	0.08	0.016
	P	.20—.25	.80—.90	.50—.70	.70—.80	.90—.95

ER = Expected ratio

A 15 : 1 ratio observed in crosses with 296 indicated that two gene pairs which are duplicatory in action are controlling SDM resistance. However, the other two crosses involving 303 as a common parent exhibited a 57 : 7 ratio which is possible in a 3-gene control of SDM resistance in which the first two loci are segregating in a 9 : 7 complementary ratio, i. e., two genes are involved in conferring resistance. Presence of both together in dominant state conferred resistance while absence of either resulted in susceptibility. The third gene in this system was more powerful which alone can give resistance in dominant condition. Thus, this gene segregated in a 3 : 1 ratio.

Hence, together the three genes resulted in a 57 : 7 trigenic ratio. It is possible to show that the third gene can give a 14 : 2 ratio with one of the two complementary genes, which was very close to the 15:1 ratio obtained in the other two crosses involving 296. The two susceptible plants observed in the F_2 of the cross involving two resistant parents, CS-3541 × 148, could be a chance occurrence, thoughsegregation of some genes with minute modifying effects which were not in a homozygous conditions in the parents could not be ruled out.

Quantitative Genetic Analysis

A perusal of the means of various generations in different crosses (Tables 2) suggested that resistance to SDM was a quantitative threshold character. The differences between the resistant and susceptible parents, F_1's F_2's and F_3's were significant. Higher susceptibility of F_2's involving 303 as a susceptible parent indicated that 303 contributed more genes for susceptibility to its progenies. The F_1 hybrid between resistant parents was absolutely resistant while the (R × S) hybrids showed partial dominance of resistance over susceptibility. However, there was no significant difference between F_2 and F_3 generations.

TABLE 2

Downy mildew susceptibility (%) in different generations of five crosses

Generation	Resistance reaction of parents	No. of crosses/ parents	Average SDM susceptibility (%)
Parents	R	2	0.00
	S	2	28.43
F_1	R × R	1	0.00
	R × S	3	4.97
F_2	R × R	1	0.56
	R × S	4	7.95
Back Crosses	(R × R) × R	2	3.33
	(R × R) × S	3	3.23
F_3	(R × S) × S	4	18.00
(CS-3541 × 296)	R × S	14	5.71
(148 × 296)	R × S	12	8.12
(CS-3541 × 303)	R × S	18	7.25
(148 × 303)	R × S	37	7.26
(148 × CS-3541)	R × R	40	0.75

The F_2 generation of R × R cross showed less than one percent susceptibility. F_3 progenies of this cross showed a narrow range of susceptibility. The F_2 variation for usceptibility in R × S crosses ranged from 4 to 10 per cent, while F_3 differences were significant in R × S crosses and this provided an opportunity to select cross *per se* as well as selection of resistant progenies within the crosses.

Gene effects were estimated in two (R × S) crosses, viz., 148×296 and 148×303 (Table 3 and 4). In the cross (148×296), resistance was governed by additive factors. The interaction effects varied in their magnitude as well as direction. Apart from additive gene effects, epistasis of duplicate nature was also involved the resistance. In

TABLE 3

Mean values (sin^{-1} %) of the six generations of two crosses

Generation	148×296	148×303
P_1 (Res.)	1.000	1.000
P_2 (Susc.)	4.075	6.345
F_1	2.595	2.415
F_2	2.670	3.315
BC-1	1.905	2.335
BC-2	5.670	3.240
F_3	8.125	7.257
MP	2.537	3.672
Heterosis (%)	2.270	—34.24

TABLE 4

Estimates of gene effects for SDM resistance in two crosses

Parameter	148×296	148×303
m	2.670	3.315
d	—3.765	—0.905
h	4.527	—3.367
i	4.470	—2.110
j	—8.840	—9.155
l	—9.355	3.135
Epistasis type	Duplicate	Duplicate
$H=(\mid \hat{h}-\hat{i} \mid - \mid \hat{d}-\frac{1}{2}\hat{j} \mid)$	—0.597	—2.415
Inbreeding depression (%)	2.89	37.27

the other cross, both heterosis and inbreeding depression were quite large and gene interaction of dominance × dominance type increased the susceptibility. The epistasis in this cross was also of duplicate type. The R^2 values were high indicating high heritability of SDM resistance.

Discussion

While extremely susceptible varieties of sorghum like DMS 652 may show near total incidence of downy mildew, several agronomically desirable varieties also show high levels of downy mildew susceptibility. In the present study the incidence of downy mildew in 296 was about 24 per cent while in 303 it was 66 per cent. Under such situations, classification into discrete classes of resistant and susceptible is possible as is frequently done, but it also presents problems. Strickberger (1968) states that "although lacking a continuous distribution with intermediate values, such characters may nevertheless be influenced by numerous polygenes. The relationship between polygenes and expression of discontinuous characters comes about through the establishment of 'thresholds'. That is, those polygenically determined genotypes which have values below the threshold show no expression of the character. Expression occurs only when the genotypes have values above this threshold". Since SDM appears to behave as a threshold character, both qualitative and quantitative analysis were attempted and attempts made to reconcile the findings.

Miller (1966) and Puttarudrappa, Kulkarni, Kaffari and Goud (1972) indicated qualitative inheritance with not more than two genes involved. It was clear in this study that there were three genes with major effects influencing SDM resistance in the parental material. When 296 was involved in crossing, only two of the three genes segregated giving a 15 : 1 duplicate dihybrid F_2 ratio; when 303 was involved, a 57 : 7 F_2 ratio was obtained indicating that two of the genes segregated in a 9 : 7 ratio and the third gene in a 3 : 1 ratio. Hence, SDM resistance in the crosses studied was controlled genetically by three pairs of genes with both complementary and duplicatory types of interactions involved in their genetics. Quantitative genetic analyss of this trait as threshold character corraborated the results of the qualitative genetic analysis. Resistance was governed by additive factors. Among the interaction types in the (R×S) crosses, duplicatory interactions were predominant. Similar duplicatory gene interactions were noticed in the segregation ratios. Presence of modifying genes was suggested by the appearance of few susceptible segregates in the (R × R) cross.

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FURTHER STUDIES ON THE INCIDENCE AND GENETICS OF RUST RESISTANCE IN SORGHUM

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ABSTRACT

The incidence of rust is higher under humid condition of Dharwad consequently increasing the susceptibility of the hypersensitive parents and frequency of susceptibles in F_2. There is no evidence for the existence of more than three genes even at Dharwad leading to the conclusion that the differential behaviovr is due to the increased inoculum attributable to favourable environment rather than the occurrence of different physiological races of the fungus The segregation pattern in tan × tan, tan ×purple and purple×purple crosses is similar Rust resistance is confirmed to be trigenic recessive of the $r_1r_1r_2r_2r_3r_3$ genetic constitution. Modifying factors appear to push a hypersensitive reaction towards susceptibility under more favourable conditions for disease development. SPV-34 and CS 3541 are better sources of resistance.

An earlier study on inheritance of rust resistance in sorghum suggested a trigenic basis, susceptibility being dominant (Rana, Tripathi and Rao, 1976). It was, however, found that some of the varieties which exhibited a hypersensitive reaction at Hyderabad become susceptible at Dharwad which has a more humid environment. A study was, therefore, taken up to examine the environmental influences on and the genetics of rust resistance.

MATERIALS AND METHODS

Four tan pigmented (SPV-34, CS 3541, SPV-104 and 168) and three purple pigmented varieties (SPV-35, SPV-86 and R-16) were selected on the basis of rust resistance, hyper-sensitive and susceptible reactions in endemic areas over several years. Among tan pigmented parents, SPV-34 (mutant derivative of GM 1-5) and CS 3541 (CSV-4) were highly resistant (R). Few pustules were observed on CS 3541 in Dharwad. SPV-104 and 168 (CSV-5) showed hypersensitive (H) reaction. The purple pigmented varieties were susceptible (S). All possible crosses among them were developed. Parents and F_2 of all the crosses except SPV-34×R-16 were tested for rust incidence during *kharif* 1979 at Dharwad which is an endemic site. F_1 and F_2 of six crosses representing R×S. R×H and H×S reaction were grown at Hyderabad during the same season.

Five other tan×tan crosses *viz.*, CS3541×148,CS 3541×303, 303×148, (148 ×CS3541) ×CS 3541, (148×CS 3541)×148 were earlier tested during *kharif*, 1976 at Dharwad. The rust infection on individual plants was scored on the basis of pustule intensity and size on a 0 (completely resistant) to 5 (highly susceptible) scale as earlier described by Rana, Tripathi and Rao (1976).

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* Part XXIX of Genetic analysis of some exotic×Indian crosses in sorghum. Part XXVIII appears in this issue.

RESULTS

The parental and F_1 scores based on 60 plants each are presented in Table 1. SPV-34 (mutant derivative of GM 1-5) was highly resistant at both the locations. CS 3541 (CSV-4) showed complete resistance at Hyderabad and moderate resistance at Dharwad. Both 168 (CSV-5) and SPV-104 were moderately susceptible on the basis of pustule intensity but hypersensitive (H) in reaction. SPV-35, SPV-86 (CSV-8R) and R-16 (CSV-7R) were highly susceptible (score 4) at Dharwad, though SPV-86 was only moderately susceptible at Hyderabad. Susceptibility was intermediate in CS 3541 × SPV-86 and recessive in SPV-34 × SPV-104; in rest of the crosses susceptibility was dominant.

The infection was markedly high at Dharwad. The frequency of resistant plants was low at Dharwad as compared to Hyderabad. Among tan × purple crosses, the resistant plants occurred in larger frequencies in SPV 34 crosses (Table 1). The segregation pattern of two tan × purple crosses, SPV-34 × SPV-86 and CS 3541 × SPV-86 showed that resistant (score '0') plants segregated in 1 R : 63S trigenic ratio (Table 2). Resistance was, therefore, governed by triple recessive genes in these crosses. The other tan × purple crosses segregated into moderately resistant to susceptible plants conforming to the 1R : 15S and 1R : 63S ratios. SPV-34 differed in two genes from SPV-35 and in three genes from CSV-4, CSV-5, (168), SPV-104 and SPV-86. Segregation among other tan × tan crosses established 2-3 genes difference. SPV-34 × CS 3541, SPV-34 × 168, SPV-34 × SPV-104, and CS 3541 × SPV-104 segregated into 1R : 63S ratio, resistance being governed by triple recessive genes. The observed frequencies of CS 3541 × 168, 168 × SPV-104 (score : 2 *vs* 3-5) crosses fitted to 1 : 15 duplicate genetic ratio. Double recessiveness conditioned complete resistance in CS 3541 × 168 and moderate resistance in 168 × SPV-104.

Under moderate infection at Hyderabad, the genetic behaviour of tan × tan crosses was different than at Dharwad. SPV-34 × CS 3541, SPV-34 × SPV-104 and CS 3541 × 168 segregated into 45 : 19 ratio indicating that under low infection and tan background a dominant gene conditioned resistance even in the presence of two dominant susceptibility genes (R_1 and R_2). It must be modifying gene which imparts resistance under low disease infection. CS 3541 × 148 and CS 3541 × 303 segregated into 1 R : 3 S ratio indicating single gene difference. CS 3541 increased the frequency of resistant plants in backcross while 148 enhanced susceptibility in backcross. It confirmed the additional resistance gene in CS 3541 as compared to 148 (CSV-5) and 303 (CSV-2).

There was a 2-3 minor gene difference among purple × purple crosses but none of them segregated out resistant plants (Table 2). These were confined to moderately resistant to highly susceptible classes. The frequency of resistant plants was reasonably high in SPV-34 × CS 3541, SPV-34 × SPV-104, CS 3541 × 168 and CS 3541 × 303 F_2's (Tables 1 and 2). All were tan × tan crosses,

TABLE 1

Rusts core, 0—resistant to 5-susceptible of pareuts, F_1 and F_2 plants

Cross	Location	P_1	P_2	F_1	F_2 frequency 0	1	2	3	4	5
			Tan × Purple							
SPV-34 × SPV-35	Dha	0.0	4.0		—	4	11	38	32	10
SPV-34 × SPV-86	Dha	0.0	4.0		2	37	61	34	—	—
CS 3541 × R-16	Dha	1.5	4.0		—	—	7	29	49	29
CS 3541 × SPV-35	Dha	1.5	4.0		—	1	8	25	29	1
CS 3541 × SPV-86	Dha	1.5	4.0		2	—	—	28	55	21
	Hyd	0.0	2.0	1.0	2	112	36	—	—	—
168+R-16	Dha	2.0	4.0		—	4	11	18	42	11
168 × SPV-35	Dha	2.0	4.0		—	5	19	23	38	6
168 × SPV-86	Dha	2.0	4.0		—	—	4	28	32	20
	Hyd	1.0	2.0	2.0	2	77	73	49	39	10
SPV-104 × R-16	Dha	2.5	4.0		—	—	11	26	38	6
SPV-104 × SPV-35	Dha	2.5	4.0		—	1	9	27	31	12
SPV-104 × SPV-86	Dha	2.5	4.0		—	—	6	15	40	4
			Tan × Tan							
SPV-34 × CS 3541	Dha	0.0	1.5		2	42	43	12	—	—
	Hyd	0.0	0.0	0.0	162	45	23	2	—	—
SPV-34 × 168	Dha	0.0	2.0		1	30	42	20	2	2
SPV-34 × SPV-104	Dha	0.0	2.5		2	34	31	25	4	2

(contd.)

TABLE 1—(*Contd.*)

Cross	Location	P_1	P_2	F_1	F_2 frequency					
					0	1	2	3	4	5
SPV-34 × SPV-104	Hyd	0.0	1.0	0.0	122	37	16	—	—	—
CS 3541 × 148	Dha	0.5	2.0	2.0	—	106	189	130	—	—
(148 × CS 3541) × CS 3541	Dha	2.0	0.5		10	31	7	—	—	—
(148 × CS 3541) × 148	Dha	2.0	2.0		—	—	12	37	—	—
CS 3541 × 168	Dha	1.5	2.0		7	15	25	44	2	—
	Hyd	0.0	1.0	1.3	101	34	12	—	—	—
CS 354 × 1303	Dha	0.5	3.0		130	131	185	85	1	—
CS 3541 × SPV-104	Dha	1.5	2.5		1	15	40	25	6	2
303 × 148	Dha	3.0	2.0	3.0	—	36	155	268	71	—
SPV-104 × 168	Dha	2.5	2.0		—	5	47	50	10	1
	Hyd	1.0	1.0	1.0	95	27	8	—	—	—
			Purple × Purple							
SPV-35 × R-16	Dha	4.0	4.0		—	—	6	16	52	14
SPV-35 × SPV-86	Dha	4.0	4.0		—	1	9	26	21	—
SPV-86 × R-16	Dha	4.0	4.0		—	—	3	27	39	14

Location : Dha = Dharwar ; Hyd = Hyderabad.

TABLE 2

Cumulative F_2 frequencies and estimate of χ^2 for different genetic ratios for rust resistance

Cross	Location	Grouping (score)	Observed frequency (R : S)	Genetic ratio (R : S)	χ^2
		Tan × Purple			
SPV-34 × SPV-35	Dha	1 : 2-5	4 : 89	1 : 15	.6029
SPV-34 × SPV-86*	Dha	0 : 1-5	2 : 132	1 : 63	.0049
CS 3541 × R-16*	Dha	2 : 3-5	7 : 107	1 : 15	.0023
CS 3541 × SPV-35	Dha	1 : 2-5	1 : 63	1 : 63	.0000
CS 3541 × SPV-86	Dha	0 : 3-5	2 : 104	1 : 63	.0726
	Hyd	0 : 1-5	2 : 148	1 : 63	.0512
168 × R-16*	Dha	1 : 2-5	4 : 82	1 : 15	.3751
168 × SPV-35*	Dha	1 : 2-5	5 : 86	1 : 15	.0886
168 × SPV-86	Dha	2 : 3-5	4 : 80	1 : 15	.3174
	Hyd	0 : 1-5	3 : 247	1 : 63	.2151
SPV-104 × R-16	Dha	2 : 3-5	11 : 70	1 : 7	.0864
SPV-104 × SPV-35	Dha	1 : 2-5	1 : 79	1 : 63	.0508
SPV-104 × SPV-86	Dha	2 : 3-5	6 : 59	1 : 15	.9856
		Tan × Tan			
SPV-34 × CS 3541	Dha	0 : 1-3	2 : 97	1 : 63	.1358
	Hyd	0 : 1-3	162 : 70	45 : 19	.0262
SPV-34 × 168	Dha	0 : 1-5	1 : 96	1 : 63	.1789
SPV-34 × SPV-104	Dha	0 : 1-5	2 : 96	1 : 63	.1458
	Hyd	0 : 1-2	122 : 53	45 : 19	.0299

(contd.)

TABLE 2 (*Contd.*)

Cross	Location	Grouping (score)	Observed frequency (R : S)	Genetic ratio (R : S)	χ^2
CS 3541×148*	Dha	1 : 2-3	106 : 319	1 : 3	.0008
(CS 3541×148)×CS 3541	Dha	0 : 1-2	10 : 38	1 : 3	.4444
(CS 3541×148)×148	Dha	2 : 3	12 : 37	1 : 3	.0068
(CS 3541×168)	Dha	0 : 1-5	7 : 86	1 : 15	.2588
	Hyd	0 : 1-2	101 : 46	45 : 19	.1813
CS 3541×303	Dha	0 : 1-4	130 : 402	1 : 3	.0893
CS 3541×SPV-104	Dha	0 : 1-5	1 : 88	1 : 63	.1111
303×148	Dha	1 : 2-4	36 : 494	1 : 15	.2661
SPV-104×168	Dha	2 : 3-5	5 : 108	1 : 15	.6424
	Hyd	0 : 1-2	95 : 35	3 : 1	.2564
		Purple×Purple			
SPV-35×R-16	Dha	2 : 3-5	6 : 82	1 : 15	.0485
SPV-35×SPV-86	Dha	1 : 2-5	1 : 56	1 : 63	.0136
SPV-86×R-16	Dha	2 : 3-5	3 : 80	1 : 15	.9839

*Reciprocal cross; Location : Dha=Dharwad ; Hyd=Hyderabad.

Discussion

The general pattern of segregation in tan × tan, tan × purple and purple × purple crosses is similar and confirms that the inheritance of rust resistance is governed by a maximum of three recessive genes. However, the frequency of resistant plants in tan × tan crosses is highest followed by tan × purple crosses. The purple × purple crosses egregated into moderately resistant to susceptible plants. Obviously, the choice to develop resistant progenies in either plant type should be confined to tan × tan and tan × purple crosses only.

The hypersensitive reaction appears to be a weaker system than resistance *per se*. Some of the tan pigmented varieties show hypersensitive reaction at Hyderabad and prove unstable under the more humid conditions at Dharwad. Examination of the segregation at both locations reveals that crosses which segregate in 1 R : 15 S at Hyderabad tend to segregate in 1R : 63S ratio at Dharwad. The susceptibles are more at Dharwad. The basic question is whether the increased susceptibility at Dharwad is due to different physiological races of rust or due to environmental influences only. There is no evidence for the existence of more than three genes even at Dharwad. It, therefore, appears that the differential behaviour may be attributable to environmental influences. Modifying factors might be playing a major role, particularly in pushing a hypersensitive reaction towards the susceptibility under more favourable conditions for the disease.

Tan types are generally more resistant to rust compared to purple pigmented types although resistance in purple types may not be ruled out. Strengthening of esistance in tan background is, therefore, necessary to provide stability of reaction under endemic conditions. R × R and R × H crosses such as SPV-34 × CS 3541, SPV-34 × 168, SPV-34 × SPV-104, CS 3541 × 168, CS 3541 × 303 involving tan parents provide good choice. Among purple pigmented varieties, SPV-86 combines better than others in tan × purple crosses.

Plant pigment and level of resistance in parental material determine the degree of dominance in F_1. Susceptibility is dominant over resistance as observed earlier by Rana, Tripathi and Rao (1976) and Patil *et al.* (1972). Miller and Cruzado (1969) observed different allelic interactions with rust at *Pu* locus and heterozygote susceptibility in some instances. As an interaction with tan plant type, dominance of resistanc was observed in one of the tantan cross (SPV-34 × SPV-104) only. Bergquist (1971) also made such observation of dominance of resistance.

A triple recessive genetic constitution $r_1r_1r_2r_2r_3r_3$ governing rust resistance in rghum is suggested. The different degrees of resistance is determined by the presence of one or more homozygous recessive genes.

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INHERITANCE OF FIELD RESISTANCE TO SORGHUM CHARCOAL ROT AND SELECTION FOR MULTIPLE DISEASE RESISTANCE*

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ABSTRACT

Six segregating and nonsegregating generations of three R x S and two S × S crosses were studied for charcoal rot resistance under epiphytotic conditions. CSV-5 (148/168) was comparatively the most resistant parent. The F_1 showed partial dominance of resistance.

The resistance appears to be a polygenic threshold character governed by duplicate epistasis with low heritability (38%). The F_3 progenies transgress the parental limits. In absence of absolute resistance for charcoal rot, selection 2 S.D. below population mean (S.I. = 1%) results in selecting resistant transgressive segregates.

Charcoal rot, SDM and leaf rust inherit independently. It is possible to combine these characters through simultaneous selection by choosing rust resistant plants from the segregating F_3 progenies possessing $<1\%$ SDM and $<10\%$ charcoal rot susceptibility.

Sorghum charcoal rot [*Macrophomina phaseolina* (Tassi) Goid.] has shown signs of being a potential danger in India in rainy and postrainy seasons during the recent years. Though the disease was reported long back in India (Uppal, Kolhatkar and Patel, 1936), its role in causing economic loss has been appreciated only recently. The disease is favoured by moisture stress ($<25\%$ available soil moisture) and high soil temperatures (35°C) at the time of grain filling in the susceptible varieties (Edmunds, 1962). Plant senescence is associated with charcoal rot (Rosenow, Johnson, Fredeiksen and Miller, 1977). Any destruction in the actively photosynthesizing leaf tissue reducing the amount of carbohydrate availability to the plant for cell maintenance can also be instrumental for predisposition to stalk rot (Dodd, 1978).

Sorghum downy mildew (SDM) and leaf rust are major diseases which can destroy leaf area and stimulate stalk rot. The inheritance of stalk rot resistance and simultaneous selection for SDM and leaf rust resistance in conjugation with stalk rot resistance are discussed here.

MATERIALS AND METHODS

Five parents, 'CS 3541 (CSV 4)', '148 (CSV 5)', '296', '303' and '168' were selected for the present study. Five crosses among first four parents were attempted and subsequently advanced

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to F_2 and F_3. The '296 × 303' cross was dropped due to its susceptibility to SDM. F_1s were crossed to both the parents and designated as BC-1 and BC-2. Nine such BCs were developed. There were 12 to 40 F_3 progenies in each cross.

The experiment was grown in randomized complete block design with two replications at U.A.S. Regional Station, Dharwar during *kharif* 1976, in a SDM sick plot. A large F_2 population of 435-532 plants was studied in different crosses. Forty plants per parent, 42-135 plants per F_1, 28-79 plants per BC and 100-150 plants per F_3 progeny (about 14000 total F_3 plants) were studied. The drought leading to moisture stress during September which coincided with grain filling resulted in epiphytotic of charcoal rot. The affected plants were assessed on the basis of hollow stem due to disintegration of pith by the fungus. Leaf rust was also endemic.

The anguler transformed susceptibility % data were used for analysis. The gene effects were estimated according to Hayman (1958) Standard statistical procedures were adopted to fit the normal curve and to compute regression and correlation coefficients.

RESULTS

INHERITANCE OF RESISTANCE TO CHARCOAL ROT

The susceptibility in parents varied from 15.6% to 40.3% (Tables 1 and 2). Among them '148' with 15.6% susceptibility was the relatively more resistant parent (LSD=12.9%). The range of variation among F_1 was from 13.7 to 35.8%. The resistant × susceptible (R × S) F_1's, i.e., '148 × 303', '148 × CS 3541' and '148 × 296' were relatively more resistant than S × S F_1s. The R × S F_1's were close to the resistant parent for resistance indicating the partial dominance of resistance. Susceptibility in F_2 varied from 22.3 to 34.9%. R × S F_2's were relatively more tolerant than S × S. In general, F_2 performance was quite close to mid-parent value with only 12.5% decrease in susceptibility. The F_2 showed 22.5% inbreeding depression for resistance.

The susceptibility decreased with an extra dose of resistant parent in (148 × 303) × 148 BC indicating clear cut dose effect of resistance genes. The dose effect in other BCs was inconsistent.

The actual F_3 mean (27.5%) was close to F_2 mean (27.9%). However, between and within F_3, differences were highly significant ($\sigma^2 F_3 = 1100.97$, $\sigma^2 e = 42.96$), '148 × 296' and '148 × CS 3541 F_3 being lowest in susceptibility (Table 2). There were 5% F_3 progenies with <10% susceptibility and 22% progenies with <20% susceptibility. None of the F_3 progeny was completely resistant. Frequency distribution of F_3 progeny means showed a close fit of observed frequencies to expected frequencies with mean=26.69 and S.D.=10.44 (Fig. 1). The alternative test to detect skewness as a supplement to χ^2 test confirmed the normality of distribution, β_1 being approximately zero. In the absence of absolute resistance, a selection pressure of 2 S.D. below population mean was considerably high resulting in 0.85% selection intensity. However, 11% progenies with <16.25% susceptibility could be selected when selection pressure was relaxed to 1 S.D. below the population mean.

TABLE 1

Generation means (angular values) for charcoal rot susceptibility % (LSD=12.90)

Generation	148×303		148×CS 3541		148×296		CS 3541×296		CS 3541×303	
	Actual	Ang. values	Actual	Ang. values	Actual	Ang. values	Actual	Ang. values	Actual	Ang. values
P_1 (R)	15.6	23.2	15.6	23.2	15.6	23.2	34.7	36.1	34.7	36.1
P_2 (S)	35.2	36.3	34.7	36.1	40.3	39.4	40.3	39.4	35.2	36.3
$\bar{P}$	25.4	29.7	25.2	29.6	27.9	31.2	37.5	37.7	34.9	36.2
F_1	18.6	25.5	13.7	21.7	17.7	24.7	35.8	36.7	—	—
F_2	28.3	32.1	22.3	28.1	22.7	28.4	34.9	36.2	30.3	33.4
BC-1 (R×S) R	12.3	20.5	57.1	49.8	28.8	32.3	40.5	39.5	50.8	45.4
BC-2 (R×S) S	55.8	48.3	30.4	33.1	16.7	24.1	30.0	33.1	40.6	39.6
F_3	28.5	32.3	23.9	29.3	21.7	27.8	30.0	33.2	35.6	36.6
Heterosis %	—26.8	—14.1	—45.6	—26.7	—36.6	—20.8	—4.5	—2.7	—	—
Inb. depression	52.2	25.9	62.7	29.5	28.2	15.0	—2.5	—1.4	—	—

TABLE 2

Charcoal rot susceptibility (%) in different generations.

Generation	Midclass values/frequencies						Total	Mean	Range	MS
	5	15	25	35	45	55				
Parents		1		3			4	31.90	15.59—40.33 (23.26—39.41)	*
F_1		2	1	1			4	22.78	13.70—35.84 (21.70—36.75)	*
BCs		2	2	1	2	2	9	35.99	12.30—57.05 (20.50—49.02)	**
F_2			3	2			5	27.90	22.81—34.91 (28.10—36.21)	
F_{3-1}		2	5	5	2		14	30.00	12.43—45.97 (20.62—42.65)	**
F_{3-2}	2	3	4	3			12	21.66	9.35—40.44 (17.76—39.47)	**
F_{3-3}	1		3	8	5	1	18	35.55	9.13—52.11 (17.46—46.20)	**
F_{3-4}		7	14	12	1		34	28.51	13.24—46.25 (21.22—42.90)	**
F_{3-5}	3	14	13	9	1		40	23.95	3.60—44.99 (10 94—42.13)	**

Angular transformed values are in parenthesis.

F_{3-1} CS 3541 × 296, F_{3-2} 148 × 296, F_{3-3} CS 3541 × 303, F_{3-4} 148 × 303, F_{3-5} 148 × CS 3541.

* Significant at 5%, ** Significant at 1%.

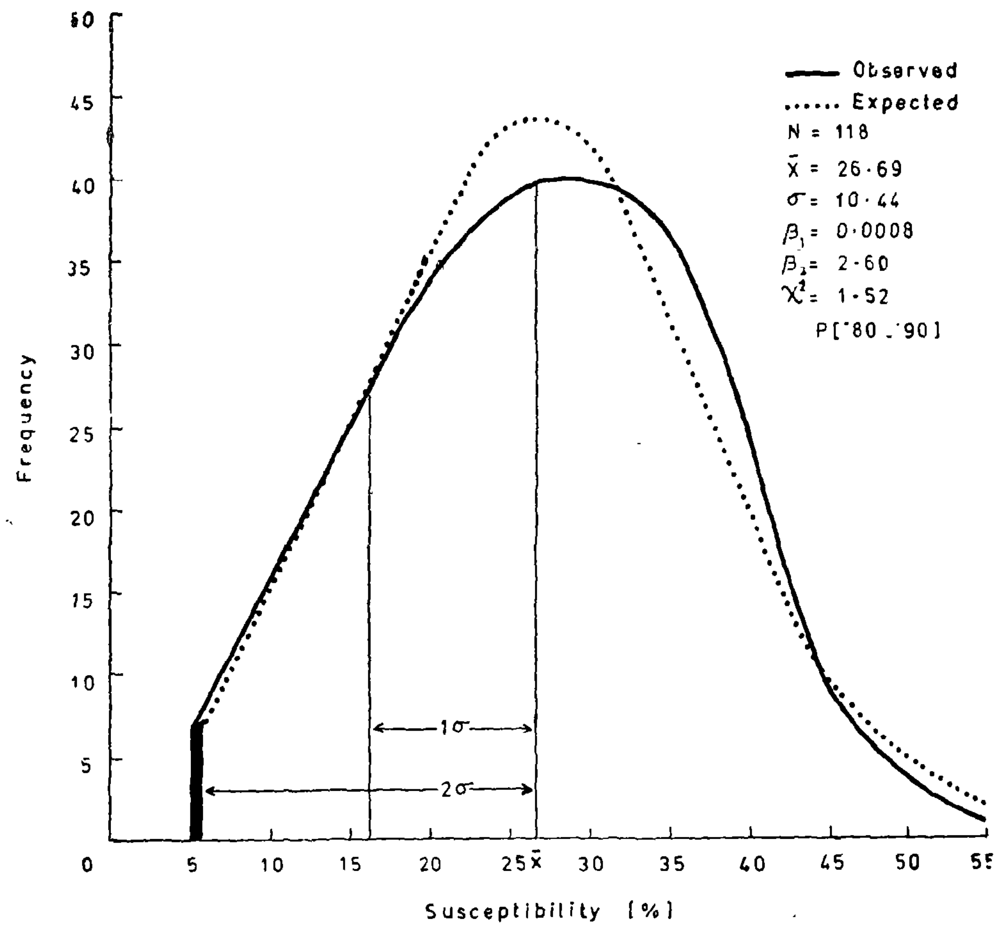

Fig. 1. Frequency distribution of F_8 progeny means.

The conclusion on gene effects was drawn on the basis of relative magnitude (Table 3). In '148 × 303', additive effect (d) was negative and responsible to reduce the susceptibility. Negative additive × dominance (j) and dominance × dominance (l) interaction effects were also quite pronounced in this cross. Additive × dominance effects were negative and largest in '148 × 296' and 'CS 3541 × 296' crosses. Heterotic (h) and dominance × dominance effects were opposite in direction. Epistasis governing resistance in all the crosses were, therefore, due to duplicate genes.

TABLE 3

Gene effects (based on angular values) for charcoal rot susceptibility (%).

Gene effect	148 × 303	148 × CS 3541	148 × 296	CS 3541 × 296
$\hat{m}$	32.10	28.15	28.45	36.20
$\hat{d}$	—27.85	16.70	8.20	6.45
$\hat{h}$	37.05	33.65	— 7.55	— 0.75
$\hat{i}$	41.30	53.20	— 1.00	0.30
$\hat{j}$	—115.20	—49.10	—46.20	—88.40
$\hat{l}$	— 68.50	—93.10	0.30	3.50
Epistasis type	Duplicate	Duplicate	Duplicate	Duplicate
$H=[(h-i)-(d-\frac{1}{2}j)]$	— 25.50	—21.70	—24.75	—36.70
Inbreeding depression (%)	25.88	29.72	14.95	— 1.36

The offspring-parent regression of F_2 on F_1 and F_3 on F_2 had low significance ($P < 0.10$). The correlation coefficients were 0.63* and 0.54* respectively (Table 4). The degree of determination of F_2 by F_1 was 40% and F_3 by F_2 30%. The heritability estimated by variance component method using estimates of between and within F_3 variance was 37.67%.

TABLE 4

Regression analysis for charcoal rot resistance

Source	F_2 on F_1		F_3 on F_2	
	DF	MSS	DF	MSS
Regression	1	89.63*	1	60.50*
Deviation	6	22.21	8	17.73
Correlation coefficient		0.6341*		0.5467*
R^2		0.4021		0.2989
Regression coefficient		0.527*±0.262		5.504*±0.272

* Significant at 1%; Heritability (σ^2 B.F_3/σ^2 B.F_3 + σ^2 W.F_3 + $\sigma^2 e$)=37.67.

SELECTION FOR MULTIPLE DISEASE RESISTANCE

The correlations (r_{12}=0.07, r_{13}=0.13, r_{23}=—0.01) among SDM, charcoal rot and leaf rust in F_3 were not significant. Resistance to these three major diseases was therefore independent of each other.

These characters can be accumulated in single progeny by adopting a suitable simultaneous selection procedure. Data in Table 5 show than when SDM, charcoal rot and leaf rust segregate independently, it could be possible to select F_3 progeny No. 98 of '148 x 296' cross and progeny No. 106 of '148 x CS 3541' cross with 1% SDM and 10% charcoal rot incidence. Similarly, other progenies such as 42 and 97 could be selected with 2% SDM and 10% charcoal rot incidence. All these progenies segregated into rust resistant and susceptible plants. It is, therefore, possible to select rust resistant plants from the progenies showing a reasonably high level of resistance to SDM and charcoal rot.

TABLE 5

Simultaneous selection for resistance to SDM, charcoal rot and rust.

	No. of rust resistant plants			
	SDM % 0 — 1		1.1 — 2	
	P. No.	R : S	P. No.	R : S
Charcoal rot %	98	39 : 50	42	12 : 53
0 — 10	106	12 : 38	97	12 : 69

P. No.—F_3 progeny number 42 — 148 × 296,
97, 98, 106 — 148 × CS 3541.

R—Resistant, S—Susceptible.

DISCUSSION

Macrophomina phaseolina is not an aggressive pathogen capable of attacking vigorous plant tissue but can overcome senescing tissue at grain-filling stage under soil moisture stress and high temperature causing a serious damage to susceptible varieties. The incidence of sorghum charcoal rot is therefore governed by environment-host-pathogen interactions and mainly depends on photosynthetic stress—translocation balance (Dodd, 1978). Host plants show variability for resistance (Frederiksen and Rosenow, 1971; Rosenow, 1978; Rao *et al.*, 1978) but absolutely resistant variety is not known. However, multilocation testing in AICSIP has helped to identify stable sources of resistance. CSV 5 (148/168) is one such variety with 16% susceptibility and significantly high resistance as compared to other parents under disease epiphytotic conditions.

Study of different segregating and non-segregating generations elucidates continuous variation indicating the quantitative nature of resistance. The distinct gradation of parents and F_1s may be due to different thresholds since those polygenically determined genotypes which have values below the threshold show no expression of the character and the expression occurs only when the genotypes have values above this threshold (Strickberger, 1968). R x S hybrids tend towards resistant parent due to partial dominance of resistance. The use of at least one highly resistant parent in hybrid programme would thus confer advantage to hybrids. Rosenow (1978) also observed less charcoal rot incidence in some hybrids with one or more resistant parents and indicated excellent progress from selection.

The degree of determination of F_2 by F_1 (40%), F_3 by F_2 (30%) and low heritability (38%) is expected due to duplicate type of epistasis and high genotype x environmental interactions predisposing to charcoat rot. However, F_3 progenies show normal distribution (truncated towards zero) and surpass the parental limits enabling one to choose the transgressive resistant progenies. In the absence of absolute resistance, selection of F_3 progenies 2 S.D. below mean results in approximately 1% selection intensity (S.I.) and <6% susceptibility.

Leaf rust, SDM and charcoal rot resistance are inherited independently. It is possible to select rust resistant plants from R × S and R × R F_3 progenies with 1% SDM and 10% charcoal rot susceptibility. Rust resistance being a trigenic recessive character (Rana *et al.*, 1976; Indira *et al*, 1982), selected rust resistant plants will breed true in F_4 but segregate for SDM and charcoal rot resistance. Further selection for SDM resistance and transgressive charcoal rot resistant segregants under epiphytotic conditions will stabilize the resistant progenies. The progress from selection for SDM is expected to be fairly rapid due to possible involvement of few major genes (Rana *et. al.*, 1982) but slow for charcoal rot due to low heritability and higher genotype × environmental interactions. 'CSV 5', 'SPV 104', 'SPV 126', 'SPV 178', 'SPV 193' and 'SPV 488' are some of the recently developed varieties which incorporate multiple resistance to these diseases.

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Transforming Traditional Sorghums in India

N.G.P. Rao*

Viewed against the background of the agricultural history of India, changes that influenced Indian agriculture during the 1960s and 1970s are perhaps the most significant. The rapid impact of these changes and the potential created do give us confidence that India could successfully meet its current and future needs of the most needed agricultural commodities. We have certainly been fortunate to be participants and witnesses to this great transformation.

Mixed cropping, crop rotations, cultural practices, organic manures, chemical fertilizers and plant protection chemicals no doubt influenced traditional agriculture, but it is the major genotypic changes brought about during the 1960s that triggered cultivar-input-management-interactions; resulted in quantum jumps in productivity; imparted stability to production and enabled practice of new cropping systems leading towards more efficient land and water use.

The transformation that began with irrigated wheat and rice soon pervaded dryland food crops like sorghum and pearl millet, commercial crops, fruits and vegetables. Changes leading towards the transformation of sorghum in India is the subject of my presentation.

Agricultural Systems of Semi-Arid Tropics: Improvement or Transformation?

Agricultural systems of the semi-arid tropics (SAT) by and large, continue to be subsistence systems and reflect the highest degree of crop diversification. Analyzing the role of risk in dryland agriculture in India, Binswanger et al. (1980) concluded that income risk, measured as the variance of income over time, is high. Variability in production is the major source of this income risk rather than price variability. For risk averse farmers they contend that such income variability leads to underinvestment. This is true of all subsistence agricultural production systems. Consequently, mixed or intercropping became an important feature of traditional agriculture and its superiority in terms of insurance from risk, higher returns and better labor use has been well documented (Abalu and D'Silva 1980, Jodha 1980).

It may, then be pertinent to examine the essential components of traditional agricultural systems. There is a striking parallelism in the evolution of tropical cultivars across continents. They are tall; late maturing, the growing period being considerably longer than the length of the rainy season; generally photosensitive; and characterized by localized adaptation and low harvest indices. Such tropical cultivars are generally adapted to low population levels and generally exhibit lower rates of fertilizer response. Under adequate moisture and low populations they do produce large earheads reflecting their individual superiority, but their community performance is poor even when there is no stress. Since flowering generally takes place after the cessation of the rainy season, rainfall fluctuations render them highly vulnerable, and crop losses approach total failure in years of low and erratic rains. Depending on the components of the cropping systems, the degree of damage may vary and one of them might provide some insurance. Yet, sole and mixed crops in traditional systems are low yielding and climate-vulnerable. This is generally so with sorghum and applicable with some modifications to other dryland crops and cropping systems.

This being the case, a pertinent question is whether research efforts should be directed to improve existing systems or should they be directed towards transformation of existing sys-

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terns. All researches in India till the 1960s and in most African countries till today have been directed towards improvement of existing agricultural systems. They generally involved crosses between related varieties for cultivar improvement, fertilizer and population studies, practices aimed at better soil and water management and modifications to existing cropping systems. These efforts were based on local or improved local cultivars and did reflect increased yields under experiment station conditions. The recommendations that emerged from such researches were aimed at marginal increases and frequently involved change of cultivars, but similar in plant architecture to locals, use of organic manures, low levels of fertilizer and low plant populations and with some soil and water conservation measures such as mulching, contour bunding, etc. The recommendations that emerged from the dry farming research stations of the Deccan *rabi* furnish examples in this direction. They were somewhat "survival-oriented" rather than "productivity-oriented" and did contribute to some yield advances but could do little to cross the environmental barrier or the yield barrier.

Analyzing crop yields in relation to rainfall fluctuations, Rao et al. (1975) emphasized the need for transgressing environmental limits and aiming at quantum jumps in yield levels to enhance the productivity of rainfed crops. A breakthrough in rainfed agriculture can, therefore, be expected by planning for large quantum jumps rather than for slow and graded increases which are within the limits of environmental fluctuations. Illustrating from data on sorghum obtained during 1972/73, which was one of the most difficult years encountered with respect to rainfall, we (Rao et al. 1975) preferred the transformational approach to that of an improvement approach. It is this approach that has yielded results in the Indian context. I consider it meaningful to the rest of the SAT.

Considering the policy implications of their risk analysis in SAT India, Binswanger et al. (1980) concluded that there is no need for advocating development of risk graded technologies so that small farmers may adopt the low yield low risk ones and the large farmers the high yield high risk ones. I fully agree with them and the transformational approach cutting across environmental limitations is the answer and I therefore, propose to further deliberate and elaborate on this.

Genotype Alteration: Performance, Adaptation, and Stability

The attributes of tropical cultivars have been listed: tallness, lateness, photosensitivity, low harvest indices, poor community performance, etc. In traditional agriculture, the timing of the main stages in the reproductive cycles of plants is optimized in relation to seasonal conditions through control mechanisms that are extremely sensitive to daylength and temperature (Evans 1980). If this is so in traditional agriculture, the design and development of productive and stable agriculture requires re-optimization of the cycles of growth and reproduction in such a way that the emphasis is on the economic product rather than on total dry matter and that the more critical phases of growth coincide with favorable periods of climate.

Water use efficiency refers to the yield of dry matter produced per unit of water consumed and drought resistance is the ability to survive, endure and compensate for or escape damage from wilting (Reitz 1974). Sorghum is no doubt efficient in water use requiring about 322g of water per g of dry matter (Briggs and Shantz 1914), but if the production of total dry matter of the plant extends beyond a limit, it will then limit water use efficiency. Severe stress during seedling, flower primordial and grain filling stages is generally critical and it is desirable that the probability of these stages coinciding with assured periods of rainfall or profile moisture be maximized.

Most traditional *kharif* sorghums of the Deccan and the central Indian plateau require 140 days or more to mature, while the duration of a normal rainy season is from the beginning of July to mid or late September. August usually represents the peak rainfall month. Such sorghums usually remain in the vegetative stage till the second week of October, and if rains cease earlier, yield losses are heavy. The total dry matter produced in normal circumstances may be as high as 450 g per plant, and nearly 70% of this is accumulated in the stalk (Rao and Venkateswarlu 1971). They are characterized by a single peak for the rates of growth coinciding with flowering. The behavior of several African sorghums is similar (Goldsworthy 1970). The temperate sorghums on the other hand produce less dry matter per plant, exhibit two peaks for growth rates coinciding with preflowering and grain-fitling stages resulting in a 50 : 50 dry matter distribution (Anantharaman et al. 1978). This is illustrated in Figure 1.

Superior sorghum hybrids and varieties developed from temperate-tropical crosses have reduced maturity duration (100-110 days) and consistently yield well (Table 1). The critical stages of growth—seedling, flower primordia, and grain filling—coincide with periods of assured rainfall or satisfactory profile moisture status. Thus, in breeding for efficient water use for grain production such corrections for duration, dry matter production and differentiation at optimal times of the season are essential and should constitute the first steps in modifying traditional tropical sorghums.

Yet arguments are still advanced that in heavy rainfall areas the duration of the traditional sorghums still represents the optimum and that improved cultivars should match the duration of locals. Efforts in Africa (Andrews 1975) to develop long-season dwarfs are yet to yield useful results. Earlier studies by Rao et al. (1973) reveal that highest yields are obtained at intermediate heights and maturities and that an "intermediate optimum" satisfies several requirements including grain, stover, input responses etc., in tropical countries. If there is an extended season, it is better to capitalize on it through practice of suitable cropping systems rather than through

Table 1. All India performance of sorghum hybrids and varieties (*kharif).*

Hybrid/ Variety	Grain yield (kg/ha)				
	1978	1979	1980	Av,	%CSH-1
			Hybrids		
CSH-1	3582	3522	3034	3379	100
CSH-5	4307	3808	3437	3851	114
CSH-6	4265	3648	3480	3798	112
CSH-9	5036	4353	3836	4408	130
			Varieties		
SPV-221	3198	3303	3160	3220	95
SPV-245	3868	3564	3237	3556	105

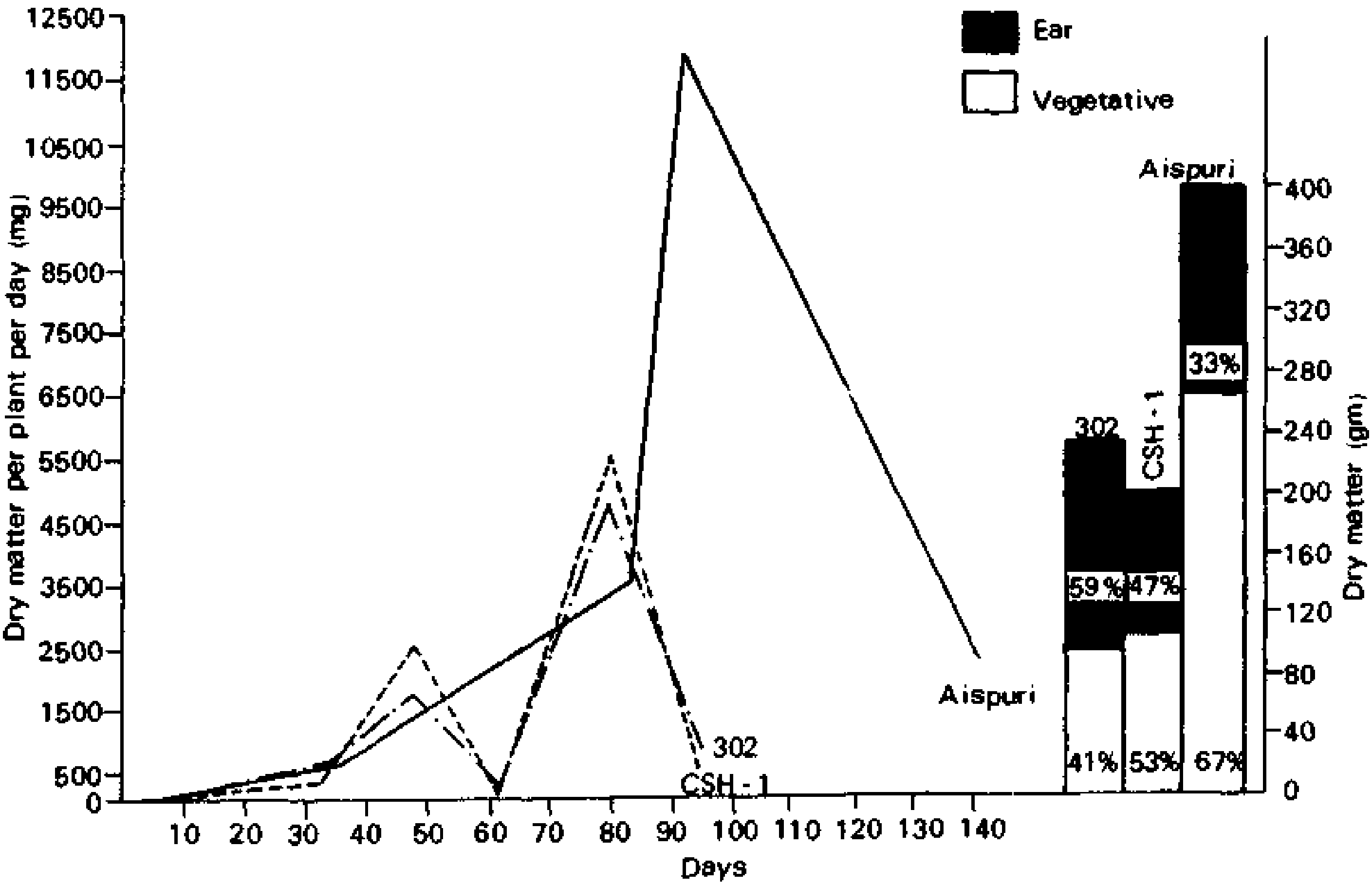


Figure 1. Rates of growth and dry-matter distribution of tropical and temperate sorghums.

growing very late cultivars. Extremely late varieties have no yield advantage.

Once, the major corrections for duration and dry matter in relation to rainfall probabilities are accomplished, we could capitalize on incorporating attributes like varietal differences for photosynthesis under moisture stress, root systems and various attributes associated with drought resistance. We have discussed these aspects earlier (Rao et al.1979) and I shall not go into them presently since other speakers may be considering them at length.

While the impact of altered genotypes of sorghum has been spectacular in some parts of India during *kharif,* attempts of altering *rabi* sorghums have met with partial success. The planting of *rabi* sorghums grown under residual moisture in black soil areas generally starts towards late September and may extend up to late October. Mid-October plantings are common. By November the temperatures begin to drop. Depending on the moisture status of the profile. the black soils begin to develop deep cracks either at flowering time or later. This results not only in moisture stress during the postflowering period, but it causes heavy lodging.

The variety M35-1 predominates in the *rabi* belt and we (Rao and Murty 1963) analyzed the reasons for its wider adaptation. Compared with compact headed types, it is earlier in maturity, has a better root system, and had optimum dry matter production. It is also the most drought resistant variety (Sullivan 1972).

The problems of varietal improvement during *rabi* are somewhat different. In years of stress, extreme earliness as exhibited by photosensitive hybrid CSH-2 enables it to escape drought effects and produce yield, but the yields are low and not comparable with M35-1 in normal years. In fact, we considered the use of such hybrids in extremely drought prone areas. The late *kharif* sorghums are also highly sensitive and become extremely dwarf, early, and low yielding during *rabi.*

The total dry matter produced by traditional winter types like M35-1 is not high like *kharif* sorghums and they do exhibit two peaks for rates of growth and a favorable dry matter distribution pattern. Efforts to further influence harvest index in favor of grain rendered types like R16 more susceptible to charcoal rot. This means, unlike *kharif.* the options for influencing duration and dry matter are limited during *rabi.*

Yet some progress has been made and hybrids like CSH-7R and CSH-8R and an improved variety SPV-86 did exhibit constant yield superiority over M35-1, even though the margin of increases were not as high as those obtained during *kharif* (Table 2). But, when the new hybrids were grown under a new set of agronomic conditions, i.e. advanced dates of plantings, fertilizer use, and optimal populations, yield differences over M35 -1 were substantial (Fig. 2). But as plantings became delayed, the yield advantage over M35-1 declined, and after a point in November they were inferior to M35-1. The parents of the hybrids had more *kharif* parentage in them, and as the plantings were delayed, apart from moisture stress, temperature sensitivity came into operation. The variety M35-1 is also less sensitive to low temperature. Therefore, I feel that development of temperature-insensitive males and females with *rabi* adaptation could lead to the development of superior *rabi* hybrids.

The *rabi* situation is difficult but is more predictable, since very little rain is received during crop growth. I believe that the limits of the moisture status and its progressive decline in *rabi* soil profiles under extreme stress, optimal, and suboptimal conditions have been quantified. It is then possible to decide on the limits of dry matter that such profiles could sustain to maturity. If these limits are known and with the present understanding of drought resistance and temperature sensitivity of genotypes, it should be possible to develop more efficient genotypes for the future.

That tropical cultivars are highly photosensitive and local in their adaptation has been well recognized. The virtues of photosensitivity in tropical situations have also been frequently overemphasized. While photosensitive varieties do tend to flower about the same time when plantings are scattered within a season, the yield

Table 2. All India average performance of *rabi* hybrids and varieties.

Hybrid/Variety	Grain yield (kg/ha)
CSH-8R (Hybrid)	3313
CSV-8R (SPV 86) (Imp. Variety)	3299
M 35-1 (Local)	2881

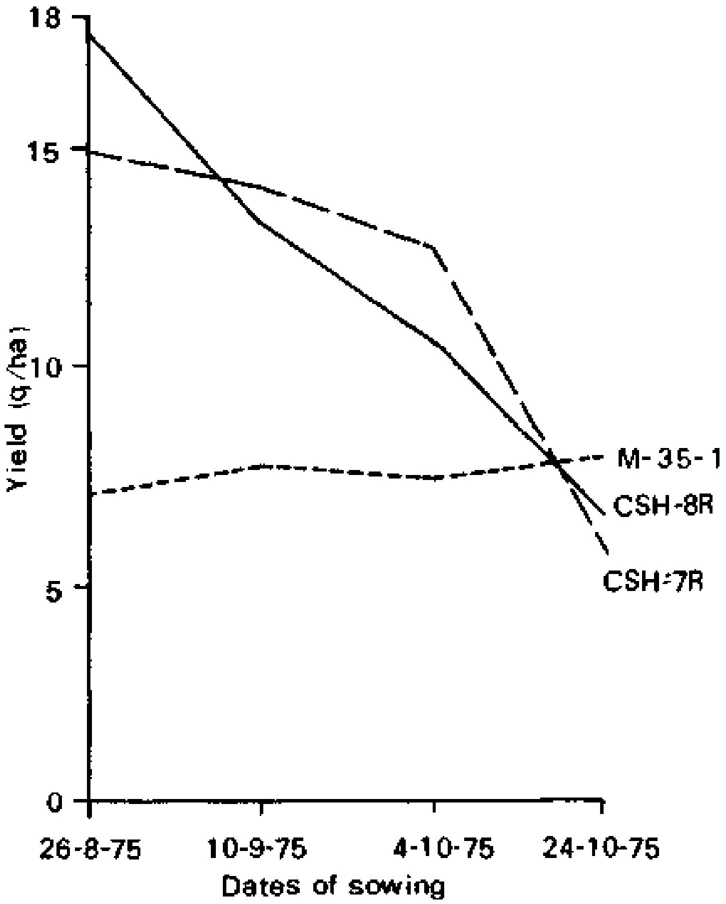


Figure 2. Yield of sorghum as affected by different dates of sowing during rabi *season (Sholapur).*

reduction on late plantings is drastic. Such cultivars, which by themselves are low-yielding and subject to climatic fluctuations in their own environments, could not be expected to adapt and perform in an altered environment.

Wide adaptation, therefore, involves genotype alterations to suit growing conditions, superiority in performance per se, and less sensitivity to daylength and temperature in some situations. Once these changes have been incorporated in altered genotypes, the entire *kharif* sorghum belt of India could be treated as one zone (Fig. 3) in place of the several small agroclimatic regions towards which breeding efforts were directed in the past (Rao 1970). This is a major conceptual change that furthered sorghum improvement efforts in the country.

The statement of Evans (1980) that high-yielding crops are neither more nor less susceptible to annual variation must be viewed with caution since the precise purpose of genotype alteration for dryland agriculture is to minimize such variation. An analysis based on over 300 experiments over several years (Rao and Rana 1980) furnished data on changes brought forth in improved cultivars developed early in the project with respect to average yield levels and coefficients of variability (Fig. 4). This is a very significant change that reflected on sorghum production over vast areas in Maharashtra and Karnataka States.

Our studies to date have also established that, compared with improved varieties, hybrids do exhibit homeostatic advantages particularly under moisture stress (Rao and Harinarayana 1968; Singhania and Rao 1976). A more recent analysis of 3 years data from All India experiments by Rao et al. (1982) further established that the hybrids CSH-9, CSH-6, CSH-5, and CSH-1 were the highest yielders in the *kharif* tracts of the entire country and were the most widely adapted. The improved varieties were no doubt superior to locals in yield and adaptability but were not comparable with hybrids. The locals were characterized by low means and high coefficients of variability We are now examining the possibilities for raising the yield of improved varieties to the level of hybrids (Balaramireddy and Rao 1981).

Further efforts to use risk aversion in plant breeding (Barah et al. 1981) point out that yield and risk preference based rankings are closely related. Also correlated are adaptability and stability lending support to our past breeding efforts towards genotype alteration and multilocational testing in the pursuit of low risk and high yields (Fig. 5).

We are now concerned with the task of incorporating greater levels of resistance to insect pests (Rao et al. 1977) and diseases (Rao et al. 1980) against the altered genetic background so as to confer greater levels of stability in performance besides reducing or even eliminating use of pesticides. Our emphasis now is on understanding and incorporating resistance to several of the insect pests and diseases together in altered genotypes (Rao 1981).

Adaptation to Soil and Climate

Soil, water (rainfall) and solar energy constitute the natural resources of semi-arid crop production systems with a well established relationship of subsistence adaptation. It has been the past experience that resource management by itself did not yield perceptible results until a relationship of productive adaptation has been established.

The SAT regions have an arid season of 5-10 months when potential evapotranspiration (PET) exceeds precipitation. Since PET is dependent on rainfall, temperature, and crop cover, crop adaptation to soil and climatological factors is of primary concern. We will now consider genotype adaptation to soil and climatic factors.

Agriculture in the tropics is said to have first developed in areas where the soils are of high base status—Vertisols, Alfisols, Mollisols, and certain Entisols and Inceptisols—which are also the centers of population density. The impact of the green revolution has also been largely con-

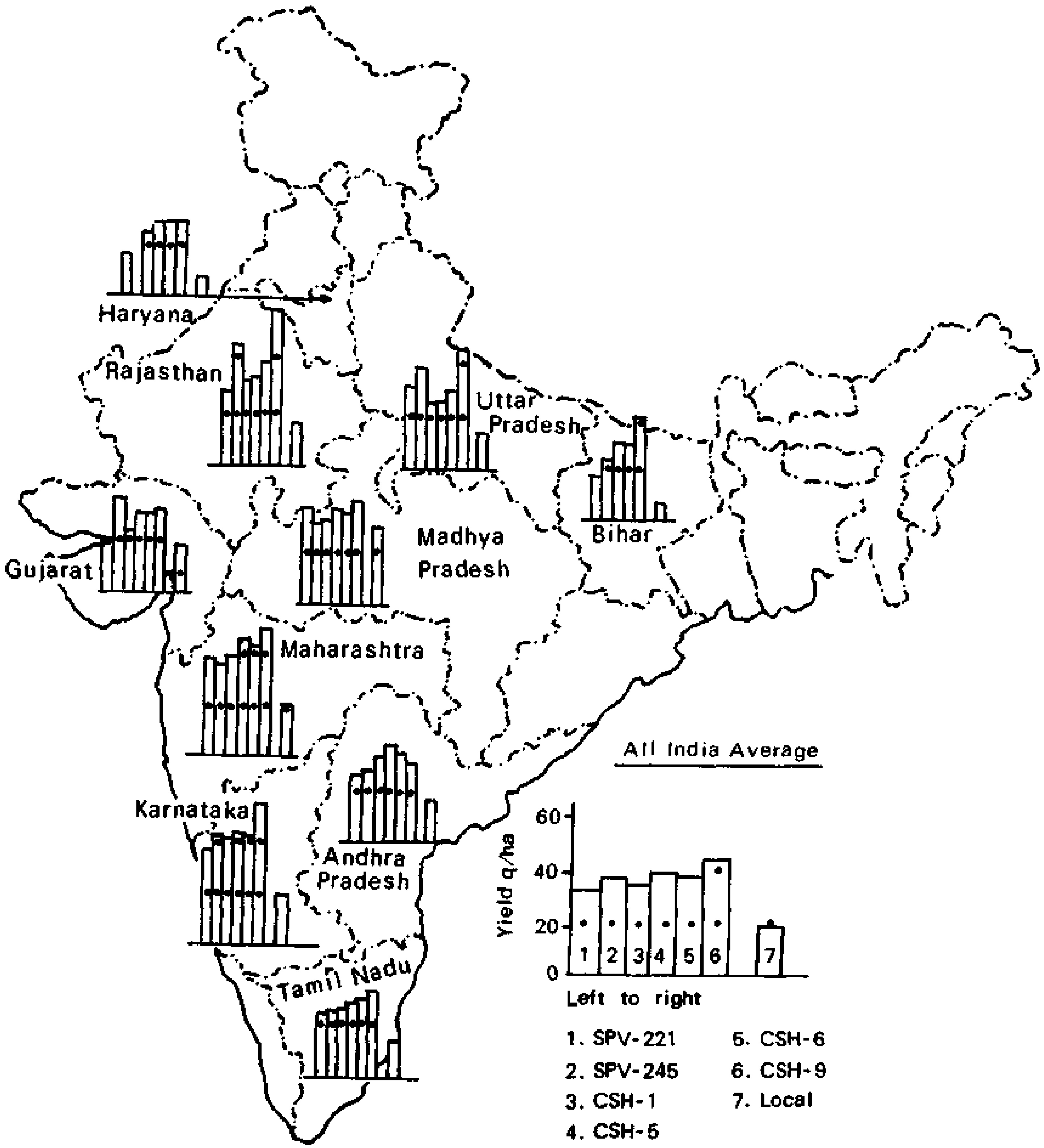


Figure 3. Hybrid and varietal performance in India (1978-80 kharif).

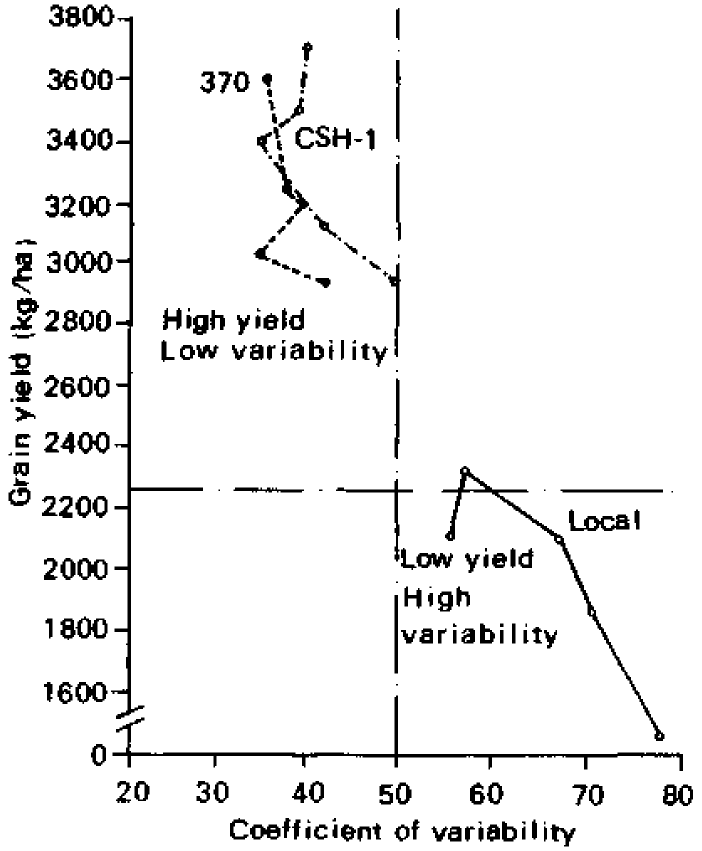


Figure 4. Adaptability of tropical and temperate sorghums.

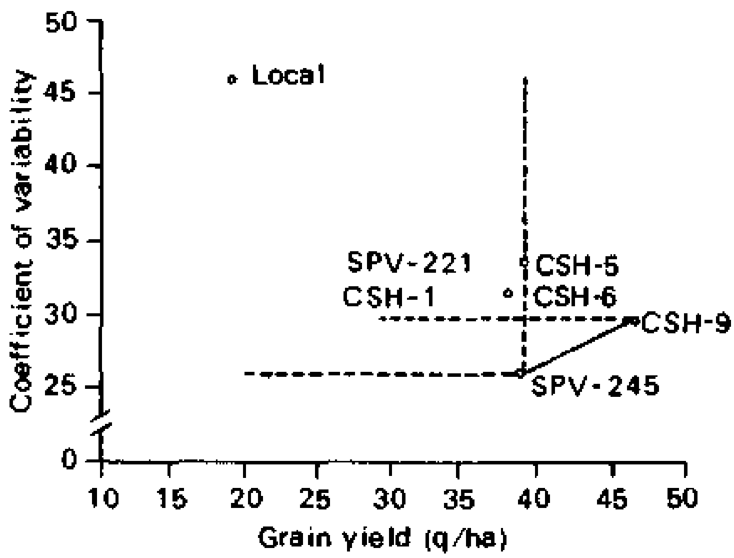


Figure 5. Adaptability efficiency of some selected hybrids and varieties (1978, 1979, 1980).

fined to areas of high base status (Sanchez and Buol 1975).

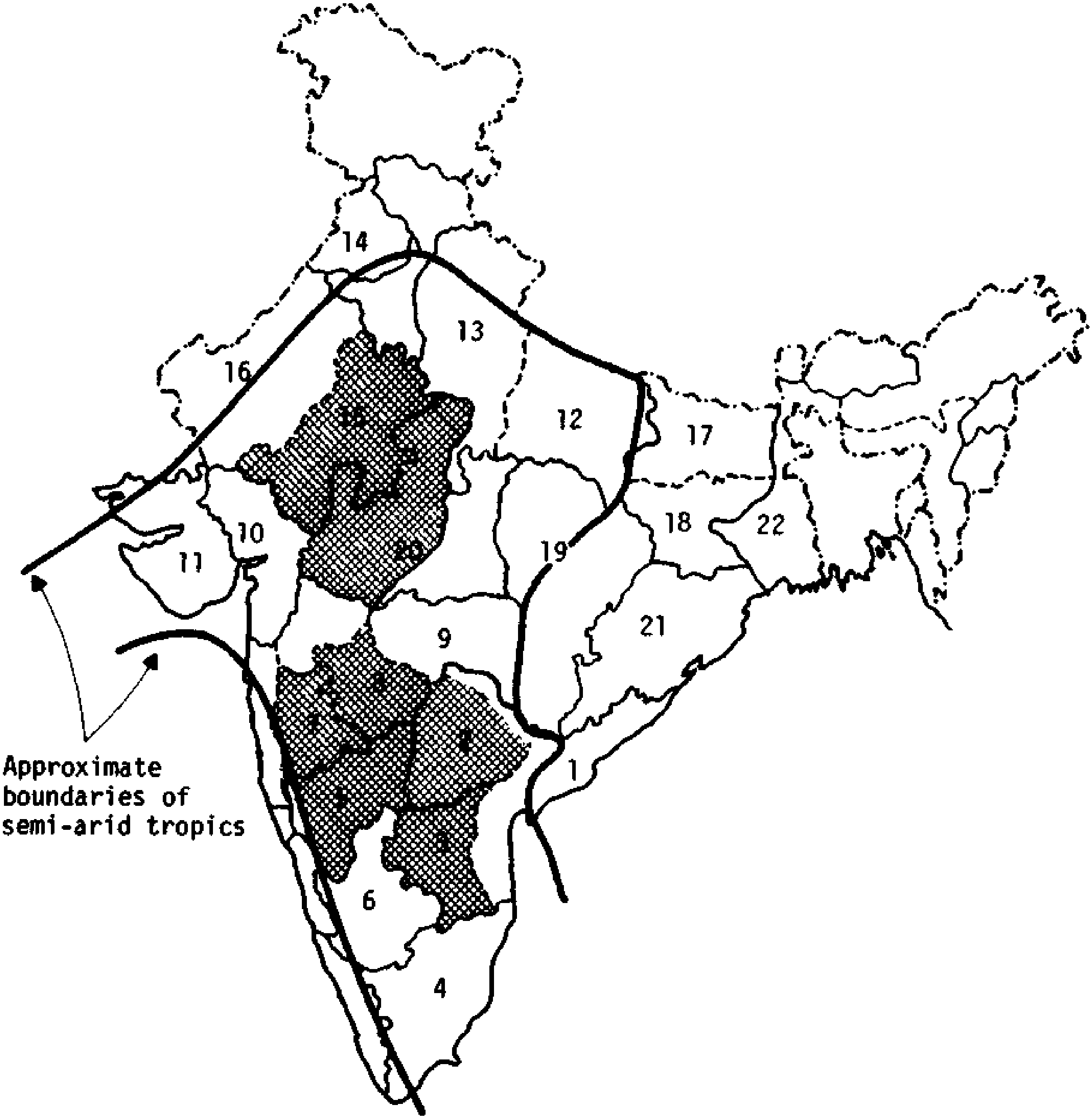
Sorghums in India are predominantly cultivated in Vertisols and to a limited extent in Alfisols and both have not posed any serious problems. The major point of concern is the ability of the soil profile to store water for crop use. Depending on the soil type, this may vary from less than 100 mm to over 250 mm. The storage ability partially mitigates the effects of irregular rainfall. Encrustation problems may be encountered, more particularly in the red soil areas, if heavy rains after sowings are followed by a hot and dry spell, but this problem has not been serious.

If water does not limit vegetative growth, total dry matter production is related to solar radiation and can be predicted. But frequently water stress does limit the rate of dry matter production. Fluctuations in rainfall, which are changes repeated over time, are a rule rather than an exception. Predictions of the amount and distribution of rainfall are difficult. Based on early rainfall in a season, some predictions of the behavior of rains may be possible. Studies by the Indian Meteorological Department estimated that climatic variations resulting in droughts, floods, etc., may account for more than half the variation in crop yields.

In recent years there has been growing interest in climate changes.and climate-food output relationships. It is believed that good or bad weather in one part of the world may have a similar influence in other parts (USDA 1975). Unfavorable weather conditions during 1964-66 and 1972-74 were responsible for a decline in global food production. Weather variability is considered to be a much more important consideration than a global cooling or warming trend (Thompson 1975). Averages of the preceding 30 years are stated to provide better guidelines for development of strategies compatible with the laws of nature to mitigate effects of climatic fluctuations on production.

The SAT region of India, excluding the coastal areas of Andhra Pradesh and Tamil Nadu, parts of southern Karnataka, eastern Uttar Pradesh, eastern Madhya Pradesh, northeastern Rajasthan, Haryana, and Punjab represents the major grain sorghum belt. Even these excluded areas grow forage sorghums. The areas prone to moderate and severe drought are depicted in Fig. 6. Of the 16-18 million hectares grown under sorghum, approximately 2/3 of the area is cultivated during the rainy season (*kharif*) and 1 /3 during winter (*rabi*) primarily in the Deccan Plateau covering near continuous areas in Maharashtra, Karnataka. and Andhra Pradesh.

The limits of the rainy season in most regions



1. Coastal Andhra Pradesh
2. Telangana
3. Rayalaseema
4. Tamil Nadu
5. Interior Karnataka North
6. Interior Karnataka South
7. Central Maharashtra
8. Marathwada
9. Vidarbha
10. Gujarat
11. Saurashtra & Kutch
12. Uttar Pradesh East
13. Uttar Pradesh West
14. Punjab & Haryana
15. Rajasthan East
16. Rajasthan West
17. Bihar Plains
18. Bihar Plateau
19. Madhya Pradesh East
20. Madhya Pradesh West
21. Orissa
22. Gangetic West Bengal

Figure 6. Major sorghum areas prone to drought.

are fairly well known. The southwest monsoon, which influences most of the sorghum belt with the exception of Tamil Nadu and a small portion of Andhra Pradesh, usually establishes towards the end of June and terminates before the end of September. The probable date of commencement of sowing rains, the months and weeks when rainfall probabilities are high and low, and the likely inter-spell duration between rains have been computed (Raman 1975). July is the least drought-prone month and October the most (George et al. 1973). Premature cessation of the monsoon by the beginning of September is not uncommon, and October rains are uncertain. Consequently traditional *kharif* sorghums may run out of moisture before flowering. The moisture status of the *rabi* soils, where sorghums are grown under residual moisture, is frequently unsatisfactory during the grain-filling period, resulting in serious yield losses. The deccan *rabi* used to be famine prone.

It is, then, the water balance that limits the length of the growing season. The mean duration of the crop-growing season for some sorghum-growing areas computed by Krishnan (1974) is summarized in Table 3. The justification for long-season sorghum seem to arise from such exercises.

A closer look at the present-day situation in areas represented by Jalgaon, Akola, and Amravati in Maharashtra, and Neemuch, Khandwa. and Indore in Madhya Pradesh, which are all in the drought-prone black soil belt, reveals that 100 -110-day hybrids with some built-in ability to stand grain deterioration when rains occur late have taken firm root, providing for assured single-crop sorghum and a possible second crop of safflower or chickpea. Areas with supplemental irrigation took to a sorghum-wheat rotation that was not possible with traditional cultivars.

Thus computed, crop-growing seasons at best indicate the longest possible growing period, and strategies to avoid failures should take into account the effective rainfall period with its attendant aberrations. One has to plan for assured single-crop yields within sole and intercropping systems in low rainfall areas, and two-crop sequences in high rainfall areas.

Table 3. Crop growing season in soma sorghum growing araas (Krishnan 1974).

Location	State	Av. annual rainfall (mm)	Av annual PET (mm)	Crop growing season: Actual duration	Crop growing season: No. of days	Remarks
Kurnool	Andhra Pradesh	674	1827	Jun 17-Oct 26	132	Alfisol-Kharif and Vertisol-Rabi
Cuddpah		743	1834	Jun 14-Nov 30	170	
Hyderabad		743	1834	Jun 14-Nov 30	130	"
Raichur	Karnataka	717	1951	Jun 12-Oct 28	139	Mostly Vertisol-
Gulbarga	"	753	1913	Jun 9 -Oct 21	135	*Rabi*
Poona	Maharashtra	715	1474	Jun 4 -Nov 21	171	"
Sholapur	"	742	1802	Jun 8 -Nov 2	148	"
Ahmednagar	"	677	1605	Jun 2 -Nov 8	160	"
Aurangabad		792	1774	Jun 5 -Nov 20	169	(Some *Kharif)*
Akola	Maharashtra	877	1730	Jun 5 -Dec 4	183	Mostly Vertisol-
Amravati	"	975	1769	Jun 4 -Dec 22	202	*Kharif*
Jalgaon	"	840	1912	Jun 9 -Nov 21	166	
Khandwa	Madhya Pradesh	961	1729	Jun 7 -Dec 30	207	"
Neemuch	"	895	1601	Jun 14-Jan 15	216	"
Hanamkonda	Andhra Pradesh	945	1787	Jun 4 -Dec 8	188	Alfisol- *Kharif* and Vertisol-Rabi
Bidar	Karnataka	977	1754	Jun 1 -Dec 13	196	Alfisol -*Kharif*
Indore	Madhya Pradesh	1053	1813	Jun 5 -Dec 27	206	Vertisol-Kharif

Statistical probabilities of the occurrence of drought have limitations, and the farmer's interest being always in the "current year," knowledge of soil and climate together with actual performance in normal, above-normal, below-normal, and aberrant years of rainfall would furnish a rational basis for decision making in the development of crop production strategies that would stand the test of time. Such years were encountered during 1964-66, 1972-74, 1975-76, 1976-77. 1980-81. etc., and both rainfall and yield data for diverse cultivars are available for analysis. This transitional period in Indian sorghums has thus furnished a valuable opportunity to assess the potentialities and limitations of alternate crop production strategies and arrive at rational conclusions. Such a strategy based on actual situations encountered seems to be the best suited to minimize climatic vulnerability and to maximize productivity when encountered with more favorable situations (Tables 4 and 5).

Genotype alterations coupled with management practices, alternate cropping systems, and contingency plans such as crop substitution under aberrant situations, furnish the means to meet adverse and favorable conditions. This leads us to a consideration of resource utilization through genotype-input-management interactions.

Genotype-Input-Management Relations

That selection must be oriented towards changing agronomic practices has frequently been emphasized. That plant breeders have more frequently selected for higher potential under favorable conditions associated with rapid rise in the use of agronomic inputs and that this may be an undesirable road to follow, more particularly, in the context of the need for increasing food production in developing countries and the limited resources of the small farmer has also been pointed out (Evans 1976, 1980). Since tropical sorghums involve developing countries and small farmers, the issues need examination.

Table 4. Rainfall attributes over test locations.

Rainfall attributes	Year 1972/73	1975/76	1976/77
1. Total rainfall (mm)	634	989	917
	(29)	(25)	(36)
2. Number of rainy days	42	69	59
	(29)	(25)	(36)
3. CV (%) of monthly rainfall	153	136	142
	(29)	(25)	(36)

Note: Figures in parentheses indicate number of locations on which the averages were based.

Table S. All India average yields (kg/ha) of released hybrids.

Hybrids	Year 1972/73	1975/76	1976/77
CSH-1	3602	2869	3138
	(35)	(32)	(32)
CSH-5	3925	3658	3568
	(35)	(32)	(32)
CSH-6	4013	3466	3090
	(35)	(32)	(32)

Note: Figures in parentheses indicate number of locations or which the averages were based

While there have been attempts to orient breeding towards changes in agronomy such as mechanized agriculture, it is now the genotype change that initiated changes in agronomic practices, eventually resulting in production advances. This has been the case with cereals like wheat, rice, sorghum, etc., and is now beginning to reflect in grain legumes. I will examine the case of sorghum at some length.

Traditional technology emphasized "local improved" varieties, somewhat delayed plantings possibly to limit excessive vegetative growth, low seed rates, periodic application of organic manures, and limited use or absence of fertilizer application. This had no doubt a survival value, but its impact on productivity or stability of production has not been perceptible. On the other hand, the effect of an altered genotype in relation to input application and management has been more conspicuous, and this has been illustrated with *rabi* sorghums earlier.

Nutritional adaptation is widespread in nature and there are distinct genotypic differences for response patterns to nutritional elements, and toxicities as well. At an application level up to 50 kg N/ha, sorghum hybrids and some improved varieties have returned 15-28 kg of grain per kg of nitrogen against 6-8 kg for traditional locals. Further, in hundreds of nitrogen response trials conducted all over India during several years, we never observed crossing over of response curves to indicate that certain genotypes (including locals) were higher yielding at lower levels of nitrogen application or, conversely, where any hybrids were yielding less than others at lower levels but outyielded them beyond a point of fertilizer dosage.

Similarly, several studies on genotype responses to population levels in All India trials established the superiority of altered genotypes for community performance compared with the improved local cultivars. Population levels of 180 000 to 200 000 plants per hectare were optimal at the field level.

The response of the altered genotypes to fertilizer and population levels are more spectacular and coupled with their lower susceptibility to climatic variables, notably rainfall, their adoption rate is on the increase, although the level of fertilizer used on commercial sorghum fields is still low. The response patterns during *kharif* and *rabi* are illustrated in Figures 7 and 8.

Considering all agronomic inputs, including use of fertilizer, pesticides, etc., it has been stated frequently that the performance of high-yielding hybrids and varieties remains satisfactory only under optimal inputs (including irrigation water) and management, and that their yields will not be satisfactory under absence or lower levels of such inputs and management. Consequently, "high yield agriculture" is associated with "high input agriculture" and it is questionable whether this is applicable to the small farmers in developing countries. This aspect has been examined in a multilocation experiment conducted over 3 years (Vidyasagar Rao et al. 1980). The top-ranking hybrids and varieties maintained their relative ranks under both types of input-management

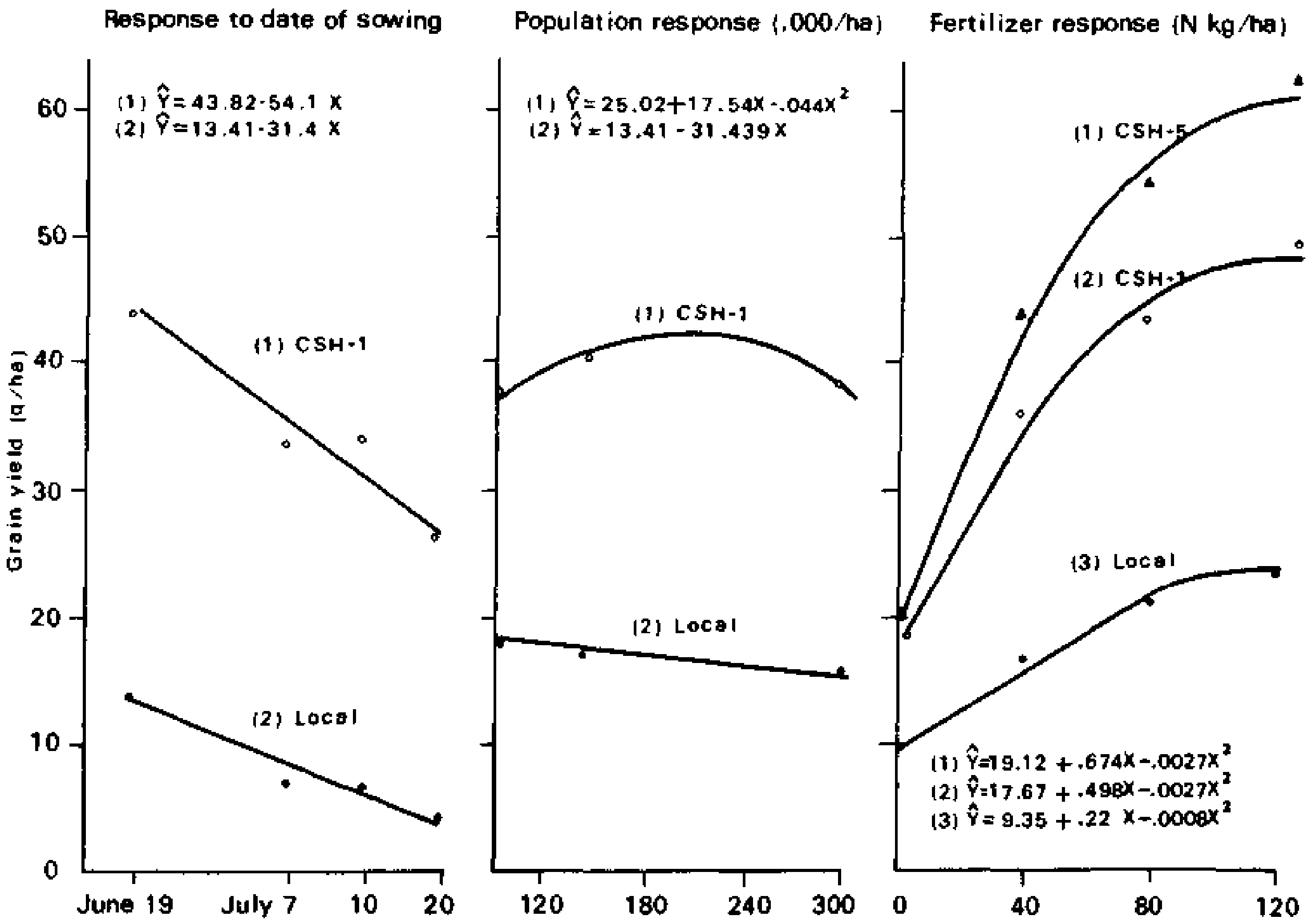


Figure 7. Components of production (kharif).

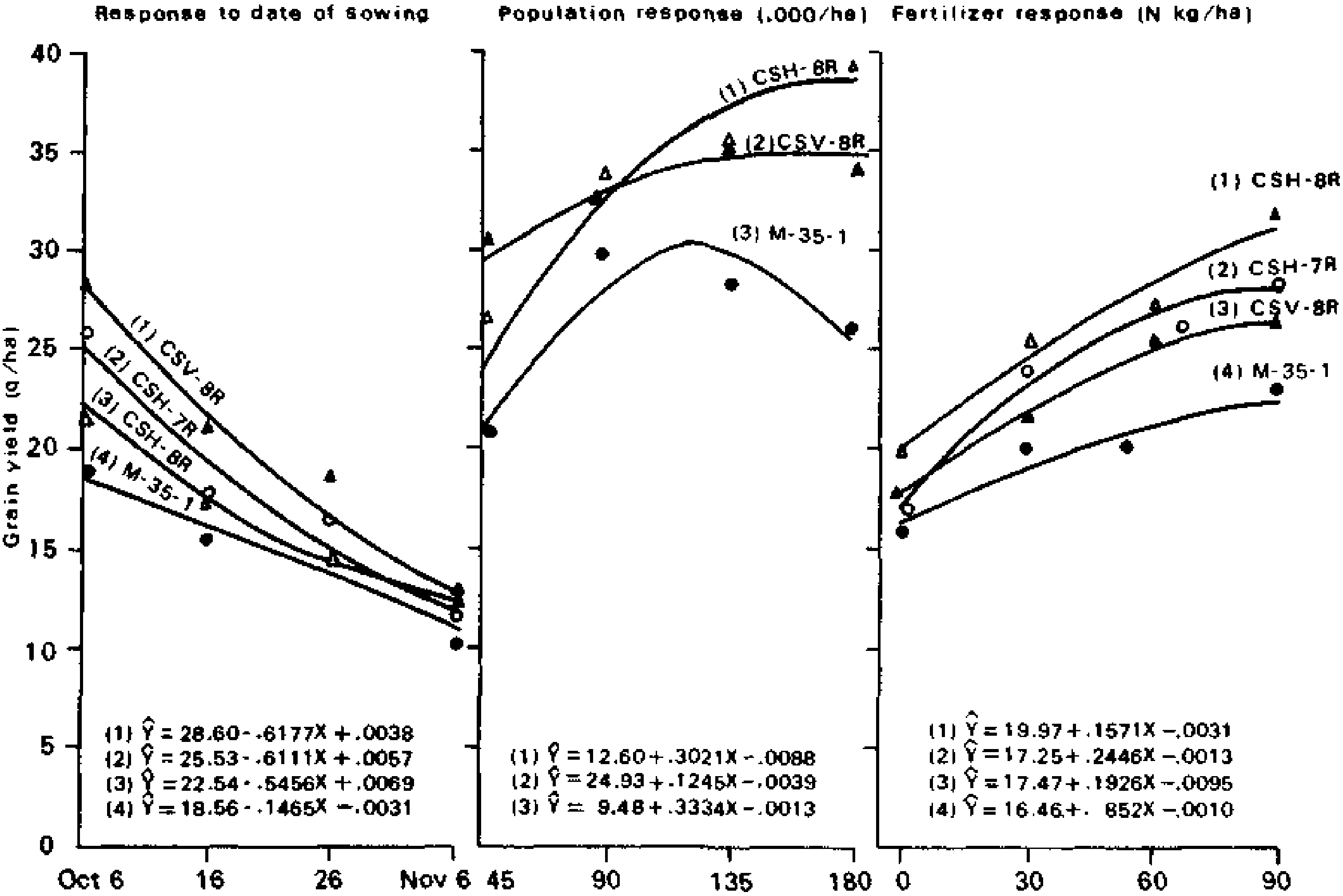


Figure 8. Components of production (rabi).

Table 6. Mean yields and ranks of some hybrids and varieties under high and low management during *kharif* seasons of 1974, 1975, and 1977.

	High management		Low management	
	Yield (kg/ha)	Rank	Yield (kg/ha)	Rank
Hybrids				
CSH-1	3569	4	2468	4
CSH-5	4514	1	3185	2
CSH-6	4125	3	3346	1
Varieties				
CSV-3	3200	5	1970	5
CSV-5	2622	6	1701	6

Table 7. Rank correlations between high and low managements.

Year	Trial	Coefficient
1974	Variety Trial	0.91**
	Variety/Hybrid Trial	0.94**
1975	Hybrid Trial	0.85* *
1977	Early Duration Trial	0.85**
	Mid Duration Trial	0.80**

*• Significant at 1%.

levels (Table 6). The rank correlations were highly significant (Table 7). The yield levels were no doubt different at different levels of management. The genotype x input-management interactions were significant only in a few cases, and even there the magnitude of the interaction m.s.s. was the lowest compared to the m.s.s for genotypes or managements.

These and various other studies indicate that agriculture based on altered genotypes is not incompatible with lower input levels, and the actual level and use of inputs gets into the realm of availability, supply, credit, and related matters rather than technology-imposed limitations. While the yield levels may vary depending on input use, altered genotypes did confer greater levels of stability and productivity. In some years and areas, the difference has been of the order of economic yields against total failure.

Traditional *kharif* sorghums in the Deccan used to be planted during mid-July. Sorghum hybrids based on temperate materials showed increased susceptibility to shoot fly under late plantings (Fig. 9a). The dominant mechanism of resistance to shoot fly is nonpreference for oviposition, and at times of shoot fly buildup, the hybrids were preferentially attacked. But once the advantages of planting with the onset of the monsoon for higher yields and avoidance of shoot fly were demonstrated, the practice caught on and virtually no insecticide is used for shoot fly control on commercial *kharif* hybrid sorghums. This is a management change leading .towards pest avoidance. At the same time, shoot fly control through carbofuran seed treatment, application of granules, etc., have been recommended and practiced under early *rabi* plantings in some areas and in seed production plots sown at altered timings (Rao 1979).

Similarly, the advent of early-sorghum hybrids and the consequent growing of early and late cultivars in the same area during initial years of hybrid spread resulted in extended periods of flowering conducive to rapid multiplication of sorghum midge (Fig. 9b), causing damage on late locals. The gains in hybrid yields were offset by reduced yields of local cultivars. A judicious policy of en-block coverage of hybrids of approximately similar maturities, in preference to a dissipated spread, resulted in the elimination of the causative factor of extended flowering and contained midge (Rao and Jotwani 1974). This is another example of a management change consequent to a genotype change. In fact, it may be said that the incidence of midge promoted hybrids in some areas.

Another example of a transitional problem is grain deterioration (Fig. 9c). Traditional cultivars normally maturing in December have clean grains. The reduction of duration to minimize climatic vulnerability caused them to ripen during mid or late October, with a low probability of occurrence of rains. Farmer reaction to the first hybrid was

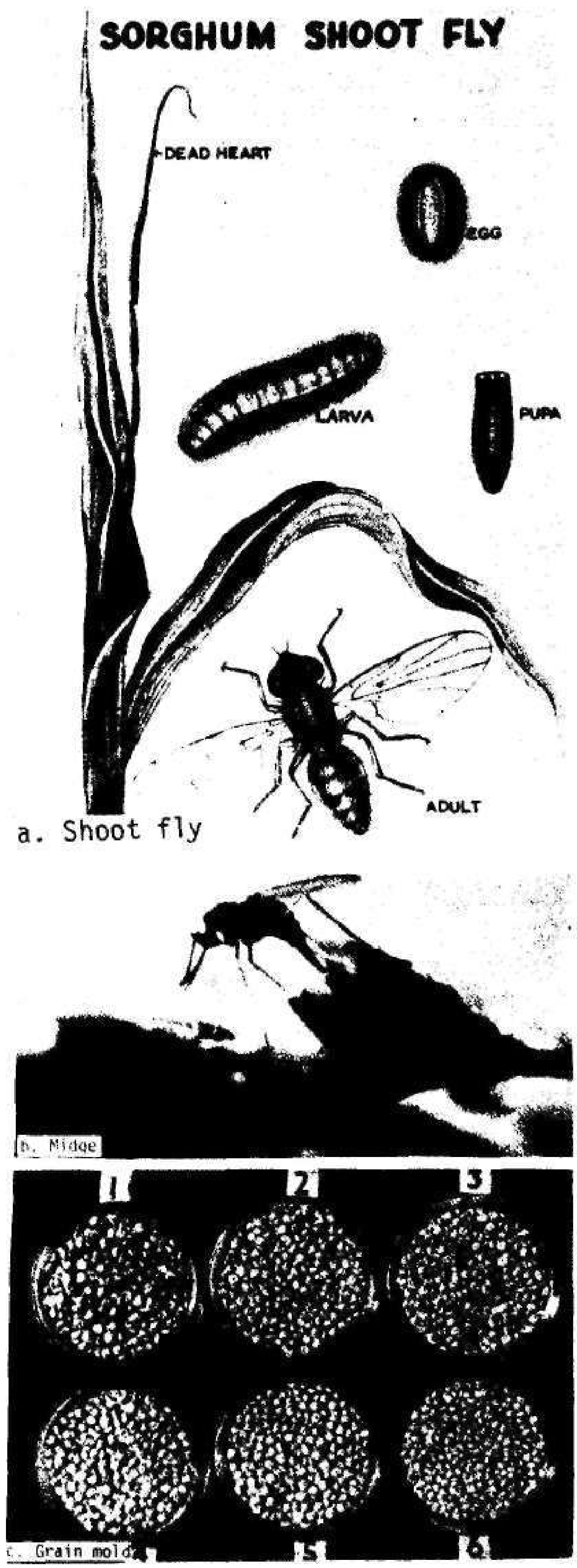


Figure 9. Problems encountered during the transition period from vulnerable to stable agriculture.

excellent in dry and low-rainfall years, since both yield and grain quality were good; but in years of extended rainfall poorer grain quality resulted and consequently the price received a setback. The demands of dry and wet years are apparently antagonistic and one has to find a satisfactory compromise. A clearer understanding of the problem of grain deterioration (Rana et al. 1978) and the development of hybrids like CSH-5, CSH-6, and CSH-9 not only reduced the magnitude of the problem of grain deterioration, but acted as an incentive to stay with early-maturing hybrids and increase yields further through the practice of sequence cropping in areas of assured rainfall.

Thus, during the period of transition from vulnerable to stable agriculture, such problems of transformation (Fig. 9a, b, c) are not uncommon, and one has to find ways and means to get over them till we move from a subsistence inequilibrium to a stable and productive equilibrium.

I will now turn to the effects of genotype modification on cropping systems. The role of mixed or intercropping in traditional agriculture has been idealized. In the African context, Abalu and D'Silva (1980) stated that while traditional intercropping systems have a socioeconomic rationale, most efforts at improvement have been towards sole crops, which have apparently not yielded anticipated results on farmer holdings. Furthermore, single crop technologies should be discouraged and in their place an approach that accounts for all crops of the farming system should be evolved. Jodha (1980) felt that the difficulties of incorporating high yielding varieties into intercropping systems may be one of the factors responsible for their limited spread. This raises questions whether sole crop technologies are at variance with intercrop technologies and whether different approaches are necessary.

One has to first realize that the component cultivars of the traditional intercropping systems are themselves the products of climate vulnerable subsistence agriculture. But for the spread of risk cover over species, they are essentially replacement systems characterized by low yields. Unless the components themselves undergo radical alteration, the system will not alter. Rao and Rana (1980) demonstrated that sole crop stability and productivity is a prerequisite for productive intercropping systems. Further, based on studies involving inter- and intra-species competition, genotype x density interactions and alternate planting patterns, Rao et al. (1981a) examined the design and practice of stable, productive and profitable intercropping systems. Summarizing data from several All India trials, Rao and Rana (1980) furnished evidence of such systems which involved sorghum as the principal crop with 90-95% of the sole crop yield and pigeonpea, soybean and groundnut as intercrops (Table 8). New and more remunerative crops like onion, garlic, etc., are now being experimented to enhance returns. Traditional intercropping systems which have given place to sole crops of hybrid sorghum have now been oriented towards more profitable intercropping (Rao and Rana 1980).

While such intercropping systems are advantageous in areas of relatively low rainfall, multiple cropping is more profitable in high rainfall areas with moisture retentive soils. A vast portion of the black soil belt of the Deccan and central Indian plateaus with 800 mm of annual rainfall which sustained 5-6 months' crops of traditional sorghums, can now take an assured crop of short-season hybrid in all years and a following crop of safflower or chickpea in normal and above normal years of rainfall (Fig. 10). Rao and Rana (1980) felt that the present shortages of grain legumes and

Table 8. Yields in sorghum based intercropping systems averaged over several experiments.

Intercropping system (monocrop/ intercrop)	Average yield (q/ha)			
	Sorghum (sole crop)	Sorghum (intercropping system)	Intercrop (sole crop)	Intercrop (intercropping system)
Sorghum/pigeonpea	35.811.9	32.4+1.4	16.5+0.9	9.410.4
Sorghum/soybean	33.0±1.9	32.211.8	13.9+0.7	5.510.3
Sorghum/groundnut	33.612.7	33.1+1.8	10.411.4	4.810.5

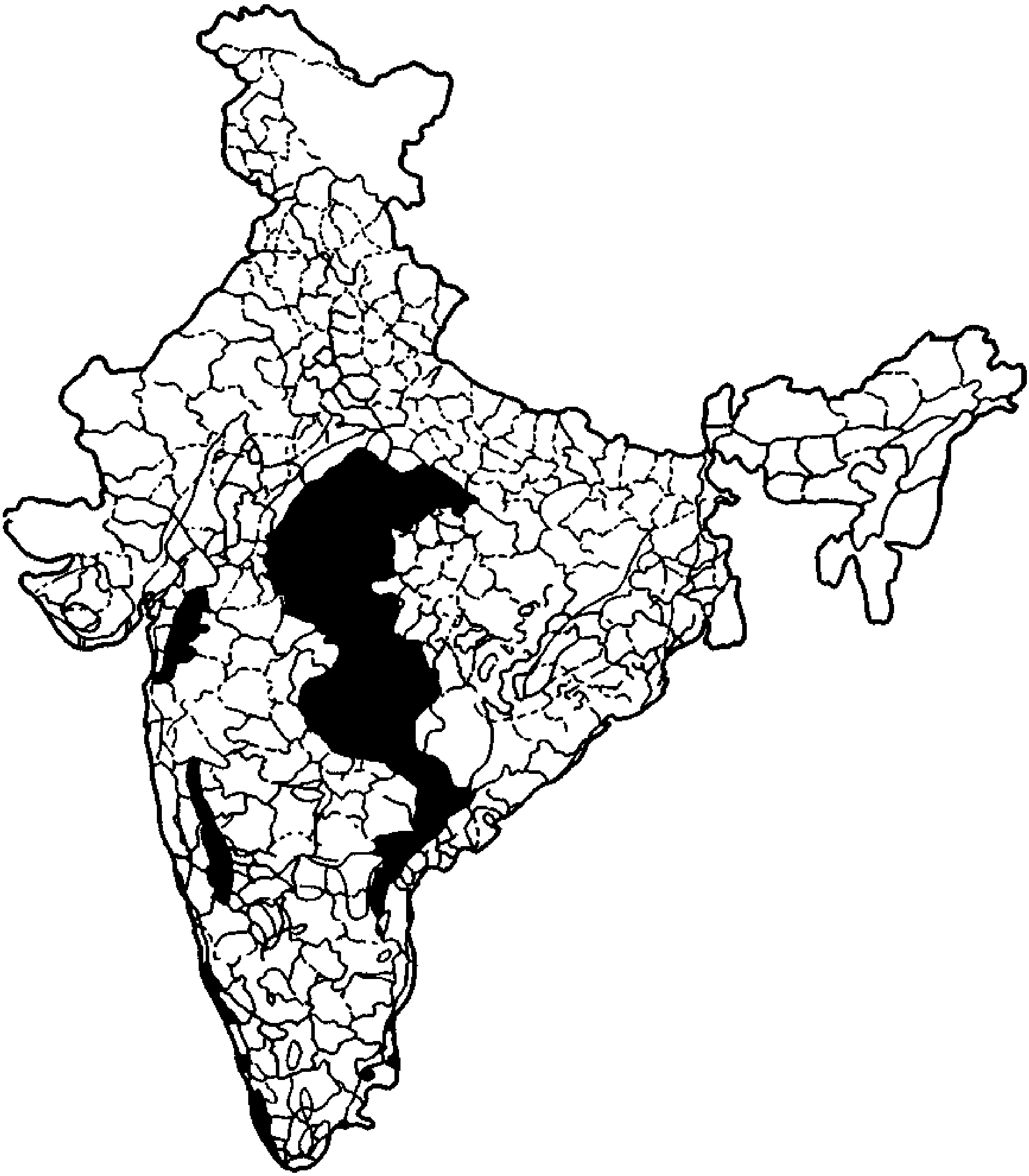


Figure W. Sorghum-growing districts for potential double cropping under rainfed conditions in India.

edible oilseeds could be met by the practice of sorghum based inter- and sequence cropping on existing sorghum acreages.

That productivity per year in the tropics will probably be achieved by attempts to maximize the number of crops rather than yield of each crop (Evans 1980) is relevant for areas where traditionally long season sorghums have been under cultivation in India and Africa. Emphasis on the manipulation of the cropping system based on modified cultivars will be more fruitful, as demonstrated in India, than attempts to breed improved cultivars comparable to late locals in maturity.

Ratooning hybrid sorghum has become a common practice in large areas of the Jalgaon district of Maharashtra, in some tank-fed areas of Andhra Pradesh, particularly when water is not adequate for rice cultivation, and under supplemental irrigation in several situations.

The advent of hybrid sorghums gave birth to an organized hybrid seed industry in the public and private sectors.

Some Case Studies

Any crop improvement strategy for rainfed lands should provide for assured yields even when unfavorable weather conditions are encountered. It should also furnish the means to maximize output if rainfall is normal or optimal. As discussed, genotype alterations coupled with management practices, alternate cropping systems and contingency plans provide ways and means to meet adverse as well as favorable conditions. This will be illustrated with a few examples.

All India national demonstrations of sorghum conducted in previous years on 1-ha plots revealed that in none of the years were average yields less than 2500/kg/ha, and maximum yields recorded were quite high (Fig. 11). In the initial years of hybrid spread during the *kharif* in the States of Maharashtra and Karnataka and their impact on overall *kharif* yields, projections were made on the possible impact of the total coverage on yields which turned out to be 2500 kg/ha. This indicates that the present average yields of *kharif* could be elevated to 2500 kg/ha. Higher order yields recorded are comparable to those obtained elsewhere in the world.

Another example is the performance of CSH-1 during the early years of its spread in the Harpanhalli taluq of Bellary district in Karnataka State. In one of the most difficult drought situations encountered, hybrid yields on an area basis were spectacular (Fig. 12).

The 1972/73 crop year witnessed widespread drought in many parts of the world including India. The yields of improved cultivars at 29 experimental sites all over India ranged from 2500 to 4000 kg/ha, against the near total failure of some late locals. Analyzing rainfall-yield relationships during this year, Rao et al. (1975) observed that the amount of variation in yield ascribable to rainfall was mostly determined by the number of rainy days and the coefficient of variation in monthly rainfall. The variation accounted by rainfall characteristics did not exceed 40% with any of the improved cultivars and it was only 15-20% with the hybrids CSH-1 and CSH-5. Early maturity coupled with hybridity conferred homeostatic advantages. The performance of CSH-1 during *rabi* in Andhra Pradesh is summarized in Table 9. This is based on early planting and fertilizer use in a year when rainfall was low.

The 1976/77 crop year was a case where rains were well distributed during July and August, but ceased abruptly by the first week of September in the Deccan and Malwa plateaus. The late locals suffered, but in Maharashtra State, where hybrids covered 52% of the *kharif* area, *kharif* sorghum production touched a record 2.96 million metric tons. The compensation of hybrids for failure of locals has been tremendous.

Assessing the results in the pilot project area of Indore in Madhya Pradesh, Choudhary (1980) reported that CSH-5 recorded the highest average yield among the various crops tried. Most farmers adopted only two practices—improved high yielding seeds and fertilizer. The technology was particularly beneficial to the small farmer. *Kharif* sorghum accounted for most of the cropping in otherwise *kharif* fallows, which would normally be cropped by rainfed wheat during *rabi.*

The minimum yield guarantee schemes of the Governments of Maharashtra and Andhra Pradesh with rainfed sorghums have been a phenomenal success. Data from Maharashtra are summarized in Table 10.

The best proof is on the impact of the hybrid coverage on *kharif* sorghum production in the States of Maharashtra and Karnataka (Table 11) where the coverages have been substantial. Other states could emulate this example.

So far, we have considered sole crop examples. The possible impact of productive inter- and sequence-cropping systems have been examined by Rao et al. (1979) and Rao and Rana (1980).

Economic Analysis

I want to conclude with a brief reference to some economic analyses.

Jodha (1980) stated that "the scope for dynamizing SAT agriculture is limited for want of viable technological options." As a solution, he com-

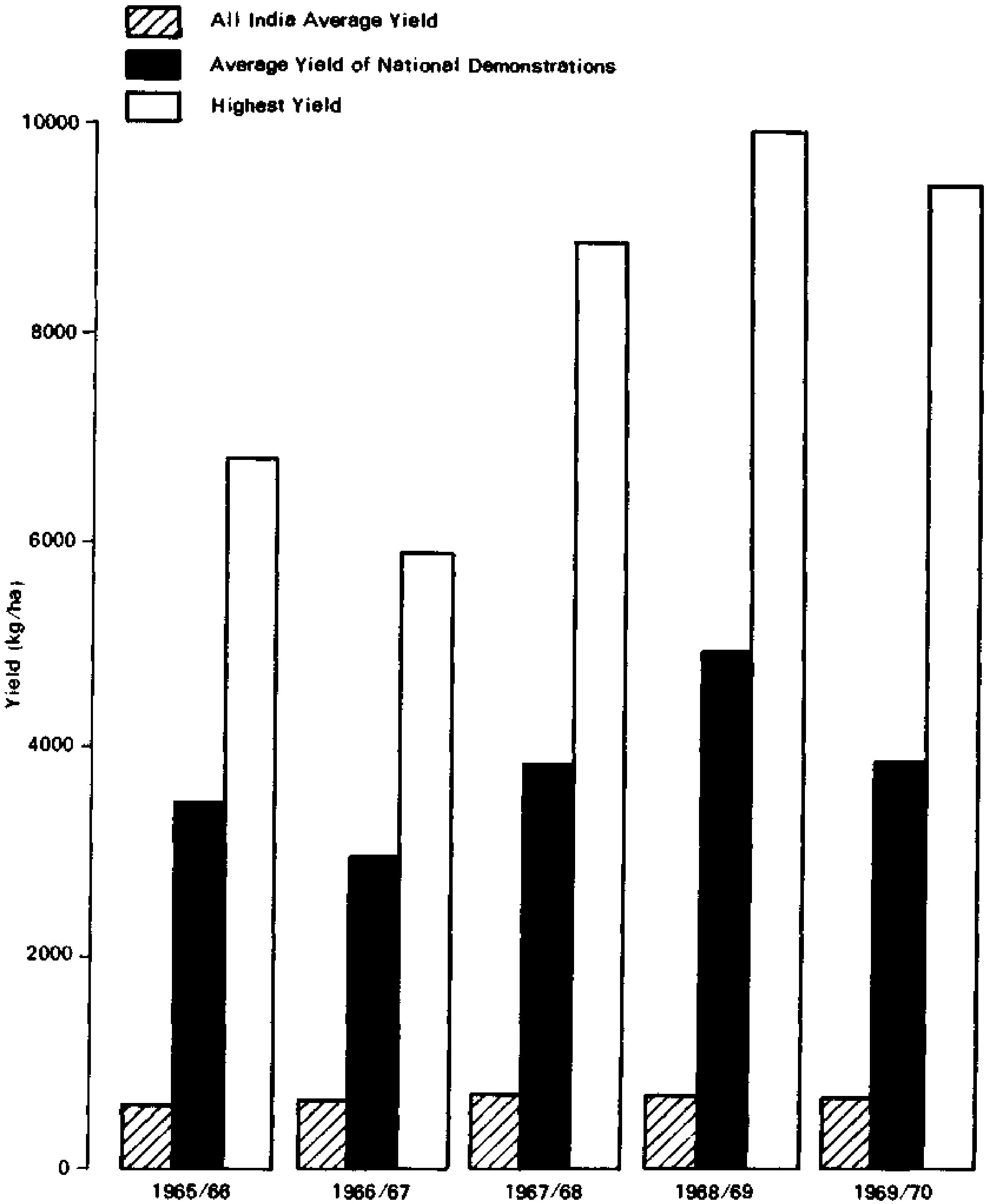


Figure 11. Yields obtained in All India national demonstrations with sorghum.

mends the resource centered approach, with the watershed as the unit, and involving land smoothing, semipermanent graded broadbeds and furrows, grassed waterways, small dams or tanks to collect runoff water for supplemental irrigation, together with agronomic inputs. It is apparent that this package is cost intensive. That risk graded technologies are irrelevant to SAT agriculture has

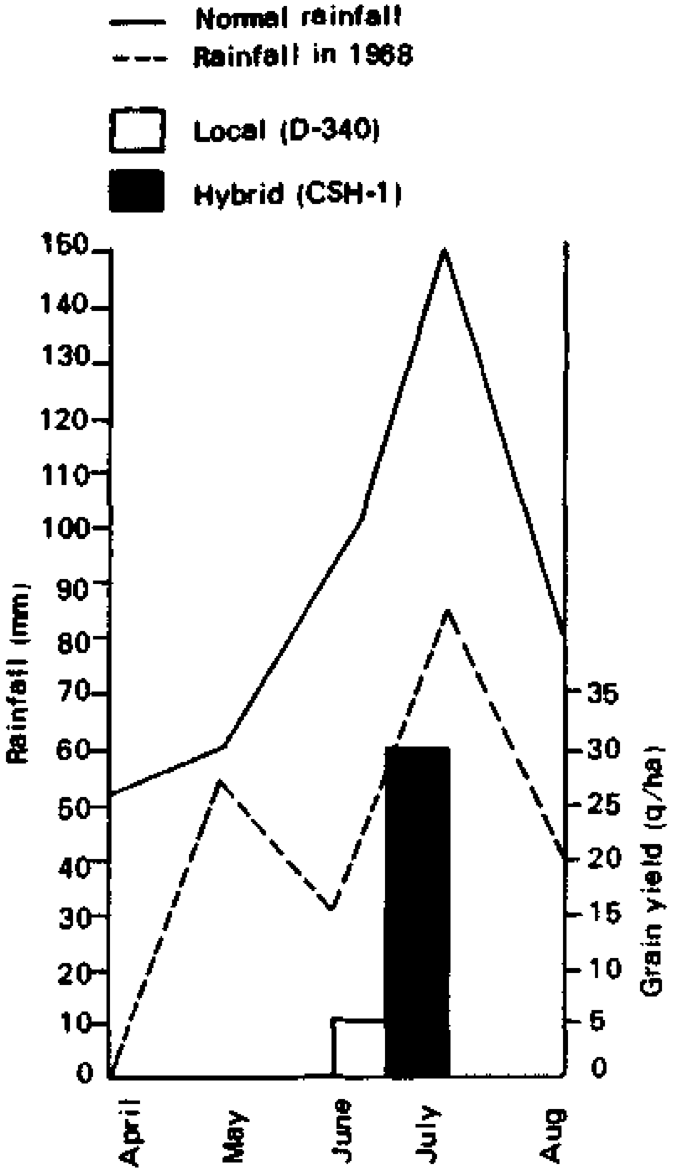


Figure 12. Performance of CSH-1 under extreme moisture stress in Harpanhalli taluq, Bellary district, Karnataka, India, kharif *1968 (rainfall received and average yield obtained over 10 000 acres).*

been borne out by the studies of Binswanger et al. (1980) and Vidyasagar Rao et al. (1981).

At the sorghum production workshop held at Udaipur. various questions were raised on the relevance and profitability of the sorghum production technology developed under the All India Sorghum Project (Rao 1979). The additional investment is primarily on seed and the level of fertilizers used. Since the technology was oriented towards quantum increases cutting through environmental limitations, its profitability was high. Its orientation towards system changes makes it more versatile. Approaches of en-block

Table 9. Number of crop experiments and mean grain yield in different Samathies of Khammam District, and Andhra Pradesh, *rabi* 1972/73.

	No of Experiments conducted		Grain yield (kg/ha)		
Samathi	CSH 1	Local	CSH-1	Local	Local
Wyra	3	3	4490	1318	340
Khammam	3	3	4983	2109	236
Burgampad	2	_	4457	—	—
Kothagudem	6	6	4915	1233	398
Yellandu	5	4	2683	1297	207
Bhadrachalam	1	1	4571	1186	385
Tirumalayapalem	8	4	4235	1742	243
Mean			4239	1477	287

Table 10. Grain yields from pilot project blocks on hybrid sorghum in Maharashtra State (rainy season).

Year	Coverage (ha)	No of experiments	Average yield (q/ha)
1976/77	75 063	5 579	27 40
1977/78	73 386	3 333	27. 30
1978/79	35 539	959	22 80
1979/80	20 832	805	22 70

transformation enhanced its acceptance. Its relevance was more to the small farmer.

The quantitative analysis of Ryan et al. (1980) termed "Steps In Improved Technology" analysis (SIIT) furnishes a sound basis for technological options. The LII (local improved variety, fertilizer use and improved soil and crop management) represents the improvement approach. The III (altered variety, fertilizer use and improved soil and crop management) represents the transformation approach for sole crops on drylands. There were various other treatments. Comparing all treatment in Alfisols and Vertisols, they concluded that both from the risk and profit point of view, the III technology (transformation approach) is beneficial. An investment of Rs. 100 in Vertisols on this

Table 11. Progress of kharif sorghum in Maharashtra.

Year	Area ('000 ha)	Production ('000 tonnes!	Average yield (kg/ha)	Area covered under HYV ('000 ha)
1970/71	2537	888	350	487
1971/72	2283	1080	473	320
1972/73	2494	907	364	330
1973/74	2763	1289	467	508
1974/75	2606	2118	813	433
1975/76	2795	2224	795	754
1976/77	3094	2958	956	1386
1977/78	3210	3487	1085	1724

approach could generate additional Rs. 1700 in net benefits (Fig. 13).

In the Hyderabad Alfisols also, the III approach was the best, the improvement approach also being profit-risk efficient. But here, the locals are of the same duration as the hybrids, whereas in most of the sorghum growing-areas the locals are very late and prone to climatic risk, and in bad years, input investments may be totally lost.

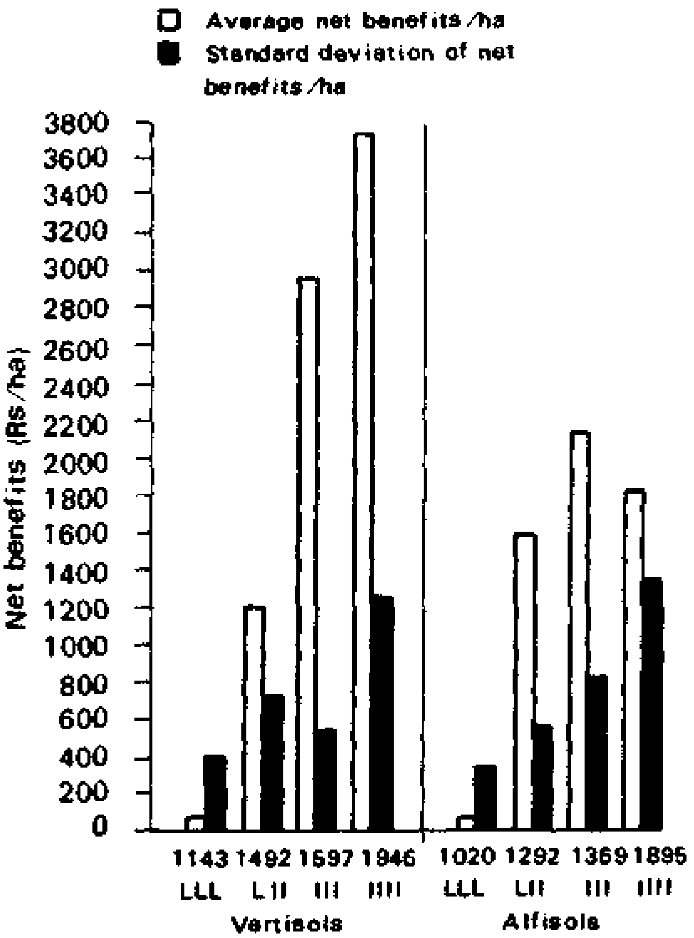


Figure 13. Average net benefits and variable costs per ha in steps-in-improved-technology experiment, (based on Ryan et al. 1980).

The advantages of Vertisol watersheds was much less compared to the SIIT experiments.

Permit me to be somewhat personal. I worked in the Indian Sorghum Program from the end of 1961 until the beginning of the 1980s. I have been deeply committed and involved in this venture. Apart from carrying out the improvement work, my colleagues and I analyzed each and every step of the technological aspects and tried to develop a rationale. Whatever I have spoken today comes from this experience. I sincerely feel that viable technological options are available for the amelioration of sorghum and that such a transformational approach is relevant to tropical drylands and could yield results, not only in other parts of India but also in the African context.

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Selection in Temperate-Tronical Crosses of Sorghum

N. G. P. Rao and B. S. Rana*

While most tropical areas of the world are less developed, the utility of tropical germplasm for crop improvement is universal; this is particularly true of sorghum. Earlier attempts at exploiting "tropical-tropical" crosses in India and Africa having proved to be of limited utility and the "temperate-temperate" crosses in USA having led to plateauing of hybrid yields, "temperate-tropical" crosses have become an integral part of all sorghum breeding programs, the conversion approaches having received particular emphasis in the USA and the more conventional approaches in India. During the past decade we have been involved in analyzing the breeding behavior of "temperate-tropical" crosses to enable us to incorporate attributes of economic worth into genetic backgrounds of higher levels of yield and yield stability. This paper attempts to project the potentialities of such crosses for sorghum improvement.

"Temperate* and "Tropical" Sorghums

All sorghums are of tropical origin. Their introduction ahd adaptation to the long-day conditions of the western hemisphere, more particularly the USA, has led to the designation of this group as "temperate" sorghums.

According to Quinby (1968). the process of temperate adaptation essentially involved the mutation of the dominant *Ma, Ma*$_1$ locus to its recessive *ma, ma,* so as to enable flowering under long-day conditions. In most "temperate-tropical" crosses, earliness is dominant when plants are grown under tropical conditions. For purposes of mechanical harvesting, U.S. workers selected the dwarf mutants. Consequently sorghums termed as "temperate"involve mutations for maturity and height and are generally characterized by earliness and dwarfness.

In this connection, it should be recognized that the mutations for height and maturity did take place in the tropics and are not consequent to their introduction in temperate regions. Dwarf (brachytic) and earlier versions of sorghums are encountered in farmer fields of Sudan, possibly Ethiopia, west and southern Africa, and other regions. Yellow endosperm *safra* and white or colored seeded *feterita* fields of different heights and maturities are common in Sudan even today. But at the same time, it has to be recognized that emphasis on selection, purification, improvement and perpetuation of dwarf and early forms was in the U.S. because of daylength and agronomic requirements. Thus, the so-called temperate sorghums are essentially mutations for height and maturity, which took place in the tropics. What is of greater consequence is the transference of attributes between the shorter and earlier versions and their taller and sometimes later maturing progenitors.

In one of our inconclusive studies on induced mutations in tropical sorghums (Rao et al. 1970). we postulated that a rare mutational event in tropical sorghums with partially exposed internodes altered them to forms with enclosed internodes and that such a change possibly disrupted the entire genotype leading to changes in growth rhythms, heights, panicle morphology.

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nsect reaction, etc. We also felt that the genetics of height and maturity, as elegantly analyzed by Quinby, apply to forms that have undergone such an a priori change, and that the allelism of height and maturity genes between forms with exposed and enclosed intemodes needs further analysis.

From the point of view of adaptation, while some of the late tropical forms do not flower under long-day conditions, all "temperate" sorghums do flower and yield in the tropics although they may understandably be different for insect and disease reaction, yield levels, etc. Thus, the so-called temperate sorghums, which are of tropical origin, differ from their tropical progenitors because of a complexity of physiological and genetical changes associated with internodal elongation and maturity. It is these associated changes that differentiate the two groups of cultivated sorghums *[Sorghum bicolor* [L.J Moench) that are significant in gene transfer. Our efforts (Rao and Rana 1978) to characterize "tropical and temperate" sorghums and their utilization established that the two groups exhibit considerable divergence both physiologically and genetically and that recombination of attributes from the two groups is difficult but accomplishable. It is felt that the two groups need a distinct varietal or subspecific status and a better terminology to which taxonomists should give consideration. These associated changes, their breeding behavior and their consequences for sorghum improvement are discussed below.

Physiological and Genetical Differentiation: The Optimum Phenotype

Traditional tropical sorghums are generally tall and late and are characterized by higher biological yields and low economic yields. Compared with the early maturing dwarfs, the total dry matter produced per plant in the tropical sorghums is much higher and its distribution is 70:30 between stalk and ear. This is consequent to a single peak for the rates of growth coinciding with flowering whereas the more productive sorghums have two peaks for rates of growth and a 50 : 50 dry matter distribution (Goldsworthy 1970; Rao and Venkateswarlu 1971; Anantharaman et al. 1978). Such tropical sorghums are generally photosensitive, usually flowering after the cessation of rains. They are highly localized in their adaptation.

The pattern of internodal elongation, to some extent, reflects the pattern of growth. Our analysis of the patterns of internodal elongation in different groups of sorghums (Balarami Reddy et al. 1981b) revealed that several "temperate" types and hybrids were generally characterized by a linear pattern, whereas a third degree polynomial curve was required for some of the cross derivatives and relatively shorter tropical forms (Fig. 1).

The two groups of sorghums also exhibit differences with respect to tissue concentration of nitrogen, phosphous and potash, their uptake patterns (Rao and Venkateswarlu 1971) and response to fertility and population levels (Rao 1979).

The agricultural consequences of such physiological characteristics of tropical sorghums are

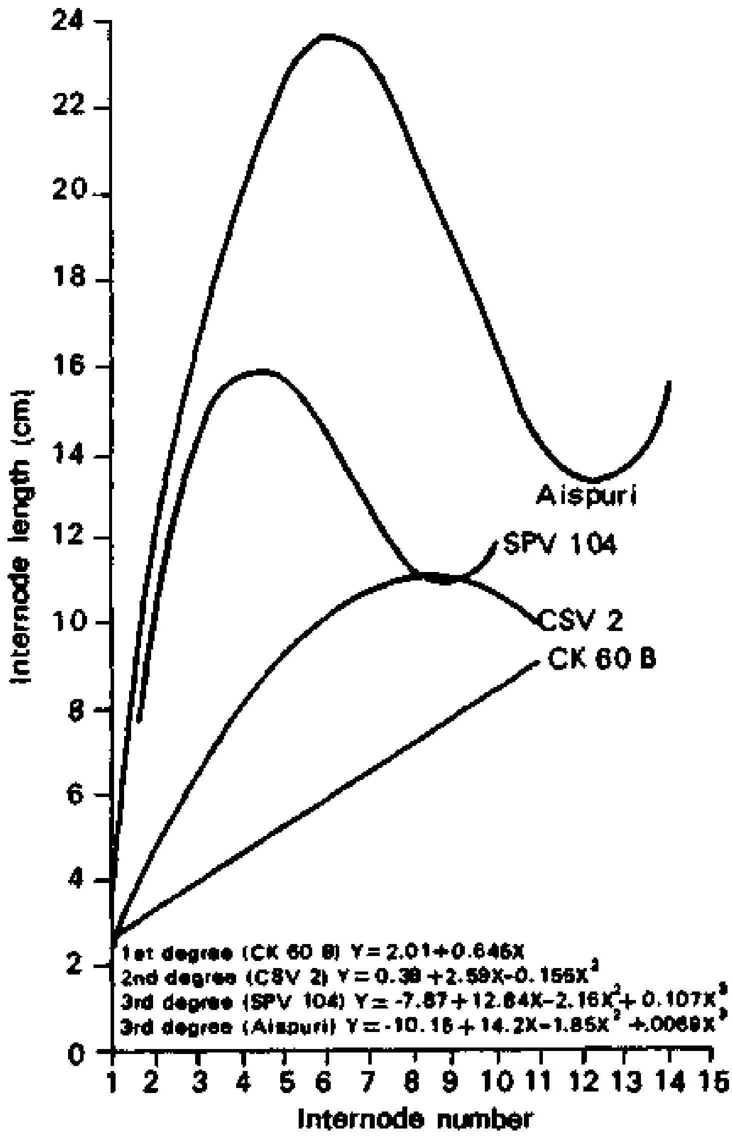


Figure 1. Expected internodal patterns in sorghums of diverse origin.

restricted adaptation, their vulnerability to rainfall fluctuations (Rao et al. 1975), adaptability to low populations, and lower rates of response to fertilizer use and low *economic* yields which together constitute subsistence agriculture (Rao 1981b.)

Genetically, the distribution of dominant and recessive alleles for grain yield, plant height and flowering is asymmetric and in opposite directions in the two groups; the "tropical" group with dominant alleles for yield and plant height and the "temperate" group with dominant alleles for earliness (Rao 1970b; Rao and Rana 1978). Consequently the associations between yield, plant height and maturity are strong, rendering recombination difficult (Harinarayana et al. 1971; Subba Reddy and Rao 1971). Gene distribution for resistance attributes (Table 1) such as shoot fly (Rana et al. 1975; Balakotaiah et al. 1975), and quality characters such as protein and lysine (Kang 1969) also exhibit group differences and present problems for gene transfer.

Attempts have been made at incorporation of the attributes of economic worth across groups. While the converted sorghums of the USA may be considered more "temperate", the derived sorghums reflected varying levels of recombination. Selections which represented productive peaks were at heights and maturities intermediate between the two groups (Rao et al. 1973) and recovery of such productive intermediates was limited and could be accomplished through emphasis on between-family selection (Tripathi et al. 1976). A majority of crosses between groups failed to yield balanced recombinants of economic worth and it was only an occasional cross where there was satisfactory recovery. Such productive crosses represent unique combinations and there is yet no predictable method of detecting them except by actual trial. Conventional estimates of combining ability do not generally lead to predictable results.

Based on some of the more productive derivatives and their parents across a range of heights and maturities, we have recently undertaken a computer exercise to determine the most productive lines in relation to height and maturity. We arrived at the conclusion that productive progenies, were obtained at heights of 175-180 cm, flowering at 68-70 days and with reduced leaf numbers. Such intermediate progenies derived from crosses between the two groups of sorghums, satisfied the needs of food and fodder and insect and disease resistance. They also combined the individual superiority of the tails and the community performance of the dwarfs besides conferring wide adaptability. Thus, the phenotypic optimum is an 'intermediate optimum' (Fig. 2). Although the recovery of such optimal types is low from direct "temperate-tropical" crosses, there are indications that a second cycle of crosses involving desirable derivatives would furnish greater opportunities since the height and maturity effects will then be minimal. Such intermediate types with optimal dry matter production and distribution, the critical stages of growth coinciding with periods of favorable weather, a linear pattern of internodal elongation and exhibiting resistance or tolerance to the prevalent pests and diseases would represent the optimum phenotype to strive for, and the vehicle is the "temperate-tropical" crosses to begin with

Table 1. Shoot fly damage In temperate and tropical sorghums and their derivatives.

Group	No. of lines	Percent damage (transformed values) Mean	Range
Temperate (exotics)	3*	54.3	35.3-70.5
	19	61.9	49.3-69.7
Tropical (Indian)	3*	283	265-31.1
	20	35.1	25.0-43.2
Temperate x Tropical	5*	34.8	30.1-45.8
(derivatives)	64	52 1	36.3-68.4
SE		4.57	

* Average number of plants ranged from 1198 to 1266; SE = 4.13

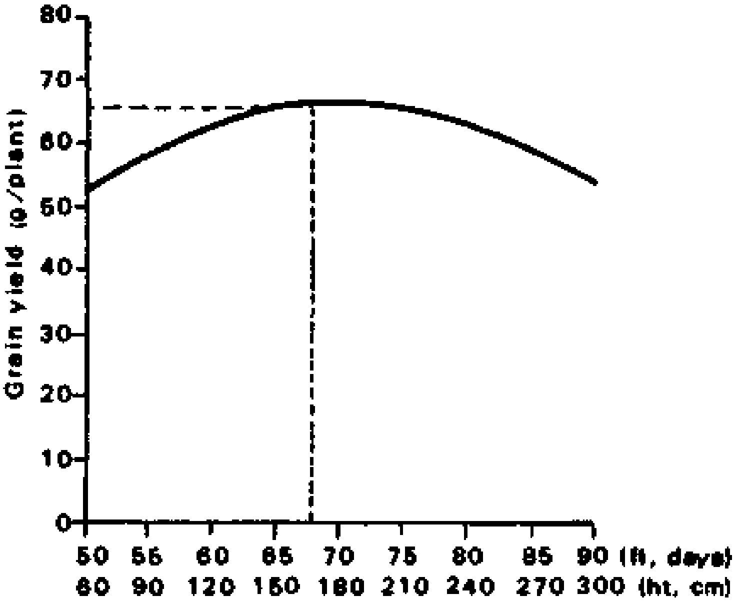


Figure 2. Optimum phenotype as related to plant height and flowering time.

and crosses among derived lines at a later stage. Such genotype alterations reflecting changes in dry matter production and distribution and growth rhythms result in efficient water use and form the very basis of improving dryland sorghums for yield and stability (Rao et al. 1979).

Hybrid Improvement: Selection of Parents

The potentialities of "temperate-tropical"crosses in hybrid breeding can be seen from Table 2.

The first commercial sorghum hybrids developed in India based on male-sterile Combine Kafir (msCK 60) did not have Indian varieties as male parents as was generally expected; they were exotic x exotic combinations. In the case of the msCK 60 x Indian variety combinations, apart from differences for height and flowering, accumulation of dry matter in the stem after flowering did not result in heterotic advantage for grain yield. The behavior of msCK 60 x Indian combinations and temperate x Indian crosses in general has been analyzed in detail (Rao 1970b, c; Rao and Venkateswarlu 1971; Rao 1972a). It should also be noted that the first sorghum hybrids, CSH-1 and CSH-2, did have some tropical parentage in that the male parents selected were from yellow endosperm *feterita* (IS 84) and yellow endosperm *begari* (IS 3691) respectively.

Subsequently the females developed in India like 2077A and 2219A, which furnished female parents for CSH-5 and CSH-6 respectively are also largely "temperate". Male improvement through selection in "temperate-tropical" crosses resulted in the development of CS 3541, 148/168, and PD3-1-11 which furnished male parents for commercial hybrids. CS 3541 has been derived from a cross between IS 3541 (African Zera Zera) x IS 3675 and furnished the male parent for the commercial hybrids CSH-5, CSH-6 and CSH-9. CS 3541 is relatively short and less photosensitive compared with its tall and sensitive progenitor IS 3541. Similarly, the male parent of the *rabi* (winter) hybrid CSH-7R was 148/168, derived from the cross IS 3687 x *Aispurian* Indian variety; PD3-1-11, the male parent of CSH-8R, was derived from the cross IS 84 x BP 53.

Amongst female parents that entered commercial hybrid combinations, 36A, derived from CK60B x PJ36K, and 296A, from IS 3922 x *karad* local, are also based on "temperate-tropical" combinations. While male improvement contributed substantially for most hybrids, it was female improvement that was responsible for the consistent superiority of CSH-9 (Rao et al. 1982).

While the first commercial hybrids of India were

Table 2. Mean performance (X) and heterosis % (H) in temperate x <temperate. tropical x: tropical, and temperate x tropical crosses.

Cross	No of Crosses	Grain yield/ plant(g)		Days to flower		Plant height	
		X	H	X	H	X	H
Temperate x Temperate	6	85 6	87.2	74.4	464	148	33.5
Tropical x Tropical	3	103.4	20.2	104.3	-2.80	287	11.4
Temperate x Tropical	12	112.8	773	87.0	-0.20	242	370
SE		2.31		0.14		2.12	

largely "temperate", parents of recent hybrids are the result of selection in "temperate-tropical" crosses. Thus, in recent years, greater attention has been bestowed on diversification of germplasm resources, as in the conversion program of the USA. and "temperate-tropical" crosses in India for deriving parents for commercial hybrids. But the actual identification of the parents that entered into commercial hybrid combination has largely been through actual evaluation of experimental hybrids in yield trials. In spite of several attempts at formulating a quantitative theory of selection for heterosis most of the information available is based on trial and error.

Most studies on heterotic responses point to the importance of seed number. Earlier studies based on crosses with msCK60 revealed that heterosis was maximum for panicle components evolved in the same direction and that considerable recombination breeding would be necessary before the compact-panicle types with reduced length of primary axis could be combined with elongated-panicle types like the *kafirs* (Rao 1970 b,c). Further studies on character associations in hybrids indicated that as long as seed numbers are not adversely affected, seed weight is important and that late maturity is not necessary to attain high yields. In fact, highest yields may be possible in hybrids flowering in 65-70 days. Heterosis for root activity also revealed distinct patterns. While heterosis up to knee-high stage and seedling vigor are common, there are cases like CSH-2 where heterosis for root activity persisted up to flowering and may be worthwhile to exploit (Damodar et al. 1978b).

Based on heterosis and combining ability studies, Rao et al. (1968) suggested using high yielding derived lines from "temperate-tropical" crosses as parental material, and this has been discussed. A subsequent study (Rana et al. 1974) furnished proof that selected derivatives used as males yielded hybrids of superior grain yields and seed weight compared with those resulting from the use of IS 84, the male parent of CSH-1.

Evaluation of male per se performance and its relation to test cross yields indicated that line performance could be used to screen potential parents (Fig. 3) and that subsequent evaluation may be based on test crosses (Singhania and Rao 1975). A parental yield trial was therefore made part of the coordinated trial program to obtain data on parental yields and flowering behavior.

The use of early testing as a method of identifying superior males (Mishra and Rao 1980a) revealed that test crosses based on F2 enable identification of crosses that could yield superior parents, and that using this information together with F3 test crosses, one could limit the number of progenies to be tested for isolating lines that could yield superior hybrids (Tables 3 and 4). While early test cross procedures also capitalized largely on additive genetic variance, there was an indication of greater use of *sca* compared with conventional methods (Mishra and Rao 1980b). Some male parents selected on the basis of their performance under favorable conditions at a single location resulted in hybrids of wider adaptability (Singhania and Rao 1975; Mishra and Rao 1980b).

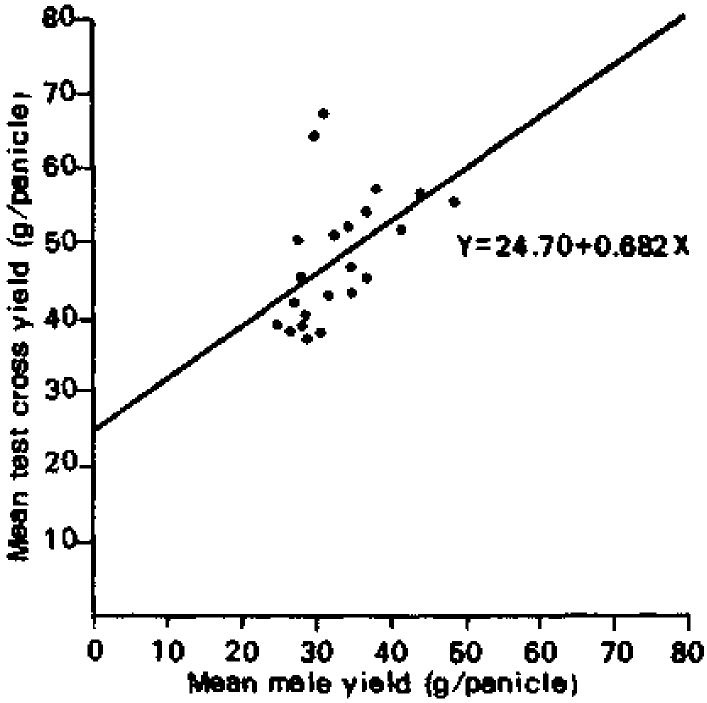


Figure 3. Regression of test cross performance on male performance.

It has now become a practice to develop populations among B and R lines respectively for selection of future parents. Studies involving BxB. BxR and RxR cross combinations revealed that BxR and RxR crosses could be preferred over BxB crosses due to their higher diversity for yield components, insect resistance (Table 5), and better grain quality ensuring higher germination (Rana et al. 1978). Hence, even for female improvement, BxR crosses with superimposition of early test cross procedures to identify maintainors could be a useful procedure (Jaya Mohan Rao et al. 1982).

Although allelic and nonallelic interactions may be the major source of heterosis, several

Table 3. Test cross performance in early generation testing in some crosses.

Cross	Mean grain yield/plant (g)					
	F_2 test cross		F_3 test cross		F., progenies	
	N*	X[6]	N	X	N	X
R24 x CSV-7R	58	79.S	29	92.9	28	75.7
IS 3922 x M35-1	55	74.8	12	72.8	34	58.2
CSV-7R x 512	64	64.6	38	70.3	34	73.8
CSV-6 x 512	31	626	8	780	20	50.7
SE		2.9		49		42

a H = No. of progenies
b X = Mean.

Table 4. Estimate of general (g) and specific (s) combining ability variance for grain yield.

Estimate		Env. interaction		Stability
$\hat{\sigma}^2 g_f$	= 68.3**	$\hat{\sigma}^2 g_f$	x e = 36 3**	Low
$\hat{\sigma}^2 g_m$	= 2.9	$\hat{\sigma} g_m$	x e = 6.7	High
$\hat{\sigma}^2 g$	= 52.9**	$\hat{\sigma} g$	x e = 29 3**	Low
$\hat{\sigma}^2 s$	= 24.2**	$\hat{\sigma} s$	x e = 7.9	High
$\hat{\sigma}^2 g/\sigma^2 s$	= 2.2:1			

•• Significant at 1%; • Significant at 5%

Table 5. RxR, BxR and BxB hybrids.

Hybrid	No of crosses	Days to 50% flowering	Plant height (cm)	Grain yield/plant (g)	% Stem borer tunnelling (angles)
			Group means		
RxR	10	77	176	62	28
BxR	20	76	205	65	27
BxB	6	74	179	59	31
			Average heterosis (% over midparent)		
RxR	10	0.6	13.3	84.4	- 10.1
BxR	20	- 1.5	17.5	127.2	- 7.5
BxB	6	- 0.2	32.8	116.3	- 16.9
Between group mss (2)		42.5**	10 369*•	331	136**
Error (88)		5.6	321	209	39

•* Significant at 1%.
Numbers in parentheses indicate degrees of freedom

reports indicate that the nature of gene action in yield heterosis involved predominantly *gca.* There are indications that the nature of gene action in different hybrids could be different (Rao and Murthy 1970). But the basic question is about the methodology to capitalize on *sca.* While selection based on morphological criteria seems largely to use additive genetic variance, the nature of gene action involved for enzymatic criteria like nitrate reductase and amylase activities seems to involve predominantly *sea* (Mishra and Rao 1981 a,b). If the value of such criteria leading to metabolic efficiency is conclusively established, they might then furnish the means to utilize *sea.*

All commercial hybrids developed todate are based on *milo* cytoplasm. Alternate sources of cytoplasmic-genetic male sterility have now been identified (Table 6) and characterized genetically, biochemically and through electron microscope studies (Rao 1962; Schertz 1977; Tripathi 1979; Tripathi et al. 1981 a,b,c,d,). It is hoped that their utility will be established in the near future.

Breeding Superior Varieties: Selection for Yield Improvement

The potentialities and limitations of "temperate-tropical" crosses for yield improvement have been considered earlier (Rao and Harinarayana 1968; Rao 1972 b). While such crosses do furnish opportunities for handling adequate genetic variability, strong character associations tend to restrict recombination. Estimates of combining ability do not provide reliable predictions of selection gains. Only certain "unique cross-combinations" yield recombinants of economic worth. A satisfactory basis for selection has yet to emerge.

Conventional pedigree, bulk and backcross methods have been extensively employed, but their limitations on exploitation of a limited gene pool, low genetic recombination and quick fixation of linkage blocks due to continuous inbreeding have often been spelt out. Population breeding procedures have been suggested to force recombination among large number of varieties. Though intermating is effective to break initial linkage blocks, its utility in self-pollinating species has been questioned since the extent to which it disintegrates the natural adaptive gene complexes, characteristic of self-pollinating species, is not known precisely (Bos 1977). Besides, crosses involving several parents also pose problems of population size, particularly when selection is aimed at improving quantitative characters like yield (Sneep 1977). These problems are very relevant to handling such diverse crosses involving the "temperate-tropical" sorghums. The breeding system in cultivated sorghum is unique in that it ranges from complete self-pollination to total outcrossing by virtue of its floral biology and known mechanisms of cleistogamy, genetic and cytoplasmic-genetic male sterility, self-incompatibility and apomixis which would permit use of diverse breeding systems (Rao and Narayana 1968; Rao 1972b; Murthy et al. 1980).

Prediction of the unique combinations where selection would yield fruitful results is no doubt difficult, yet the initial choice of parents has to be between the tropical and temperate groups. Presence of desired genes, diversity among genotypes, parental performance per se and the nature of combining ability are still the best criteria. In spite of the fact that most of the tropical cultivars are excessively tall, late, and low in productivity due to excessive dry matter production and inefficient translocation, the dominant genes for yield are present in tropical cultivars. "Temperate" sorghums present different gene constellations and furnish genes for dwarfing, earliness and population performance. Hybridization between the two groups, therefore, forms

Table 6. Cytoplasmic-genetic Interaction for seed sat in F1.

	B-lines						Restorers		
ms lines	CK60B	NAG-B	MAL-B	M31-2B	VZM2B	G1B	GM1-5	K-Local	Nandyal
CK60A	S	S	F	F	F	F	F	F	F
Nagpur-A	s	S	F	F	F	F	F	F	F
Maldandi-A	s	S	S	S	S	S*	F	F	F
M31-2A	s	S	S	S	S	F	F	F	F
VZM2A	S	S	S	S	S	S	S	S	S
G1A	S	S	S	S	S	S	S	S	s

* Fertile in summer. S = sterile; F = fertile.

the basis of yield improvement in both tropical and temperate regions. There is evidence that selection of crosses for higher F1 and F2 mean performance results in a large number of promising progenies in further generations. At least one of the parent in such crosses is always a good general combiner (Seshagiri Rao 1979).

While the generally positive relationship of yield with maturity and height has been established, continued selection for short stature, earlier maturity and high yields resulted in the dissipation of such effects; optimal yields are obtained at intermediate heights and maturities (Rao et al. 1973). Our studies (Tripathi et al. 1976) indicated that with choice of suitable parents and emphasis on selection between families, directional selection using pedigree method could result in isolation of desirable homozygotes in spite of the strong character associations. Subsequent use of such derivatives in cross combinations would result in rapid progress since the height and maturity effects will be minimal.

The recombination patterns in single, backcross, three-way and double crosses involving "tropical and temperate" parents and their crosses derivatives have been investigated by Seshagiri Rao (1979). The probability of obtaining high yielding plants was high in dwarf (D) x tall (T) and DxD combinations; in the (DxT) D three-way crosses, the choice of the third parent was critical. The use of a tall parent in the grandparentage was useful and gains from DxT crosses could be improved if the effects of height genes were rapidly minimized by an extra dose of dwarfing genes. Backcrosses and three-way crosses in specific combinations resulted in isolation of high-yielding dwarfs and mid-tails in greater probabilities. Reciprocals of good backcrosses. random three-way crosses, and double crosses failed to accomplish this goal. These studies on mating systems (Table 7, Fig. 4 and 5) are thus indicative that gene frequencies could be shifted in the desired direction only under controlled and specific cross combinations. The results did not favor the breaking up of adaptive gene complexes indiscriminately in diverse crosses. It strengthens the view of adaption of specific cross combinations. Yet. there is some evidence from the USA that population approaches could result in selection gains. The base populations used in the USA did not provide the variability for height and maturity encountered in "temperate-tropical" crosses. After correction for height and maturity, and obtaining high yielding derivatives, limited intermating between such derivatives may be useful.

The criteria for selection in yield improvement need some consideration. Selection based on phenotypic criteria such as yield components and index approaches have been considered, but they are of limited utility (Subba Reddy and Rao 1971). Hence selection based on yield per se providing for proper accounting of environmental variability has been more frequently employed. Yet, selection criteria unrelated to height and maturity could be useful. Genotype differences for tissue concentration and response patterns of major nutrients have been demonstrated (Rao and Venkateswarlu 1971; Ramachandran and Rao 1973). The tissue concentration of nitrogen seems to be positively correlated with yield and could furnish a useful criterion (Fig. 6). Genotypic differences for root activity have also been demonstrated and might be useful (Damodar et al. 1978a). Nitrate

Table 7. Cumulativa probabilrtias (%) of selection for grain yield in single, back, thraa way, and double croaaaa in sorghum.

Yield/Plantt (g)	SC		BC		TWC			DC	
	DxD	DxT	(DxD)xD	(DxT)xD	(DxD)xD	(DxD)xT	(DxT)xD	(DxD)x(DxT)	(Dx:D)x(DxD)
> 60	9.1	5.2	3.6	9.9	4.7	3.3	16.7	1.9	1.8
> 70	2.4	1.6	0.7	4.1	1.0	0.7	7.7	0.3	0.3
> 80	0.2	0.4	0.5	1.6	0.1	0.1	3.1	—	
> 90	—	0.1	—	0.5		—	1.0	—	
>100	—	—	—	0.1		—	0.3	—	

SC * single cross; BC = backcross; TWC = three-way cross; DC - double cross. D = Dwarf, T = Tall.

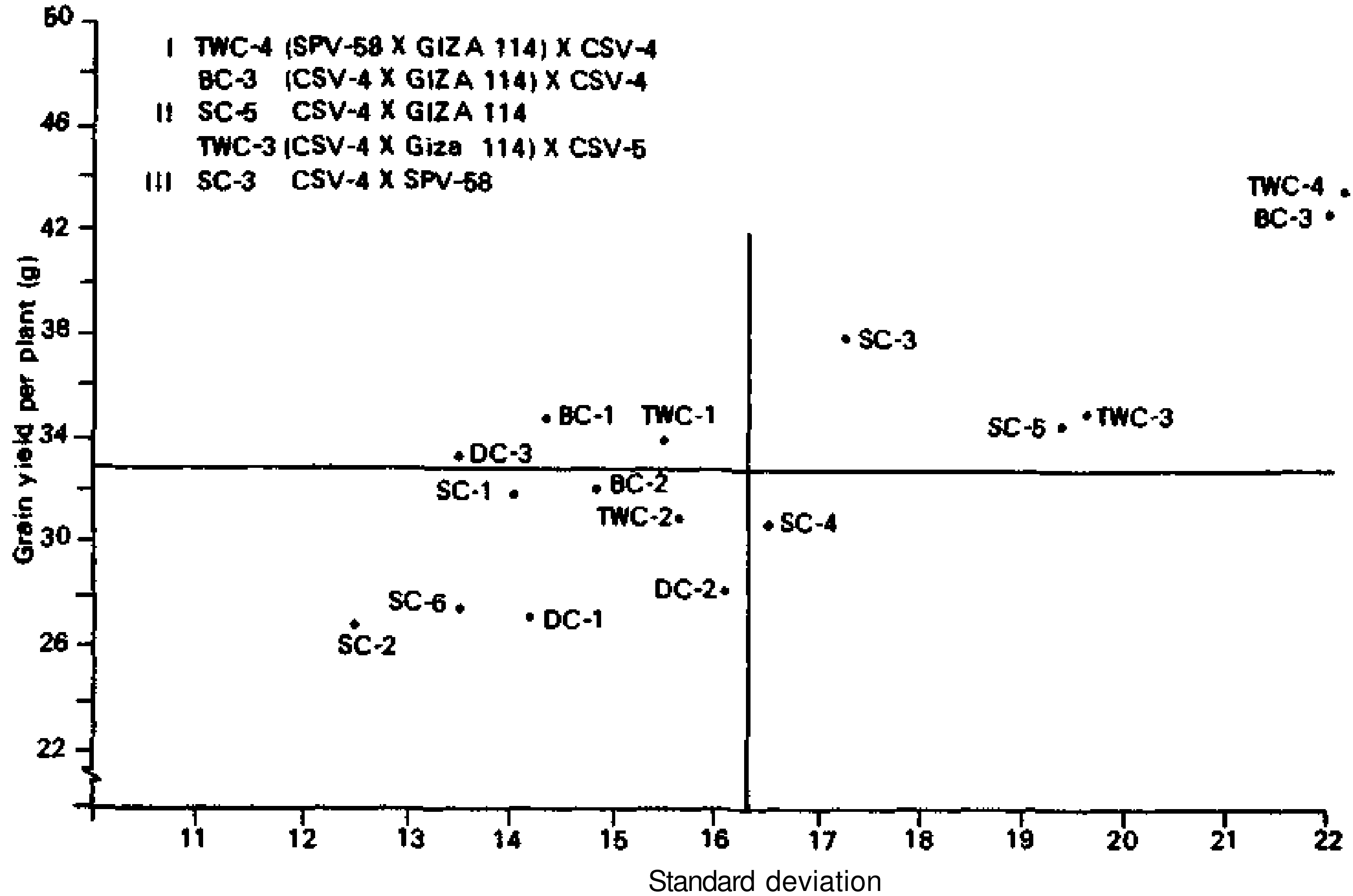


Figure 4. Mean and variability in F2 generation under different mating systems.

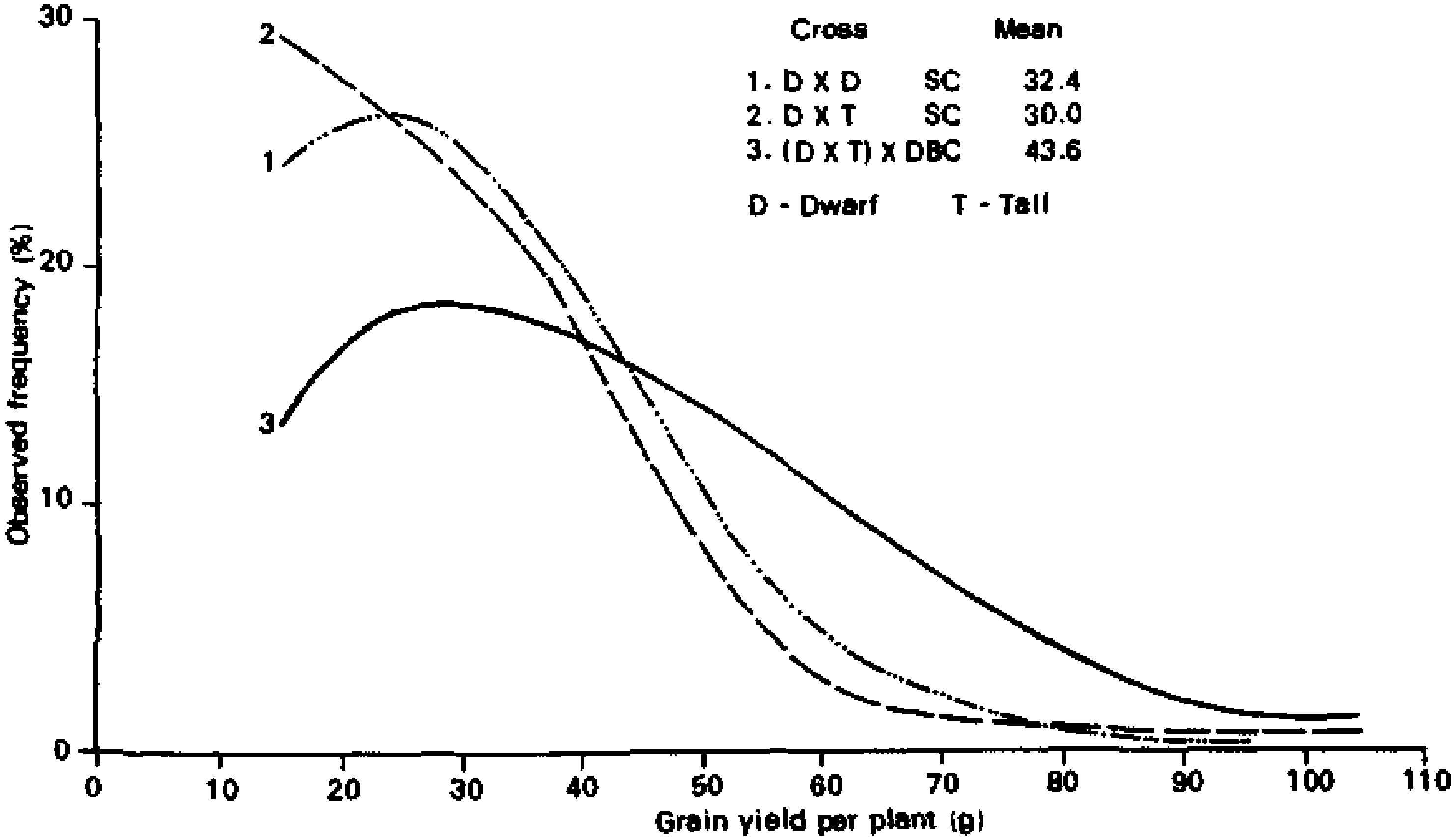


Figure 5. Average yield performance in different mating systems in F2.

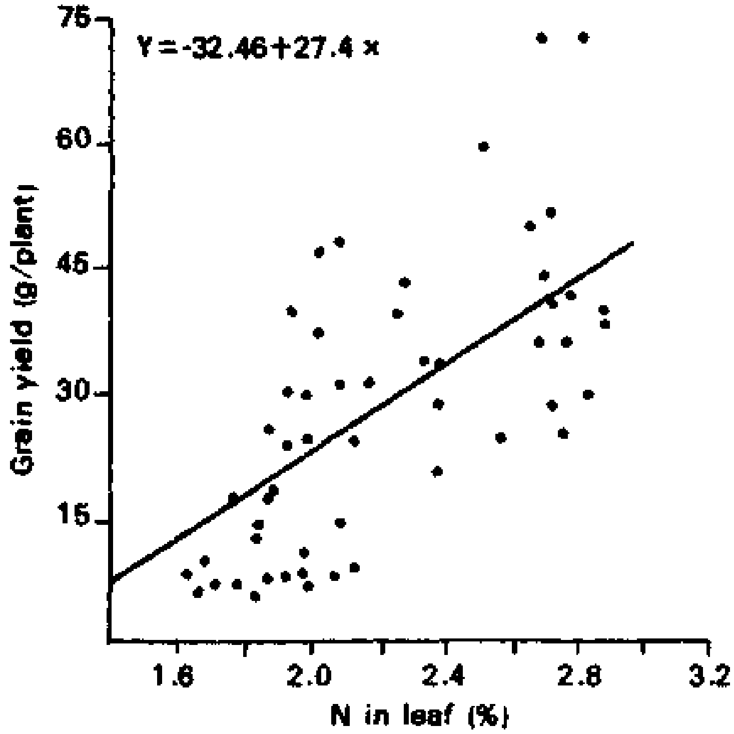


Figure 6. Relation between grain yield and leaf nitrogen (%).

reductase activity at the vegetative stage appears to be phenotypically correlated (r = 0.68*) with yield and might yet be another physiological criterion (Mishra et al. 1981a). Nutritional considerations in selection, particularly the incorporation of the high lysine trait, have been a subject of discussion (Nanda and Rao 1975). Our efforts (Jaya Mohan Rao 1980) to transfer high lysine to agronomically desirable grain types of acceptable yield levels indicate possibilities of dissipating the generally known negative relationship between protein and lysine and that the incorporation of this trait is not an impossible task. Efforts in this direction should continue.

It has been frequently stated that the performance of high yielding hybrids and varieties is satisfactory only under optimal input and management, but with sorghum being a crop of tropical drylands, selection should be practiced under suboptimal conditions. Consequently, it was not uncommon to select and test under two different sets of growing conditions. Our studies (Vidyasagar Rao et *al* 1981) have established that selection under optimal conditions is advantageous (Table 8). Yield based rankings and rankings based on risk aversion criteria did not differ markedly, indicating the validity of our selection under optimal conditions in combining yield with stability under varying management and climatological conditions (Barah et al. 1981).

Table 8. Estimates of H, H and E(Δ y) under high and low input management environment (total locations = 20).

Parameter	High management (H)	Low management (L)	H/L(%)
H	0.84	0.77	109.1
VH	092	0.88	104.4
E(A y) kg/ha	759	569	133.4

VH—Logical measure of joint effect of d^2e and d^2g on the value of the test environments
E(A v)—Expected genetic gain

To date, nine high yielding varieties (CSV-1 to 9) have been released and more are under prerelease multiplication. The relative Derformance of hybrids and varieties established hybrid superiority, but the derived varieties are superior to locals (Rao et al. 1981). Improved varieties like SPV 221 and SPV 245 and several others are superior to CSH-1, the first hybrid, in yield levels. We are presently in the process of approaching CSH-5 in yields at the varietal level. Varietal improvement is a continuous process which will contribute both directly and as parental material for hybrid improvement. There is a case for superior varieties of approximately similar maturity as the hybrids. Since hybrid seed production is a repetitive process and might not cover the entire production area, varietal supplementation will minimize the losses due to the vulnerability of late locals to drought and midge. It is necessary to reestablish the maturity equilibrium of sorghum to match the duration of the rainy season.

The shifts in flowering, height, and yield accomplished with "temperate x tropical" crosses are depicted in Figure 7.

Selection and Adaptation

Hybridization of "temperate and tropical" *sources* of germplasm provides for opportunities as well as problems related to adaptation and adaptability. One of the major consequences of genotype alteration is changed adaptation.

Since traditional cultivars are known to be highly local in their adaptation, past breeding efforts have been oriented towards the needs of several

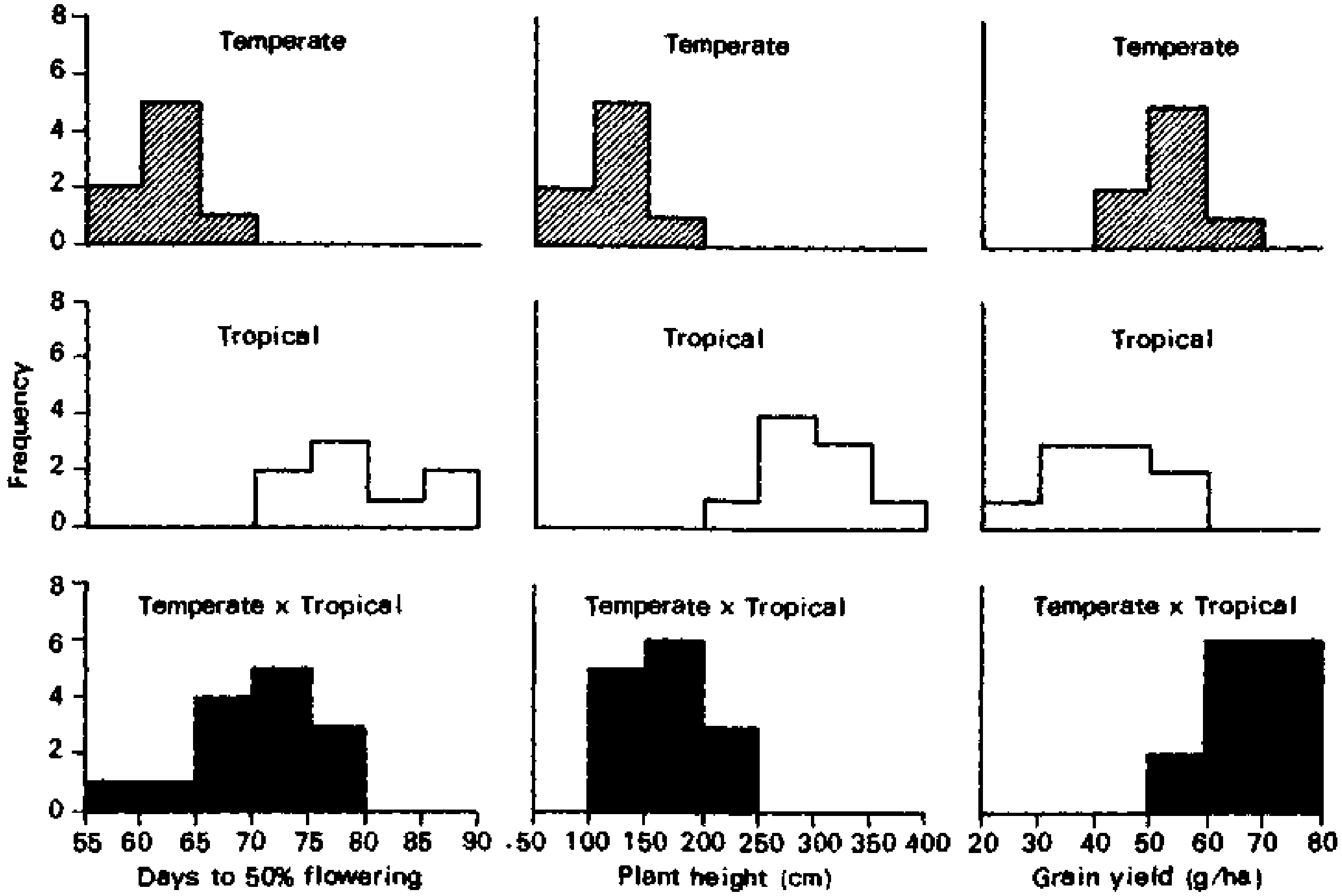


Figure 7. Days to flower, plant height, and grain yield characteristics of temperate, tropical, and temperate x tropical derivatives.

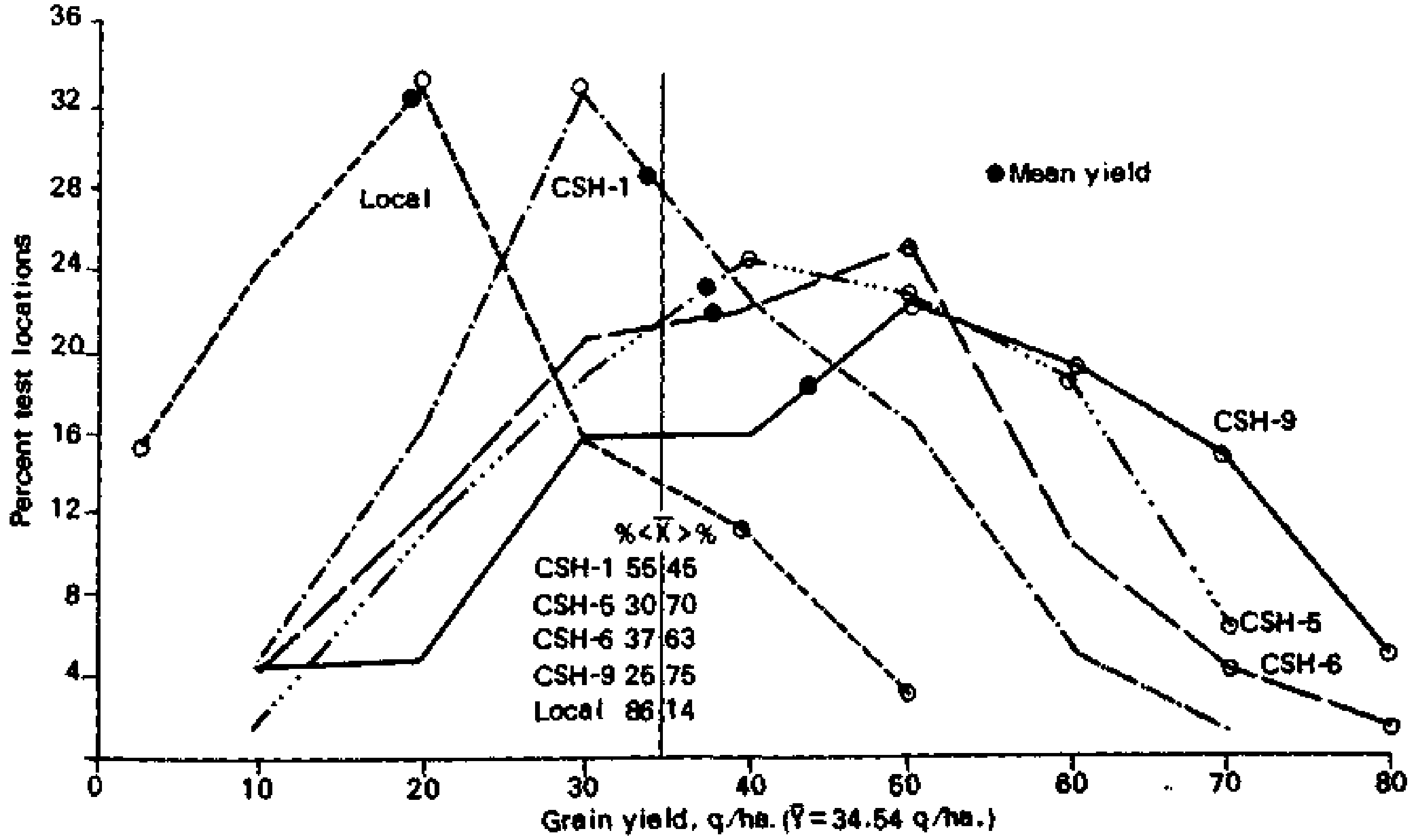
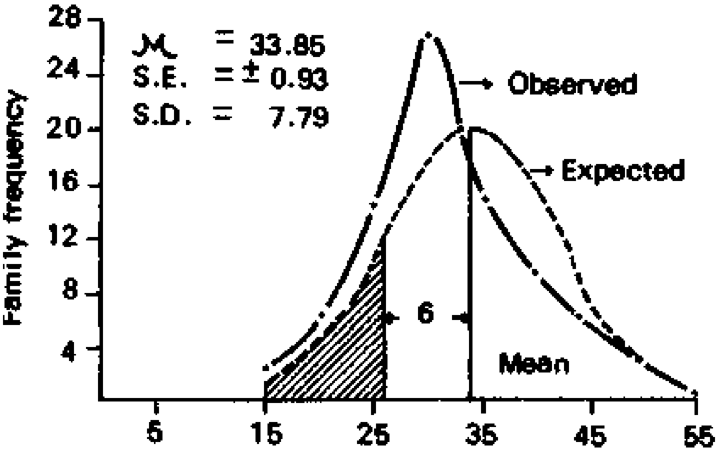


Figure 8. Yield performance of hybrids over 63 to 100 locations (Kharif 1978-1980).

pockets limited by eco-geographical and agroclimatic considerations. The development and release of new hybrids and varieties of sorghum, less sensitive to photoperiod. have resulted in cutting across traditional barriers (Rana et al. 1971). Their adaptability over vast areas covering almost the entire *kharif* (monsoon) sorghum tract of the country (Fig. 8) covering low and high rainfall areas, has been established (Rao 1970a; Rao et al. 1975; Rao et al. 1981). They have performed well in several other countries as well. The genotype x year interaction is low and with the multilocational testing mechanism spread all over the country, the superiority of a genotype could now be established in a single year's testing. All India releases which could not be conceived earlier are today fait accompli. While the homeostatic advantages of hybrids are more pronounced (Rao and Harinarayana 1968; Singhania and Rao 1976a. b; Rao et al. 1981). efforts to bridge this gap between hybrids and varieties are currently in progress (Balarami Reddy and Rao 1981). A more detailed consideration of adaptation of sorghums in relation to soil and climatic considerations has been discussed in the paper "Transforming Traditional Sorghums in India" (Rao 1982), in this symposium.

Consequent to the changes in the genetic background, adaptational problems in relation to pest and disease occurrence need particular consideration in selecting new genotypes.

"Temperate" sorghums, when introduced into tropics, tend to exhibit greater susceptibility than "tropical" types to shoot fly *(Atherigona varia soccata* Rond.) and stem borers, while midge incidence is generally similar in the two groups. A comprehensive account of insect resistance in sorghum covering sources and mechanisms of resistance and breeding aspects has been presented by us earlier (Rao et al. 1977). Sources of resistance to shoot fly and stalk borers *(Chilo partellus, Busseola fusca* and *Sesamia inferens) are* mostly of tropical origin (Rao and Rana 1978). Several of the sources also exhibit resistance to both shoot fly and stem borer, and it has been possible to combine tolerance to both pests in some of the derivatives from "temperate-tropical" crosses. Nonpreference is the primary mechanism of resistance to shoot fly, stem borer and midge although some evidence of antibiosis is available. The genetic basis of nonpreference, particularly, with shoot fly has been analyzed in detail and a breeding methodology outlined (Rao



Percent damage (Transformed values)

Figure 9. Frequency distribution of F3 families for shoot fly damage, shaded portion indicating the area where selection for shoot fly resistance is effective.

et al. 1974; Balakotaiah et al. 1975; Rana et al. 1975; Sharma et al. 1977; Singh et al. 1978). Inheritance of shoot fly resistance is quantitative (Fig. 9) and recent selections are intermediate in their reaction to shoot fly. Efforts are in progress to incorporate higher levels of resistance. Recent selections also exhibit higher levels of resistance to stem borers compared with their temperate progenitors. Resistance to midge is available from both tropical and temperate sources and some of the midge resistant lines like IS 12660C and IS 2508C reported from USA are from the conversion program. Earhead bugs are common in several parts of Africa and India, and there is some evidence that resistance to midge and head bugs could be incorporated simultaneously. Present emphasis is on incorporating resistance to several of the common pests of tropical sorghums in potential lines of agronomic worth being derived from the "temperate-tropical" crosses.

Compared with insect resistance, incorporation of resistance to major sorghum diseases has resulted in greater success (Rao et al. 1978). Consequent to the development of early maturing cultivars, the probability of such sorghums being caught in late October rains during some years does exist and breeding for resistance to grain deterioration in early maturing types assumes importance. The total process of grain deterioration, including the physical and fungal aspects, received our attention (Rana et al. 1777; 1978). Sources of resistance have been identified, the genetic basis of resistance and selection criteria have been established and agronomically desirable hybrids and varieties with satisfactory levels of resistance to grain deterioration have been released. The hybrids CSH-5, CSH-6 and CSH-9, and CSV4, CSV5, SPV126 and SPV245 among varieties are some such examples. Several male steriles like 2219A, 2077A, 323A, and male parents like CSV4(CS 3541), CSV 5(148/168) and several of the released hybrids and varieties have high levels of resistance to downy mildew.

The genetic basis of downy mildew resistance has been established (Rana et al. 1982). Several released hybrids and varieties also combine resistance to leaf spots and rust (Rana et al. 1976). Resistance to charcoai rot is presently receiving increased attention. Current emphasis is on incorporation of multiple resistance in agronomically desirable backgrounds and commercial varieties and hybrids (Rao et al. 1978).

There has been progress in identifying sources of resistance to the Asiatic and African species of *Striga.* The cultivar N13 of Nandyal in Andhra Pradesh, in particular, exhibited resistance to both *S. asiatica* and S. *hermonthica. Striga* resistance also seems to come from tropical sources and several progenies derived from crosses between groups are presently under evaluation.

From the point of view of adaptation to insect pests and diseases in the tropics, shoot fly, stem borer, midge and head bugs among insect pests, grain deterioration, downy mildew, grey leaf spot *(Cercospora sorghi)* and sooty stripe *{Ramulispora sorght)* among diseases, and the two species of *Striga* need particular attention in selecting altered genotypes of sorghum with wide adaptation. On present evidence, it is not difficult to incorporate satisfactory levels of resistance to these pests and diseases in cultivars of commercial value.

Food habits and various food preparations of sorghum across the tropics at first sight seem to impose limitations on acceptability of new genotypes. Recent studies from ICRISAT reveal that hybrids like CSH-5 and the M35-1 variety satisfy the culinary requirements of a range of food preparations in Asia and Africa. As such, food preferences need not present adaptability barriers in developing newer genotypes of wide adaptability.

Thus, selection for adaptation involves the agricultural system in its entirety. In our efforts to transform the traditional subsistence system to a more productive and stable alternative, genotype alterations through "tropical-temperate" crosses have played a major role and furnished the very basis of such a change (Rao 1981a). Adaptation,

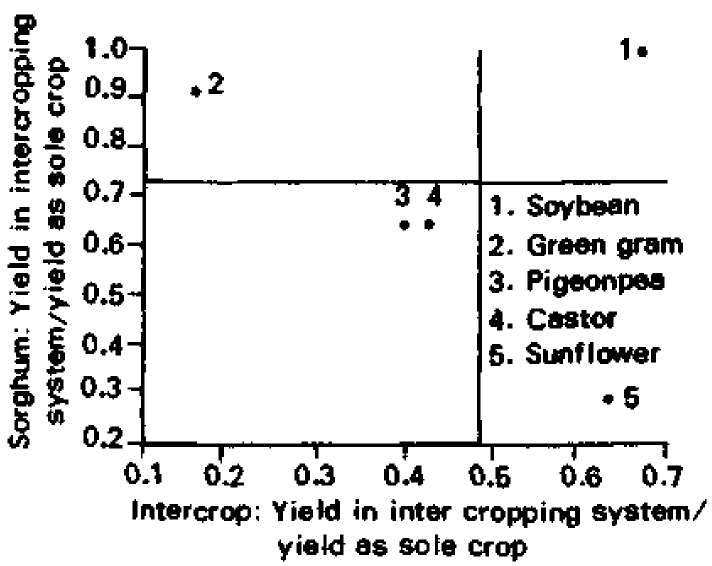


Figure 10. Species competition in sorghum-based intercropping systems.

therefore, involves not only higher levels of yield and stability accomplished through genotypic changes for dry matter production and distribution, duration, growth rhythms, insect and disease resistance, food preference, etc., but also adaptation to a new agricultural system involving changes in agronomic practices and cropping systems (Fig. 10). Response to improved populations, fertilizer use, suitability to sole-, inter-, and multiple-cropping systems (Table 9) and ratoonability—all formed part of the selection process. Its success in enhancing stability, productivity and profitability in sole-, inter- and multiple-cropping systems have been illustrated (Tarhalkar and Rao 1974; Rao and Rana 1980; Raoetal. 1979). While plant breeding in the past was oriented towards changing agronomy, it is the altered genotypes that ushered in changes in agronomic practices and cropping systems in recent years.

Outlook

"Temperate-tropical" crosses of sorghum provided the major means of genotype alteration in the seventies. Their contribution towards the movement from the climate-vulnerable subsistence farming of narrow adaptation to a more stable and productive alternative of wider adaptation, particularly in the Indian subcontinent, is a significant event. It involved a significant conceptual change. In depth research of a basic nature during the eighties should open up new vistas in sorghum improvement. Manipulation of diverse

Table 9. StabilKy parameters for total yield (kg/ha) in intarcropping systams.

IS	Sorghum			IS	Groundnut		
	X	b_i	σ^2_d		X	b_i	σ^2_d
S + P	5685	092	NS	G + S	3877	2.11**	
S + C	3957	1.00	NS	G + P	2315	0.89	NS
S + G	5053	0.99	NS	G + C	1654	0.51**	*
S + SB	5553	1.03	NS	G + SB	1734	0.49**	ft*
Mean	5358				2395		
S.E.	61.9				31.1	0.11	

* Significant at 5%; ** Significant at 1%; NS = Not significant
S = Sorghum, P = pigeonpea, C = castor, G = groundnut, SB = soybean
IS = Intercropping system.

cytoplasmic sources, apomixis, nutritional quality, metabolic efficiency, multiple resistance to insect pests, diseases and *Striga* should reinforce the foundations laid during the seventies. *Rabi* sorghum improvement in India, for which better guidelines are presently available, will be a priority item during the eighties.

While genotype alteration will continue to provide the focus, genotype adaptation to African agricultural systems might provide for a conceptual change and transformation of traditional African sorghums. Unique performance and wide adaptability are not uncorrected; they are in fact closely correlated. Improvements based on "temperate-tropical" crosses already accomplished will have value for countries in Africa. Traditional African agricultural systems with inherent relay plantings, wide spacings and late cultivars offer unlimited opportunities for system manipulation towards better utilization of the natural resources. Only altered genotypes could open up new opportunities (Rao 1981a). Together with local breeding efforts, adaptation of altered genotypes to African agricultural systems should furnish the major event for sorghums in Africa during the eighties.

The fascinating breeding system in sorghum ranging all the way from complete self-pollination to total outcrossing with known mechanisms of cliestogamy, genetic and cytoplasmic-genetic male sterility, self-incompatibility, cross sterility, apomixis, etc., has several secrets that are yet to be unraveled.

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NUTRITIONAL QUALITY IN GRAIN SORGHUMS : VARIABILITY FOR PROTEIN, LYSINE AND LEUCINE*

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ABSTRACT

A study of variability for protein, lysine and leucine in representative germplasm collections, hybrids and cross derivatives revealed that the opaque types of fractions were marginally superior over translucent endosperm forms. The generally negative relationship between protein per cent and lysine per cent was confirmed in all plump endosperm types examined. None of them were comparable in lysine content to the shrivelled Ethiopian lines. The plump seeded types, dwarf white *milo* and *saffra*, seem to combine moderately high levels of protein and lysine with desired leucine: lysine ratio. Dwarf white *milo* is comparable or even slightly superior to 'P 721' and deserves further attention.

THE variability for protein and lysine in sorghum has been under investigation and from time to time a number of lines have been reported to be of superior protein quality. With the exception of 'IS 11758' and 'IS 11167', the shrivelled seeded Ethiopian types, data on protein and lysine have been rather inconsistent. The present study is an attempt to study the variability for protein, lysine and leucine in some land races of India and Africa, some cross derivatives and hybrids. The locational and seasonal influences on protein quantity and quality have also been studied.

MATERIALS AND METHODS

Several land races, cross derivatives and hybrids of sorghum were grown over locations and seasons. The opaque and translucent endosperm fractions were separated under a light box. Protein was estimated by microkjeldalh's method and lysine and leucine by microbiological assays (Steele *et al.*, 1949) at the National Institute of Nutrition. Standard statistical procedures were used for analysis of data.

RESULTS

The variability for protein, lysine and leucine was studied in 40 Indian, 24 African land races, 19 cross derivatives and 17 hybrids. Even though some of the lines, *viz.*, 'BP 53', 'IS 1216', 'IS 955', 'Jowar No. 98-2, 'C 53', 'IS 4906', etc., exhibited higher levels of lysine at low protein levels, retesting revealed that protein per cent increased with concurrent decline in lysine content. Data on the promising lines only is summarised in Table 1.

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*This contribution is the XXXI part of the series on "Genetic analysis of some exotic × Indian crosses in Sorghum".

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TABLE 1

Nutritional attributes of some promising varieties

Sl. No.	Variety	Protein (g %)	Lysine (g/100g protein)	Seed type
1.	Saffra	11.61	2.91	Plump
2.	D. W. Milo	13.12	3.02	Plump
3.	P-721	12.36	2.28	Plump
4.	IS 11758	13.34	3.06	Shrivelled
5.	IS 11167	13.16	3.51	Shrivelled

Twenty seven of the Indian types exhibited variation for the opaque and translucent endosperm character and hence the fractions were separated under a light box and analysed separately. The means for the two classes are presented in Table 2. The opaque fraction is marginally low for protein and high for lysine.

TABLE 2

Mean protein, lysine and leucine in different seed types of some Indian local varieties

	Protein (g %)		Lysine (g/100 g protein)		Leucine (g/100 g protein)	
	PO	PT	PO	PT	PO	PT
Mean	9.27	9.49	2.38	2.20	11.4	11.7
S.Em ±	0.58	0.46	0.08	0.09	0.51	0.28

PO=plump opaque; PT=plump translucent.

Thirteen promising types were grown over two seasons and analysed. The analysis of variance indicates significant seasonal difference but not for varieties × seasons interaction. Nineteen varieties derived from exotic × Indian crosses were grown at 3 locations (Indore, Parbhani and Dharwad); combined analysis of variance showed the locational differences for protein and leucine were significant. The interaction was not significant. Similarly, 17 hybrids were also grown at the same three locations. The differences were not significant indicating that the hybrids are relatively more stable for nutritional attributes.

Discussion

There have been quite a few studies on the variability for protein, lysine and leucine in sorghum germplasm collections. With the exception of 'IS 11758' and 'IS 11167' of Ethiopian origin (Singh and Axtell, 1973), which have high protein and lysine values against shrivelled endosperm, data on consistent superiority for protein and lysine in plump types has not been forthcoming. Virupaksha and Sastry (1968), Deosthale, Mohan and Rao (1970), Deosthale (1972) and Austin, Singh, Hanslas and Rao (1972) studied the variability for lysine and leucine and classified the genotypes into appropriate groups. Based on such studies, Deosthale *et al.* (1970) recommended 'IS 5262', 'IS 5928', 'IS 5478' and 'IS 3950' as having moderately high protein, lysine and low leucine: lysine ratio and hence as good breeding materials. Austin *et al.* (1972) observed 'IS 4532' and 'IS 4952' to be superior in both protein and lysine.

In the present study, most Indian cultivars exhibited variability within the same variety for opaque and translucent characters. The opaque fraction was slightly superior in lysine compared to the translucent fraction but even here, the negative relationship between protein and lysine seem to operate. Cultivars like 'Jowar No. 98-2', 'C 43' and 'B. P. 53'—all from Gujarat, 'IS 1216' and 'IS 4906' yielded high lysine and low protein values. But retesting revealed that per cent protein increased and per cent lysine decreased further establishing the negaiive relationship. Three lines, 'IS 4570', 'IS 4840' and 'IS 15075' seemed to maintain moderately high protein and lysine levels. Even 'P 721', an induced mutant reported by Mohan (1975) was inconsistent for protein and lysine. Among the introduced varieties, 'Dwarf white Milo' from Sudan has reasonably high protein and lysine values. '*Saffra*', another yellow endosperm variety from Sudan was reasonably good. However, these varieties need further testing and confirmation.

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NUTRITIONAL QUALITY IN GRAIN SORGHUM—BEHAVIOUR OF CROSSES BETWEEN HIGH LYSINE SORGHUM AND AGRONOMICALLY SUPERIOR TYPES*

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ABSTRACT

The genetic behaviour of protein, lysine and leucine was examined from F_1 to F_8 generations in crosses involving shrivelled high lysine Ethiopian sorghums and some agronomically desirable types. In F_1, the plump opaque fraction was marginally superior to the plump translucent fraction for lysine; the shrivelled opaque was, of course, the most superior. There was very low level of recombination between plump and shrivelled fractions of the same ear head in the segregating generations. The shrivelled types exhibited superiority over plumps with respect to both protein and lysine in F_1 as well as in advanced generations. The lack of association between protein and lysine content in shrivelled seed indicates the possibilities of recovering high lysine with high protein.

Selection in crosses resulted in the isolation of dwarf photo-insensitive agronomically desirable shrivelled types like N 82, N 93 and N 94 with high protein (13·6%) and high lysine (2·73%). Among plump selections, N 49, N 55 and N 59 have moderately high lysine at normal protein level. Their progenies do throw plants with more than 3 percent lysine. The frequency of occurrence of high lysine plants in F_6–F_8 generations indicated greater possibility of stabilising lysine between 2·5 to 2·8 percent in plump back ground.

THE discovery of high lysine Ethiopian sorghums by Singh and Axtell (1973) raised hopes of breeding nutritionally superior sorghums; in actual practice, the transference of the high lysine trait from the shrivelled to plump grains could not be accomplished so far. The present study was taken up to study the genetic behaviour of protein, lysine and leucine in crosses involving high lysine Ethiopian sorghums and their inter-relationships with seed type and yield attributes.

MATERIALS AND METHODS

The high lysine Ethiopian sorghums IS 11167 and IS 11758 were crossed with agronomically desirable 148 and 370 and several other parents with the object of recovering dwarf and photo-insensitive varieties of plump as well as shrivelled backgrounds with high lysine. The segregating generations of the crosses were grown over years under optimal growing conditions. In some of the generations, the plump and shrivelled fractions on segregating earheads were separated and analysed. Nutritional analysis of the grains for protein, lysine and leucine was carried out at the National Institute of Nutrition, Hyderabad using standard analytical procedures. Microbiological assays were done for the estimation of lysine and leucine (Steele, Sauberlich, Raynolds and Baumann, 1949). Established statistical procedures were used for analysis and interpretation of data.

*This contribution is the XXXII part of the series on "Genetic analysis of some exotic × Indian crosses in Sorghum".

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TABLE 1

Summary of nutritional analysis over generations

Generation	Protein (g %)		Lysine (g/100 g protein)		Leucine (g/100 g protein)		Leucine/lysine ratio		Remarks
	Plump	Shrivelled	Plump	Shrivelled	Plump	Shrivelled	Plump	Shrivelled	
F_1	11·59	13·84	2·05	2·86	11·93	10·13	6·03	3·57	
F_2	11·40	—	1·82	—	12·97	—	7·29	—	
F_3	—	—	—	—	—	—	—	—	Very few plants analysed and hence not included.
F_4	10·48	14·24	2·27	2·79	10·70	10·89	4·88	4·10	
F_5	10·94	15·49	2·15	2·97	12·23	11·50	5·84	4·58	
F_6	9·22	15·95	2·21	3·60	10·77	10·35	4·80	2·91	
F_7	11·36	14·34	2·18	2·66	11·51	9·38	5·41	3·74	
F_8	10·27	14·63	2·21	2·80	11·27	11·97	5·16	4·35	
Mean	10·75	14·75	2·13	2·95	11·63	10·70	5·63	3·88	
S. E.±	0·32	0·33	0·06	0·14	0·31	0·39	0·33	0·25	

Results

Twenty seven crosses, 9 single and 18 three-way combinations, were built up with the Ethiopian high lysine sorghums as one of the parents to explore the possibilities of deriving plump and agronomically desirable types with high lysine. Means and character associations were studied from F_1 to F_8 generations.

(1) MEAN VALUES

Mean nutritional status of different seed types is presented in Table 1. The shrivelled types are superior to plump for protein, lysine and leucine : lysine ratio. Available analytical data based on seed fractions, plump or shrivelled, is presented in Table 2. The plump fraction has slight superiority over plump and the shrivelled fraction is inferior to the shrivelled, indicating low level of recombination. This is a significant point indicating that recombination for nutritional attributes between plump and shrivelled types does take place although at a very low level.

TABLE 2

Summary of nutritional analysis involving various seed types

	Generation			
	F_2	F_4	F_5	Mean
	Protein (g %)			
Plump	11.4	10.5	10.9	10.9
Plump fraction	11.5	10.7	13.6	11.9
Shrivelled fraction	13.5	12.5	13.2	13.1
Shrivelled	—	14.2	15.5	14.9
	Lysine (g/100 g protein)			
Plump	1.8	2.3	2.2	2.1
Plump fraction	1.8	2.2	2.3	2.1
Shrivelled fraction	2.8	2.2	2.6	2.5
Shrivelled	—	2.8	3.9	2.9
	Leucine (g/100 g protein)			
Plump	13.0	10.7	12.2	12.0
Plump fraction	12.5	10.5	13.9	12.0
Shrivelled fraction	10.9	10.2	11.8	11.0
Shrivelled	—	10.9	11.5	11.2
	Leucine/lysine ratio			
Plump	7.2	4.9	5.8	6.0
Plump fraction	7.0	4.9	5.2	5.7
Shrivelled fraction	4.0	4.8	3.7	4.1
Shrivelled	—	4.1	4.6	4.3

(2) CHARACTER ASSOCIATIONS

The correlation coefficients of protein per cent with lysine per cent and leucine: lysine ratio for various generations are summarised in Table 3.

In the F_1 generation, the superiority of the plump opaque over plump translucent is reflected in that the correlation coefficients between protein per cent and lysine per cent is significant only at 5 per cent level in plump opaque, where as it is significant at 1 per cent in plump translucent. The correlation between protein and leucine : lysine ratio is significant at 5 per cent in plump whereas it is not significant in plump opaque or shrivelled opaque classes.

In the F_2 generation, where the associations were worked out for the various fractions, the advantage of the plump fraction over plumps is brought out in that the negative relation between protein percent and lysine percent is significant at 1 percent in the plump group and 5 percent in the plump fraction. This again confirms that there has been some recombination in the plump fraction.

TABLE 3

Correlation of protein (g %) with lysine (g/100 g protein) and leucine : lysine ratio

Generation	Seed type	Correlation coefficients between protein (g %) and: Lysine (g/100 g protein)	Leucine : lysine ratio
F_1	Plump translucent	–0.67**	0.44*
	Plump opaque	–0.48*	0.30
	Shrivelled opaque	–0.46*	0.08
F_2	Plump	–0.53**	–0.08
	Plump fraction	–0.39*	0.31
	Shrivelled fraction	–0.05	–0.36
F_7	Plump	–0.37**	0.08
	Shrivelled	0.51**	–0.64**
F_8	Plump	–0.23**	–0.17
	Shrivelled	–0.08	–0.26**

The associations in the F_4 to F_6 reflect the sample behaviour. In the advanced generations of F_7 and F_8, the negative associations between protein and lysine are maintained in the plump group, but the association is significant at 1 percent in F_7 and 5 percent in F_8. By F_7, the shrivelled types became high lysine types and got stabilised by F_8 as reflected by no association between protein percent and lysine percent in the shrivelled group. In the shrivelled, the association between protein percent and leucine: lysine ratio is negative and highly significant which is also desirable.

TABLE 4

Means for nutritional and yield attributes in F8 generation

Seed type	Means								
	Protein	Lysine (g/100 g protein)	Leucine (g/100 g protein)	Absolute lysine (g/100 g food)	Absolute leucine (g/100 g food)	Leucine/Lysine ratio	100-grain weight (g)	Grain hardness (kg)	Yield/plant (g)
Plump	10·2722	2·2117	11·2716	0·2260	1·1499	5·1696	3·6718	5·1947	69·9324
Shrivelled	14·6280	2·7958	11·9727	0·4080	1·7440	4·3520	2·1260	1·8480	38·0733

(3) RELATION BETWEEN YIELD AND NUTRITIONAL ATTRIBUTES IN ADVANCED GENERATION

Two hundred and nineteen single plants in the plump group and 139 in the shrivelled group, all derived from single and three way crosses in the F_8 generation, were taken up for analysis (Table 4). The protein in the plump group ranged from 7·91 to 13·65 per cent with an average of 10·27. In the shrivelled, the range for protein was 12·07–17·09 percent with an average of 14·63 per cent. For lysine, the range in the plump was from 1·35 to 3·16 percent in the plump and 1·74 to 3·59 percent in the shrivelled. In the plump group also, plants do occur with high lysine content even though with a low frequency.

The analysis of variance (Table 4) for nutritional and yield attributes reveals that the shrivelled group is not only superior to the plump group for nutritional attributes, but the differences between crosses are also more pronounced in this group.

However, in the plump and shrivelled groups, some of the single plants derived from the 148 × IS 11167 cross are decidedly superior although the progeny as a whole, the plump ones yet do not exhibit marked superiority. The plumps are decidedly superior in yield.

The associations between nutritional attributes and yield attributes in the plump and shrivelled categories are presented in Tables 5 and 6. In the plump group, the relationship between protein and lysine is still negative, although the coefficient is low and significant at the 5 percent level in the shrivelled group this relationship is not significant. The leucine: lysine ratio and lysine are also negatively and significantly related. The seed weight and grain hardness are positively related to yield in both plump and shrivelled categories. There is apparently no correlation between yield attributes and nutritional attributes.

The shrivelled types besides being dwarf and early, are relatively photo-insensitive and could be grown in all seasons. The lysine (percent) is high and stable. They all have good white/creamy seeds and the yield levels are also reasonably high.

The plump types are agronomically desirable, dwarf, early, relatively photoinsensitive, but they are not stable for lysine. However, they do throw plants with high lysine and the average lysine content is reasonably high compared to normally grown commercial sorghums.

Regression analysis (Tables 5 and 6) reveals significant differences, the partial regression coefficients, b_1 (protein), b_2(absolute lysine) and b_5(leucine: lysine ratio) being significant in both groups and b_3 (leucine) only in the plump category.

(4) SELECTION EFFECTS

An index approach to selection towards improvement of lysine reveals that the scope, in fact, is greater in the plump group (18·5 vs. 6·4 in shrivelled) although there are hurdles in accomplishing the objective.

TABLE 5

Character associations and regression analysis of variance in advanced generations (Plump/types)

Character	Protein (g %)	Absolute lysine (g/100 g food)	Leucine (g/100 g protein)	Absolute leucine (g/100 g food)	Leucine/lysine ratio	100 grain weight (g)	Grain hardness (kg)	Yield/plant (g)
Lysine (g/100 g protein)	−0·2278*	0·7781**	0·2339*	0·0811	−0·6048**	0·0038	−0·0264	0·0611
Protein (g %)		0·4021**	−0·4543**	0·2805**	−0·1685	−0·0072	0·0121	−0·0331
Absolute lysine (g/100 g food)			−0·0851	0·2264*	−0·6780**	0·0137	−0·0114	0·0241
Leucine (g/100 g protein)				0·7196**	0·6122**	0·1510	0·0315	0·0679
Absolute leucine (g/100 g food)					0·5213**	0·1618	0·0399	0·0145
Leucine/lysine ratio						0·1165	0·0628	0·0121
100-Grain weight (g)							0·3861**	0·3320**
Grain hardness (kg)								0·2502*
$\hat{Y}$ = a 1·9009	b_1 −0·0788x_1*	b_2 +4·9642x_2*	b_3 +0·1081x_3*	b_4 −0·1553x_4	b_5 −0·1988x_5*	b_6 −0·0128x_6	b_7 +0·0032x_7	b_8 +0·0002x_8
SE_b =	1·9160	0·3522	0·0179	0·1730	0·0164	0·0078	0·0074	0·00018

*significant at 5 per cent, **significant at 1 per cent

TABLE 6

Character association and regression analysis of variance in advanced generation (Shrivelled types)

Character	Protein (g %)	Absolute lysine (g/100 g food)	Leucine (g/100 g protein)	Absolute leucine (g/100 g food)	Leucine/ lysine ratio	100-grain weight (g)	Grain hard- ness (kg)	Yield/plant (g)
Lysine (g/100 g protein)	−0·0759	0·8723**	0·0297	−0·0173	−0·7687**	−0·2099*	0·0710	−0·0898
Protein (g %)		0·4175**	−0·5242**	0·1935	−0·2560**	−0·0174	0·1044	0·0868
Absolute lysine (g/100 g food)			−0·2283*	0·0781	−0·8254**	−0·1963*	0·1074	−0·0419
Leucine (g/100 g protein)				0·7306**	0·5958**	0·0995	−0·1208	0·0178
Absolute leucine (g/100 g food)					0·4746**	0·0923	−0·0358	0·0464
Leucine/lysine ratio						0·2064*	0·1473	0·0583
100-grain weight (g)							0·1998*	0·3096**
Grain hardness (kg)								0·2694**

	a	b_1	b_2	b_3	b_4	b_5	b_6	b_7	b_8
$\hat{Y}$ =	2·7004	$-0{\cdot}1679x_1$*	$6{\cdot}6228x_2$*	$2{\cdot}1382x_3$	$-0{\cdot}0224x_4$	$-0{\cdot}0482x_5$*	$-0{\cdot}0064x_6$	$0{\cdot}0067x_7$	$0{\cdot}00005x_8$
SE_b =		0·0181	0·1916	0·0215	0·1467	0·0174	0·0042	0·0047	0·00013

TABLE 7

Attributes of some derived lines from Ethiopian crosses

Selection	Seed type	Protein (g %)		Lysine (g/100 g protein		Leucine (g/100 g protein)		Days to flowering	Plant height (cm)	Yield/plant (g)		No. of plants studied
		Mean	Range	Mean	Range	Mean	Range			Mean	Range	
N 49	Plump	10·40	7·20–13·46	2·44	1·75–3·71	10·78	7·14–14·88	67	115	57	26–97	22
N 55	Plump	10·45	7·10–11·95	2·19	1·57–3·29	10·55	9·13–12·12	68	155	73	38–133	23
N 59	Plump	9·16	7·00–12·32	2·23	1·86–2·52	12·14	11·31–12·97	68	150	84	70–94	8
N 82	Shrivelled	13·51	10·40–15·62	2·99	2·50–3·66	10·16	8·43–12·02	78	113	48	26–59	19
N 93	Shrivelled	13·73	10·15–16·27	2·66	1·99–3·74	11·43	7·51–12·88	66	158	48	31–73	29
N 94	Shrivelled	13·57	9·38–15·92	2·53	1·98–3·97	11·44	9·10–13·82	68	171	59	26–77	27
P-721	Plump	12·33	8·40–15·40	2·59	2·50–2·81	12·12	11·11–13·67	58	103	35	22–43	11

As a result of selection in crosses involving Ethiopian high lysine sorghums with desirable lines, promising agronomically desirable and nutritionally superior derivatives have been obtained. Their nutritional attributes are presented in Table 7.

Discussion

(1) BEHAVIOUR OF PROTEIN, LYSINE AND LEUCINE IN SEGREGATING GENERATIONS INVOLVING ETHIOPIAN PARENTS

In plump × plump crosses of sorghum Liang, Heyne, Chung and Koh (1968) observed that inheritance of protein was conditioned by partial dominance. They estimated two gene groups and low heritability for protein content. From another study of plump × plump crosses, Nanda and Rao (1975) recorded that the inheritance of protein, lysine, threonine and tryptophan was predominantly additive.

Even though Singh and Axtell (1973) postulated a single *hl* gene governing high lysine content in shrivelled seeded Ethiopian sorghums, its transference to plump seeded types through breeding methods became a near impossibility and the single gene hypothesis needs further examination. A simply inherited partially dominant single gene is reported to govern the inheritance of lysine in 'P 721' opaque mutant with plump seeds which is expected to be more useful in breeding programmes.

In literature, there is no evidence on the behaviour of the *hl* gene in crosses with plump seeded types except that the anticipated transfer has not been achieved. The present study analyses the behaviour of nutritional attributes from F_1 to F_8 generations in crosses between shrivelled seeded, high lysine Ethiopian and agronomically desirable sorghums.

In the F_1 generation, protein and lysine were the highest in shrivelled opaque followed by plump opaque, plump translucent having the lowest values. Differences for leucine content were not pronounced in the different categories, but the leucine : lysine ratio followed the same order as lysine. Absolute lysine was the highest in the plump opaque category.

From F_2 and F_5, most plants exhibited segregation for seed type within the head and the segregating fractions were separately analysed. In F_2, the shrivelled fraction was the most superior and the differences between plump and plump fraction were not pronounced for all the attributes. The superiority of shrivelled types for protein, lysine and leucine : lysine ratio was maintained throughout the segregating generations upto the advanced F_8 generation.

Association between increase in protein content and prolamine fraction and the consequent negative relationship between protein per cent and lysine per cent is well established (Naik, 1968; Virupaksha and Sastry, 1968; Pickett, 1968; Mertz, 1976). However, evidence that the relationship between protein and lysine need not always be negative is also available from the studies of Piva (1964) and Robinson and Sageman (1968) in maize and from Johnson, Mattern, whited and Schmidt (1969) in wheat. Nanda and Rao (1975) observed, even though the relationship between protein and lysine was negative, lysine and methionine were positively correlated with yield which could be advantageous.

Based on the advanced generation material of the present study an index approach was attempted which indicates that progress is possible for simultaneous improvement of protein and lysine although the process is beset with difficulties.

(2) SELECTION IN CROSSES INVOLVING SHRIVELLED ETHIOPIAN PARENTS

The results of selection for combining higher levels of lysine content with moderate protein levels against a plump seeded background have not been very encouraging and the negative association between protein and lysine has been maintained throughout. However, individual plants with higher levels of lysine do occur in advanced generations. Their frequencies are depicted below:

Frequency of high lysine plants in advanced generation (within **plump** *category only)*

Generation	% plants with lysine content of	
	2·51 to 2·80 %	>2·8 %
F_6	7·14	21·43
F_7	6·16	6·16
F_8	12·78	3·66

From the results, it appears that it is possible to stabilise lysine against good plump seed between 2·5 per cent to 2·8 percent lysine. Selection for lysine content above 2·8 per cent seem to reduce their frequency.

Selection for high lysine against a shrivelled background is not difficult. The gains of selection for plump and shrivelled seeded types in crosses involving Ethiopian lines may be summarised as follows (Table 7). (a) It has been possible to derive dwarf, early and relatively photoinsensitive types with high levels of protein and lysine with reasonable yield levels. Such types like N 82, N 93 and N 94 are shrivelled seeded but do not suffer from the agronomic disadvantages of the tall, late, photosensitive Ethiopian lines. If desired, they could be grown and used directly for preparation of special foods for weaning children and other vulnerable groups. (b) The plump types like N 49, N 55 and N 59 are agronomically desirable, photoinsensitive and do throw plants with high levels of lysine. The average lysine, however, is around 2·5 percent. They may prove to be good breeding materials for further improvement.

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BREEDING FOR SUPERIOR QUALITY STORAGE PROTEINS IN GRAIN SORGHUM*

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ABSTRACT

A diallel set of crosses among recently developed high lysine and agronomically desirable plump and shrivelled parents was examined together with the corresponding F_2 and back cross generations for protein and lysine content. The shrivelled × plump crossed seed become plump exhibiting xenia effect. The reciprocal differences were also significant. Non-additive gene action was predominant for protein as well as lysine. The shrivelled-seeded parents were better general combiners than the plump types. 'P 721' was found a better parent for transference of protein and lysine together compared to the rest of the plump parents. 'P 721' as a female parent improves protein while as a male tends to increase lysine in crosses particularly with shrivelled parents. Compared to the F_2, the back crosses generally tended to increase protein percent with concurrent decrease in lysine. Some plump seeded segregants combining 10 to 16 percent protein and 2·7 to 3·9 percent esimated lysine values have been isolated.

THE behaviour of crosses involving Ethiopian high lysine sorghums and promising agronomically desirable types has been presented earlier (Jaya Mohan Rao, Deosthale, Rana, Vidyasagar Rao and Rao, 1983). An induced mutant, P 721, with relatively higher levels of lysine (Mohan, 1975) is reported to be unstable (Riley, 1980) and its transference to a corneous endosperm type is yet to be achieved. The present study explores the possibilities of developing agronomically desirable plump seeded types with higher levels of lysine (2·50–2·80 g/100 g protein) at normal protein levels (10·00–14·00 g %) using cross combinations of derivatives from Ethiopian × Indian crosses and the P 721 mutant.

MATERIALS AND METHODS

A diallel set of crosses was built up using N 49, N 55, N 59 and P 721 as plump types and N 82, N 93 and N 94 as shrivelled high lysine (>3·00g/100 g protein) parents. N 49, N 55 and N59 are plump derivatives from the cross 148 × IS 11167 with reasonable levels of protein (10·00–14·00 g %) and lysine (2·50–2·80 g/100 g protein). All the three lines are dwarf, relatively insensitive to photo-period and with plump corneous seed and agronomically desirable. P 721 is a Purdue mutant with reasonably high lysine content and with floury endosperm. N 82 is a derivative from the cross IS 11758 × 370, whereas N 93 and N 94 are derived from the cross 148 × IS 11167. N 82, N 93 and N 94 are dwarf derivatives with shrivelled and corneous endosperm with high lysine comparable to the Ethiopian parents. The F_1s

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were utilised to build up the back crosses with both parents resulting in 84 crosses. This study included 7 parents, 42 F_1s, 42 F_2s and 84 back crosses.

The experiment was laid out in randomised complete block design at IARI-Regional Station, Hyderabad, during summer 1979 season with four replications. One row of F_1s, 10 rows of each F_2 and one row of each back cross per replication were planted. The crop was grown under optimal conditions.

Five competitive plants of parents, F_1s, BCs and 50 plants in F_2s were selected in each plot for recording observations. All the BC F_1s where P 721 was one of the parents were advanced to BC F_2s and 20–25 plants were selected for observations. All these samples were analysed for protein by colorimetric procedure using the technicon auto-analyser method and for lysine using a modified procedure of Udy (1971) as reported by Jambunathan (1980). Even though the entire diallel in various generations was grown together, protein and lysine analysis through dye-binding was confined to all F_1s and segregating generations involving P 721, because the analytical facility was limited. The number of samples analysed for protein (g %) and lysine values (g/100 g protein) in different generations are 45, 208, 555' 402 and 471 in parents, F_1, F_2, BC F_1 and BC F_2, respectively. The crossed seed (Fo) was also analysed for protein and lysine. Combining ability analysis was done using Method 1, Model 1 of Griffing (1956).

Results

The crossed seed (F_0)

When the shrivelled type is used as the female parent, the crossed seed became plump exhibiting xenia effect (Fig. 1). Such crossed seed also went down in lysine (%) indicating that a plump seed on the same maternal background tends to result in reduction of lysine. The plumpness *per se*, therefore, was responsible, for the generally low lysine percentages recorded on such seed types and that transferance of high lysine to plump seeds is, therefore, beset with difficulties. The reciprocal means and effects on protein, lysine and leucine, indicated that they were not significant. However, examination of reciprocal means of individual crosses did reveal significant differences. The combining ability analysis of variance and *gca* effects did not reveal any significant differences; the *sca* effects were also not significant.

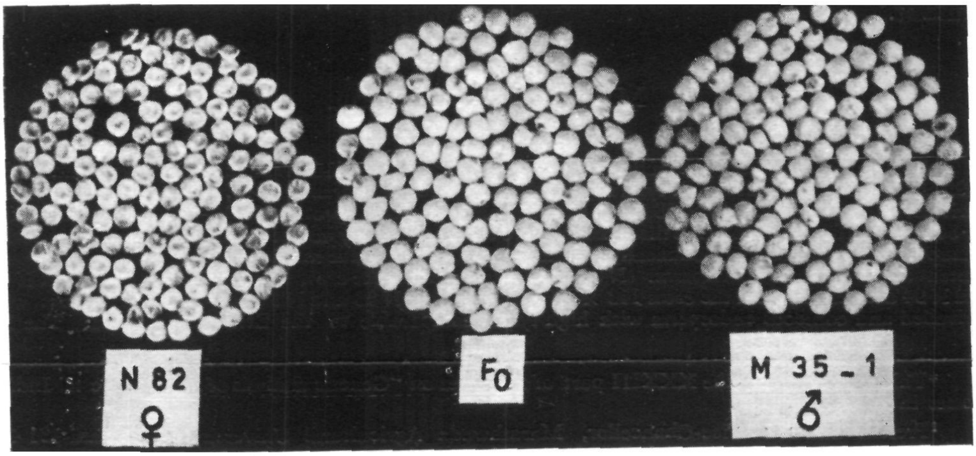

Fig. 1 : Xenia effect in crosses involving shrivelled high lysine sorghums (♀) with plump (♂) parents.

THE F_1 GENERATION

The differences for means of protein and lysine were significant. The reciprocal effects (Table 1) were also significant. The variance due to *gca*, *sca* and reciprocal effects are highly significant. The *gca* effects for protein and lysine are generally negative and significant with plump types and positive with shrivelled types (Table 2). With P 721, the *gca* effects are positive and significant for protein, while it is negative but not significant for lysine. Obviously, the gene distribution for protein and lysine in plump and shrivelled types is in opposite directions, but in P 721, some improvement has taken place for lysine. The *sca* effects for lysine are positive and significant for the plump × plump

TABLE 1

Reciprocal effects (*F_1 generation*)

Pedigree	Protein	Lysine
N 49 × N 55	0.87*	-0.07
N 49 × N 59	0.12	-0.06
N 49 × N 82	1.17**	-0.11
N 49 × N 93	-0.29	0.04
N 49 × N 94	0.73	-0.10
N 49 × P 721	-0.30	-0.01
N 55 × N 59	0.65	-0.02
N 55 × N 82	-0.23	-0.02
N 55 × N 93	1.45**	-0.01
N 55 × N 94	-0.95*	-0.05
N 55 × P 721	1.37**	-0.02
N 59 × N 82	-1.23**	0.08
N 59 × N 93	0.24	-0.06
N 59 × N 94	0.36	-0.15*
N 59 × P 721	-0.93*	-0.01
N 82 × N 93	0.95*	-0.17*
N 82 × N 94	-1.86**	0.00
N 82 × P 721	-0.05	0.83
N 93 × N 94	-0.28	0.14*
N 93 × P 721	0.07	0.00
N 94 × P 721	-1.70**	0.01
S.E. R(i, j)	0.39	0.07
C.D. (5%)	0.78	0.14

*Significant at 5 percent; **Significant at 1 percent.

crosses, N 49 × N 55 and N 55 × N 59. Amongst plump × shrivelled crosses, N 82 × P 721 is a desirable cross. This same cross also exhibited significant reciprocal differences for lysine (%).

TABLE 2

General combining ability effects (F_1 generation)

Parent	Protein	Lysine
N 49	–0.901**	–0.233**
N 55	–0.695**	–0.256**
N 59	–1.240**	–0.200**
N 82	0.553**	0.328**
N 93	1.275**	0.274**
N 94	0.521**	0.116**
P 721	0.486**	–0.021

**Significant at 1 per cent.

THE GENERATION MEANS

The back crosses involving one of the plump seed parents other than P 721 do not indicate any particular trend. However, (N 82 × N 55) N 82, (N 59 × N 93) N 93 and (N 94 × N 59) N 94 crosses exhibited 9 to 11 percent protein and 2·6 to 3·1 percent lysine appear to be promising.

In crosses involving P 721 (Tables 3 and 4) the lysine values in F_1, F_2 and BC_1F_1 are satisfactory for the cross P 721 × N 55, but the values of protein are low. This cross seems to exhibit reciprocal differences for protein as well as lysine, since its reciprocal has higher protein values and relatively low lysine. Amongst promising crosses for selection of high lysine include (N 59 × P 721) P 721; (N 82 × P 721) N 82; (N 93 × P 721) P 721. The reciprocal effects of P 721 for protein are more pronounced in crosses with shrivelled types than crosses with plump types. In such crosses P 721 as female improves protein. For lysine, the change is not perceptible. As such, combinations of P 721 when used as female, may be desirable for improving protein. But for lysine improvement, it is better used as a male.

TABLE 3

Generation means for proteins (g %) in crosses involving P 721

Cross	Generation					
	F_1	F_2	BC_1F_1	BC_1F_2	BC_2F_1	BC_2F_2
	Plump × plump and reciprocals					
N 49 × P 721	8.54	9.87	9.70	11.76	11.66	10.27
P 721 × N 49	9.14	8.98	9.76	10.72	9.42	11.20
N 55 × P 721	10.60	9.96	10.20	10.53	9.86	9.75
P 721 × N 55	7.86	9.57	8.54	9.98	7.50	10.35
N 59 × P 721	8.84	7.96	9.95	10.15	10.26	10.01
P 721 × N 59	10.70	10.07	10.34	10.00	7.82	10.30
Mean	9.28	9.40	9.75	10.03	9.42	10.31
	Shrivelled × plump and reciprocals					
P 721 × N 82	11.76	10.80	9.14	13.24	9.72	11.10
N 93 × P 721	13.42	10.19	9.32	9.86	12.72	9.66
P 721 × N 93	13.28	10.84	11.80	10.25	11.24	9.48
N 94 × P 721	7.78	8.39	8.22	10.64	8.96	10.18
P 721 × N 94	11.18	10.29	13.70	10.74	10.44	10.31
Mean	11.48	10.10	10.44	10.95	10.62	10.14
	Plump × plump					
P 721 as male	9.33	9.26	9.95	10.81	10.59	10.01
P 721 as female	9.23	9.54	9.55	10.23	8.85	10.62
	Plump × shrivelled					
P 721 as male	10.60	9.28	8.77	10.25	10.84	9.92
P 721 as female	12.07	10.64	11.54	11.41	10.47	10.29

BC_1=Back cross with ♀ parents; BC_2=Back cross with ♂ parents.

FREQUENCY DISTRIBUTION

The frequency distribution of plants for protein and lysine levels in overall F_2s and back crosses and reciprocal differences in P 721 crosses is given in Fig. 2. Straight and back cross F_2s reveal that compared to straight F_2s, back crossing has increased protein (%) and reduced lysine content.

P 721 as a female in P 721 × plump crosses tended to yield more plants with high protein and as male, it is desirable for lysine. It could be used to combine high lysine with moderately high protein levels. In combination with shrivelled high lysine parents, P 721 as female increases protein and definitely lowers lysine. In such combinations, it is desirable to use it as a male parent. Thus, the direction of cross seems to become more important in plump × shrivelled crosses than in plump × plump crosses. Under the circumstances, it appears desirable to concentrate for lysine and protein in selected crosses.

TABLE 4

Generation means for lysine (g/100 g protein) in crosses involving P 721

Cross	Generation					
	F_1	F_2	BC_1F_1	BC_1F_2	BC_2F_1	BC_2F_2
		Plump × plump and reciprocals				
N 49 × P 721	2.38	2.33	2.06	1.97	2.52	2.03
P 721 × N 49	2.40	2.76	2.48	2.29	2.28	1.86
N 55 × P 721	2.14	2.38	2.26	2.05	2.38	2.26
P 721 × N 55	2.46	2.48	2.56	2.32	2.36	2.10
N 59 × P 721	2.24	2.27	2.16	2.01	2.40	2.06
P 721 × N 59	2.26	2.15	2.54	2.33	2.48	2.03
Mean	2.31	2.39	2.34	2.16	2.40	2.06
		Shrivelled × plump and reciprocals				
P 721 × N 82	3.82	2.35	2.36	2.30	2.22	2.07
N 93 × P 721	2.48	2.35	2.28	2.29	2.48	2.24
P 721 × N 93	2.48	2.23	1.90	1.96	2.04	2.02
N 94 × P 721	2.24	2.31	2.24	1.99	2.30	2.21
P 721 × N 94	2.26	2.00	2.30	2.17	2.24	2.04
Mean	2.66	2.25	2.22	2.14	2.26	2.12
		Plump × plump				
P 721 as male	2.25	2.33	2.16	2.01	2.43	2.12
P 721 as female	2.37	2.46	2.53	2.31	2.37	2.00
		Plump × shrivelled				
P 721 as male	2.36	2.33	2.36	2.14	2.39	2.23
P 721 as female	2.85	2.19	2.19	2.14	2.17	2.04

BC_1=Back cross with ♀ parents; BC_2=Back cross with ♂ parents.

MOST PROMISING PLANTS FOR PROTEIN AND LYSINE

Maximum number of promising plants for high protein and lysine with plump seeds occurred in the F_2 of the crosses P 721 × N 93 and P 721 × N 82 which are plump shrivelled combinations. Some of the plump × plump combinations like N 49 × P 721, N 55 × P 721 and their reciprocals have also combined high protein and high lysine. It is on such plants, future improvement programmes should be based.

DISCUSSION

Available literature does not furnish any guidelines to plant breeders interested in improving quality of storage proteins of sorghum. A diallel mating system involving plump and shrivelled high lysine types together with the F_2 and back cross generations provided some basis for high lysine breeding of sorghums. The salient features of this study are:

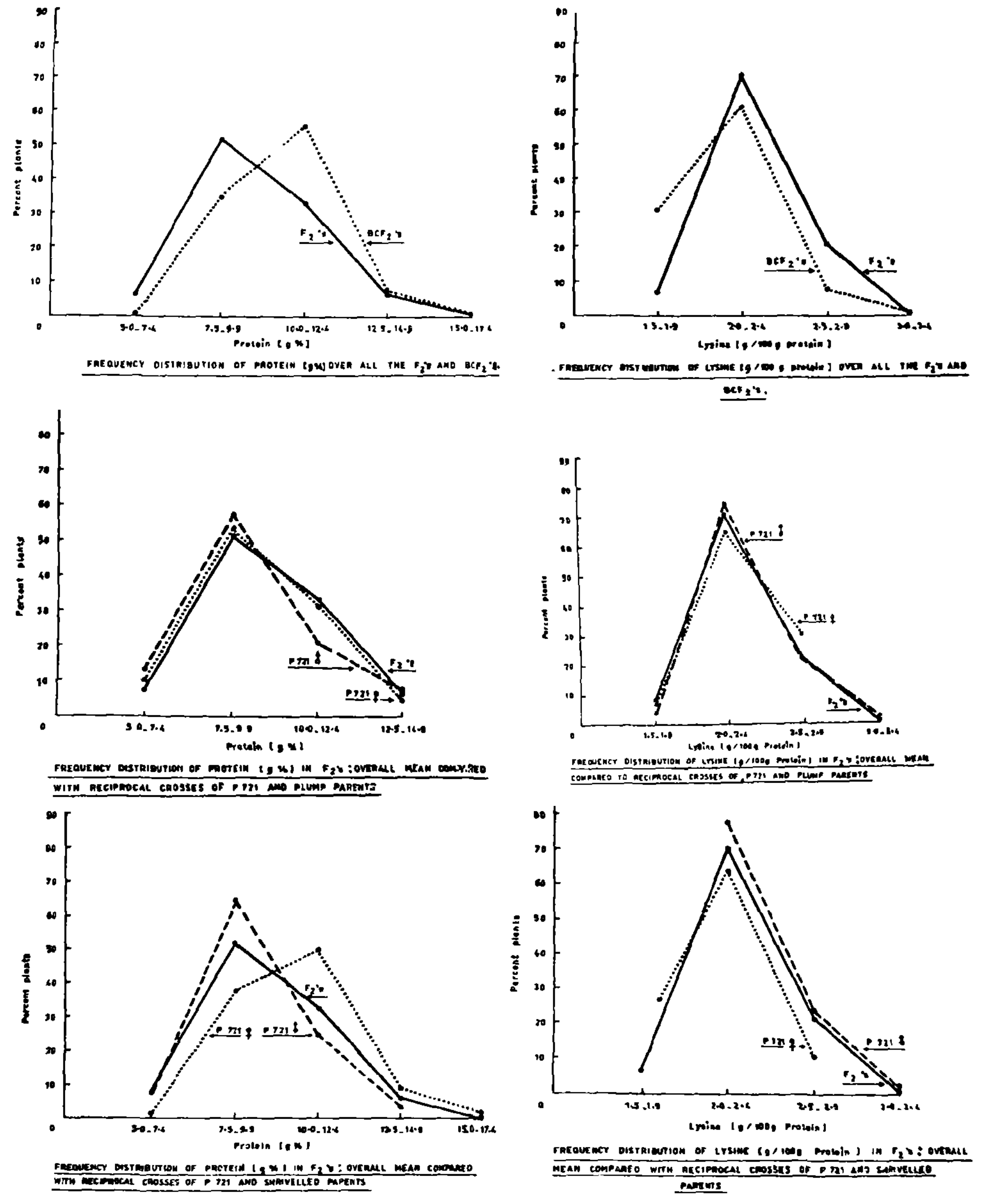

Fig. 2. Frequency distribution of protein (g%) and Lysine (g/100g Protein) in over all F_2's and BC's and Reciprocal differences in P 721 crosses.

(i) In shrivelled × plump crosses, the crossed seed itself becomes plump exhibiting xaenia effect. The protein content of such crossed seed is comparable to the shrivelled parent, but the lysine content gets reduced. This means, the genetic back ground remaining the same, the plumpness *per se* has resulted in the reduction of lysine content but not of protein. In view of this behaviour, the *gca*, *sca* and reciprocal effects for these nutritional attributes were calculated on F_0 seed but were found not significant.

(ii) Unlike F_0, in F_1, the means, *gca*, *sca* variance and reciprocal effects were highly significant. However, the *sca* is greater than *gca* for both protein and lysine indicating the greater importance of non-additive genetic variances.

The three plump parents N 49, N 55 and N 59 had negative *gca* effects, while the shrivelled parents N 82, N 93 and N 94 had positive *gca* effects. For P 721, the *gca* effects for protein is positive while for lysine, it is not significant. P 721 is, therefore, a better parent for transference of protein and lysine compared to other plump parents.

The *sca* effects reveal that the crosses N 49 × N 55, N 49 × N 59, N 55 × N 59 and N 82 × P 721 may be desirable combinations for combining protein and lysine in plump seeds, but the nature of gene action will play a major role in determining the transmissibility of high lysine.

(iii) A study of generation means in F_2 and back cross generations enabled identification of the following as promising cross combinations.
(N 49 × N 55) × N 49; (N 59 × N 49) × N 49; (N 59 × N 55) × N 59; (N 93 × N 49) × N 93; (N 93 × N 49) × N 49; (N82 × N 55) × N 82; (N 59 × N 82) × N 82; (N 59 × N 93) × N 93; (N 59 × N 94) × N 94; (N 94 × N 59) × N 94; (N 59 × P 721) × P 721; (N 82 × P 721) × N 82; (N 93 × P 721) × P 721.
These crosses result in segregates combining moderate levels of protein and lysine.

(iv) The direction of the cross or the choice of the male or female parent, particularly when P 721 is used as one of the parents appears important. This appears particularly so when P 721 is used in combination with shrivelled high lysine types. In such crosses, P 721 used as female improves protein and as male influences lysine in the positive direction.

(v) Compared to F_2, back crosses generally tended to increase protein percent with a concurrent decrease in lysine. In crosses involving P 721 with plump parents, when used as female parent segregation for protein percent is comparable to F_2, but as male, the frequency of plants with low protein percent are relatively more. For lysine, P 721 is desirable as male, but the differences between reciprocals are not that pronounced.

On the other hand, when P 721 is used as female parent in combination with high lysine shrivelled parents, there is a marked increase of plants with high protein. As such, there is a marked and consistent improvement for lysine. This is a significant guideline for plant breeding practice. The production of proteins is regulated by the allelic dosage present in triploid endosperm. Alleles that require single, double and triple doses to manifest themselves were distinguished in barley. This indicates reciprocal differences depending on the constitution of the female.

overall, the crosses N 93 × P 721, N 49 × P 721 and N 55 × P 721 were the best to combine high levels of protein and lysine. These crosses should be vigorously pursued.

From the point of view of overall superiority for protein and lysine, straight F_2s seem to have advantage over back cross procedures and in all crosses, P 721 happened to be the male parent lending credibilty to the overall hypothesis.

(vi) The plump opaque seed types was generally superior to plump translucent type for lysine.

Out of 44 most promising segregants only 11 segregants are from straight crosses. The cross N 93 × P 721 and P 721 × N 93 yielded maximum segregates combining both proetin and lysine. Other promising crosses include those involving P 721 with N 49, N 55 and N 82.

In these segregants, the protein content ranged from 10 to 16 per cent and lysine 2·7 to 3·9 per cent. This is a significant improvement, but these plants will be expected to segregate. Yet, since they have been identified with a high protein, the effect of negative relationships between protein percent and lysine percent is expected to be minimum. All these segregates turned out to be opaque plump, indicating that when selected for high lysine and protein, opaque type was favoured. The endosperm of several of these opaques is corneous.

In the light of the nature of gene action for protein and lysine, suitable breeding procedures need to be developed for capitalising the use of such segregates in developing stable lines combining high protein and lysine.

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GENETICS OF HOST PLANT RESISTANCE TO CHARCOAL ROT IN SORGHUM

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Abstract

Two sets of F_2 and F_3 diallel progenies among seven parents were evaluated for charcoal rot resistance under artificial epiphytotic conditions during post-rainy season without any supplementary irrigation. Progenies in F_3 were relatively more susceptible than in F_2. Reduction in F_3 resistance due to inbreeding was 24%, 64% and 74% respectively for susceptibility index (SI), % infection and number of nodes crossed by charcoal rot. These resistance parameters in F_3 were positively and significantly correlated among themselves.

General combining ability effects of parents showed significant differences in both generations. 'SPV 34' was most effective parent to transmit resistance in crosses. Resistance is mainly governed by non-additive genetic variance, with high degree of dominance. Heritability varied from 10–28% and was low for different resistant parameters. Though F_3 mode pertains to 0–4% class interval of disease infection, the genetic advance is expected to be low. Thus, resistance to charcoal rot can only be built up gradually in the newly developed tropical varieties of sorghum.

Charcoal rot [*Macrophomina phaseolina* (Tassi) Goid] is particularly serious under high temperature and moisture stress during grain-filling stage in both monsoon (July-Oct.) and postmonsoon (Oct.-Feb.) seasons in India. The disease occurrence pattern has particularly shifted after the introduction of high yielding hybrids and varieties with high harvest index. New tropical adapted varieties and hybrids should therefore be improved for disease resistance. Indira, Rana, Reddy and Rao (1982) documented the stability of charcoal rot resistance in sorghum. Subsequently, the behaviour of varietal crosses in F_1 generation was studied and the partial dominance of resistance for % infection and susceptibility index reported (Indira and Rana, 1982). While this information was valuable to exploit F_1 heterosis, information on inheritance in subsequent generations is necessary to transfer the resistance into homozygous varieties and parental lines of hybrids. The present investigation is aimed to study the components of genetic variance in early segregating generations to understand the inheritance pattern of disease resistance.

Materials and Methods

Two sets of diallel in F_2 and F_3 generations including seven common parents (p) and p (p–1)/2 crosses were evaluated for charcoal rot resistance under epiphytotic condition. The experiments were planted during post-monsoon (Oct-Feb.) season in vertisol soil under receding moisture condition without any supplementary irrigation or precipitation. F_2's and F_3's were sown in 4 row plots each of 3m length The spacing of 60 × 15 cm between rows and plants and a fertilizer dose of 80 kg N and 30 kg P_2O_5

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were uniformly adopted for both the experiments. All the experiments had 3 replications. The single plants were artificially inoculated by toothpick method after a week of flowering.

Ten random plants of parents and 20 plants from two middle rows of F_2 and F_3 were selected for observations. Data were recorded on number of nodes crossed by the charcoal rot, % infection in terms of disease spread in the stem and susceptibility index. The susceptibility index was calculated as the square root of proportion diseased plants × disease intensity grade (1-resistant, 5-susceptible). The observations were recorded at crop maturity. Diallels were analysed following Method 2 Model 1 of Griffing (1956).

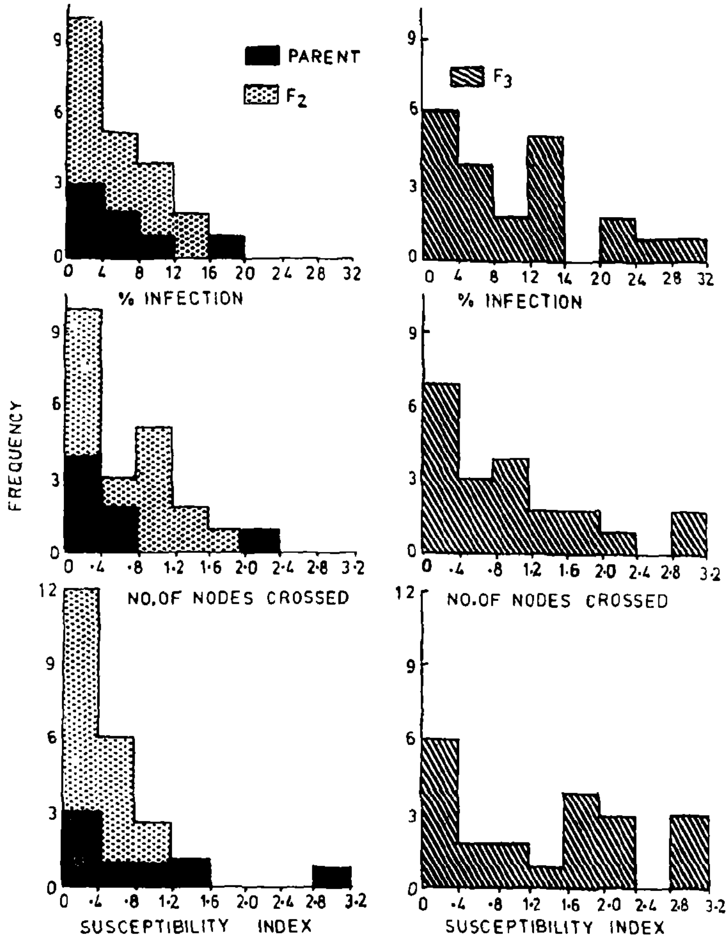

FIG 1-VARIABILITY AMONG PARENTS, F_2s AND F_3s PROGENIES FOR CHARCOAL ROT RESISTANCE.

RESULTS

1. VARIABILITY AMONG F_2 AND F_3 GENERATIONS

The F_2 variability was continuous, positively skewed and limited to parental range (Figure 1) but the F_3 progenies exceeded both parental and F_2

limits towards susceptibility classes. The parental and F_3 variation was discrete and bimodal. However, the modal classes in P, F_2 and F_3 generations were same. The highest frequencies were limited to 0–4% class interval of disease infection, 0·4 node crossed and SI in all the three generations.

The mean susceptibility of parents and F_2 progenies in terms of % infection, number of nodes crossed and SI was also less than F_3 progenies (Table 1). The phenotypic variability in F_3 was equal to F_2 for % infection but 27% higher for number of nodes crossed and 11% higher for SI. The inbreeding depression in F_3 varied from 24·4 to 73·5%. The positive value indicated depression of resistance in F_3. The maximum depression was in case of nodes crossed (73·5%) followed by % infection (64%).

TABLE 1

Susceptibility in different generations

Generation	% disease infection		No. of nodes crossed		Susceptibility index	
	Mean	% P	Mean	% P	Mean	% P
Parent (P)	6.72	100	0.57	100	0.83	100
F_2	6.39	95	0.68	119	0.82	99
F_3	10.48	156	1.18	207	1.02	123
PCV % (F_2)	44.0		70.5		78.1	
PCV % (F_3)	44.5		97.0		89.3	
I.D.	64.0		73.5		24.4	

PCV—Phenotypic coefficient of variability.
I.D.—Inbreeding depression in F_3 over F_2.

Among released varieties, 'CSV 8R' showed better field tolerance than 'CSV 4' and 'CSV 7R' while 'CSV 5' was moderately resistant. Among the experimental varieties, 'SPV 34' was highly resistant (R) and 'SPV 104' moderately resistant. Examination of means over generations revealed that seven crosses, (SPV 104 × SPV 34, CSV 5 × SPV 34, CSV 8R × CSV 5, CSV 8R × SPV 104, CSV 7R × SPV 34, SPV 35 × SPV 34, SPV 35 × SPV 104) were highly resistant in F_2 and F_3 generations and 'CSV 8R × SPV 34', 'CSV 4 × CSV 5' and 'CSV 4 × SPV 104' were moderately resistant. Among them, 'SPV 34 × SPV 104' and 'SPV 34 × CSV 5' represent R×R crosses and rest S×R crosses. None of the S×S crosses were found resistant.

The % infection was positively and significantly correlated with number of nodes crossed and SI in F_3 but not in F_2 generation (Table 2). However, number of nodes crossed was significantly and positively correlated with SI in both generations. Correlations observed in F_3 generations were highly significant.

TABLE 2

Correlation among different resistance parameters

Parameter	Generation	% Infection	Nodes Crossed	Susc. Index
% Infection	F_2	1.000	0.193	0.358
	F_3	1.000	0.944**	0.904**
Nodes crossed	F_2		1.000	0.558**
	F_3		1.000	0.945**
Susceptibility index	F_2			1.000
	F_3			1.000

**Significant at 1%.

2. COMBINING ABILITY ANALYSIS

There was significant variation among F_2 and F_3 crosses. While general combining ability (g c a) effects were significantly different in both the generations, specific combining ability (s c a) effects were significant only in F_3. The variance estimates revealed that σ^2 g c a both in F_2 and F_3 were considerably lower than σ^2 s c a for all the three resistant parameters. Degree of dominance varied from 0·9 to 2·8 for various characters. Low degree of dominance (·9) for SI in F_2 indicated slightly higher proportion of additive genetic variance as compared to non-additive genetic variance. Degree of dominance in F_2 was less than in F_3. Heritability estimates (h^2) varied from ·10 to ·28 and were uniformly low for all the three parameters.

Negative general combining ability effects (g c a) were desirable (Table 3). Among all the parents, 'SPV 34' showed significant and negative g c a effects for all the parameters in both the generations. 'CSV 7R', on the other hand, transmitted susceptibility to its crosses, as shown by positive g c a effects. General combining ability effects of 'CSV 4' and 'CSV 5' were negative but not significant. 'CSV 8R' was poor general combiner for % infection.

DISCUSSION

The evolution of disease resistance and pathogenity is a simultaneous system in nature due to an ecological balance between host and pathogen. As the new genotypes are introduced for cultivation to replace the land races, a new balance arises between host and pathogen. Even a minor disease sometimes assumes an epiphytotic proportion, e.g., appearance of charcoal rot (*Macro-*

phomina phaseolina) on CSV 7R variety of sorghum. Thus "management system for resistance genes" should be understood which leads to cultivars of crop plants that are uniformly resistant (Frey *et al.* 1977). *Macrophomina phaseolina* is a non-obligate parasite on sorghum and variability of races cannot be ruled out. Inspite of that, some of the sorghum varieties such as 'SPV 34', 'SPV 104' and 'CSV 5', the tropical adapted derivatives of temperate × tropical crosses, possess diversity of resistance. Some of the R×R and S×R crosses e.g. 'CSV 8R × CSV 5', 'CSV 8R × SPV 104, 'CSV 7R × SPV 34' and 'CSV 4 × SPV 104' also exhibit high degree of resistance consistently over F_2 and F_3 generations.

TABLE 3

Combining ability effects for different resistance parameters

Parent	% Disease infection		No. of nodes crossed		Susceptibilty index	
	F_2	F_3	F_2	F_3	F_2	F_3
SPV 34	–3.28**	–3.17**	–0.42**	–0.52	–0.42*	–0.84**
SPV 35	–1.20	1.22	0.00	0.63	0.00	0.85**
SPV 104	0.75	–1.02	0.06	0.04	0.03	0.26
CSV 4	–0.93	–0.42	–0.14	–0.20	–0.14	–0.39
CSV 5	–1.36	–1.73	–0.10	–0.30	–0.10	–0.50
CSV 7R	3.85**	3.03**	0.36*	0.05	0.36	0.00
CSV 8R	2.17**	1.88	0.25	0.31	0.26	0.63*
S.E. ($\hat{g}_i$)	0.81	1.15	0.14	0.26	0.19	0.32
S.E. ($\hat{g}_i$–$\hat{g}_j$)	0.85	1.73	0.16	0.30	0.22	0.37

*Significant at 5%, **Significant at 1%.

Resistance to charcoal rot in sorghum shows continuous variation in F_2 but not in parents and F_3. This may be due to differential quantitative thresholds as earlier reported by Rana *et al.* (1981) and high degree of genotype × environmental interactions (Indira *et al.* 1982). The absence of absolute resistance and range of variation warrant handling of this character as a horizontal resistance system in recombination breeding programme to ensure a greater tropical adaptation into the new crop genotypes. The recombination variability in F_2 and F_3 varietal crosses involving resistant sources and susceptible high yielding *rabi* varieties elucidates that the range of susceptibility in segregating F_3 progenies is greater than the parental varieties and F_2s but the phenotypic coefficient of variability for % infection remains almost similar. Inspite of this, the F_3 modal value pertains to 0–4% class interval of disease infection. Thus, the probability of occurring resistant progenies remains fairly high in F_3 as observed in F_2.

The resistance parameters are positively correlated among themselves in F_3 and governed by high degree of dominance and low heritability. The magnitude of non-additive genetic variance is relatively higher in F_3 as compared to F_2 but this cannot be utilized under constant inbreeding in pedigree breeding programme. Inspite of breaking original linkage blocks and evolution of new variability due to recombinations, the heritability in F_2 and F_3 remains low as earlier observed in F_1 (Indira and Rana, 1982) and for soft stalk in F_3 (Rana *et al.*, 1982). The genetic advance for resistance after a cycle of selection in F_3 is expected to be lower than observed in F_2.

The significant variability among parents for their general combining ability shows that some parents are superior than others in transmitting the resistance to their progenies. 'SPV 34' has the best breeding value followed by the average combining ability of 'CSV 5'. The *per se* performance of these parents is reflected in their crosses. Since, 'SPV 104' contains 'CSV 5' in its parentage, only 'SPV 34' provides diversity of alleles. The nature of inheritance suggests that the resistance in R × R and S × R progenies to *Macrophomina phaseolina* can be built up by regular screening under epiphytotic condition but the progress from selection in segregating generations is expected to be fairly low.

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HOST PLANT RESISTANCE TO RUST IN SORGHUM

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Abstract

Four experiments were conducted to determine the stability of varietal resistance and dominance of rust reaction in F_1 hybrids under different genetic (plant pigment) and cytoplasmic backgrounds. All the tan pigmented varieties and hybrids were not resistant to rust. CSV-4 and SPV-312 were tan (T) parents highly resistant and stable in rust reaction over environments. Male sterile and B-lines were moderately susceptible.

Purple (P) pigmented parents transmitted susceptibility as dominant character. Incomplete dominance of resistance was observed in some of the T × T crosses where one of the parent was highly resistant. The T × T hybrids were relatively more resistant than T × P or P × P crosses. Partial dominance mechanism of resistance observed in some T × T crosses could be useful to develop commercial hybrids.

Occurrence of sorghum rust (*Puccinia purpurea* Cke.) leading to deterioration of forage quality and yield losses is not uncommon. The estimated loss in susceptible variety is reported to the extent of 50% at Indore (Sharma, 1978). Though available systemic fungicides are potential to control rust, host plant resistance is a most economical means for its control. The genetic basis of rust resistance was studied by Coleman and Dean (1961) and Bergquist (1971), who showed rust resistance to be inherited as a monogenic dominant trait. In India, Patil-Kulkarni *et al.*, (1972) and Rana *et al.*, (1976) reported that susceptibility was dominant in varietal crosses.' The hybrids are commercially utilised in sorghum and thus F_1 reaction to diseases is major decessive factor along with yield for its acceptability. Recently some high lysine dwarf varieties are also developed which may be potential parents for the development of hybrids of high nutritive value (Jaya Mohan Rao *et, al.*, 1981). Therefore, the rust reaction of some parental lines in crosses has been studied under different genetic and cytoplasmic backgrounds to provide the guide line for hybrid programme.

Materials and Methods

The host plant resistance was tested in two sets of parents. The first set included 13 high yielding but low lysine parents and the second set included nine high lysine derivatives and donor lines. The 13 parents of the first set were represented by 10 best restorers developed in the project and three B-lines. These parents were screened at Hyderabad and Dharwad in total four environments each grown in randomized block design (RBD) with three replications to examine the stability of resistance and superiority over CSV-4, the donor parent for rust and other leaf spot diseases. Both these locations are endemic for rust incidence.

Two sets of crosses were generated from these parents. In first set of crosses, nine of the parents were crossed in diallel fashion to generate hybrids among restorer and maintainer lines. Among them, CSV-4 and CSV-5 were released dwarf varieties and restorer parents of commercial hybrids; SPV-104, SPV-232 and SPV-290 were recently bred high yielding restorers and 296 B, 2077 B and 2219 B were maintainer counter parts of male sterile (A) utilised in commercial hybrids.

The additional maintainer line 323 B was bred at Dharwad under high disease pressure. The parents and resulting hybrids were grown in RBD with three replications. In second set of crosses, the B-lines were replaced by male sterile (A) counter parts. Ten of the restorer lines and six new lines were crossed with three male steriles in line × tester mating system to enable evaluation of hybrids in different cytoplasmic back grounds. Among the new parents, SPV-126 is the tall mutant of CSV-4; SPV-226 and SPV-228 are the sister lines of SPV-225 and PD 3-1-11 is the restorer line of CSH-8 R. All the parents had tan pigment except PD 3-1-11. The 19 parents and 48 hybrids were grown in a three row plot of 3 m. long in RBD. The observations were recorded on the middle row of the plots.

The second set of parents which involved five tan pigmented parents (N-49, N-55, N-59 and N-94) and four purple pigmented parents (N-82, P-721, IS 11167 and IS 11758) was used to generate 9 × 9 full diallel. N-49, N-55, N-59 and N-94 were derived from the cross of CSV-5 × IS-11167 and N-82 from IS 11758 × CSV-3. All these lines possess moderate to high lysine. The parents and resulting 72 hybrids were evaluated during *kharif*, 1978 to examine the reciprocal differences. The experiment was grown in RBD with two replications.

The intra- and inter-row spacing of 60 × 15 cm and fertilizer dose of 80 kg N + 40 kg P_2O_5/ha were uniformly followed for all the trials. The rust infection was endemic every year. The data were recorded on five random plants in each row following the scores described by Rana *et al.* (1976). Score '0' indicates no rust pustule at all. The scoring system differed from Miller and Cruzado (1975), who classified as susceptible if 5% or more leaf area surface was covered with ruptureduredia.

Results

The varietal reaction to rust over four environments showed that SPV-290, SPV-291, SPV-311, SPV-312 and CSV-4 were highly resistant parents (Table 1). B-lines were moderately susceptible. According to risk aversion technique of stability analysis which is based on $\bar{X}$ and CV (Barah *et al.*, 1981), only SPV-312 was highly stable for rust resistance followed by CSV-4. Among B-lines 323B was fair. SPV-104, SPV-232 and CSV-5 which showed the hypersensitivity and moderate susceptibility at Hyderabad become more susceptible to rust at Dharwad.

TABLE 1

Mean rust reaction (Score 0–Resistant, 5-Susceptible) of some promising varieties and maintainer B-lines

Varieties	Hyderabad			Dharwad	Mean	C. V. (%)
	1978	1979 a	1979 b	1979		
SPV-104	1.60	0.33	2.50	2.00	1.60	34.36
SPV-225	3.50	1.60	2.60	4.00	2.92	36.11
SPV-232	2.00	1.00	2.30	4.00	2.32	53.64
SPV-257	2.00	1.00	2.60	1.60	1.50	38.49
SPV-290	0.90	1.00	0.00	1.00	0.72	66.98
SPV-291	1.40	0.50	0.00	1.00	0.72	83.80
SPV-311	0.00	0.33	2.00	1.00	0.83	106.07
SPV-312	1.00	0.33	0.60	1.00	0.73	44.80
CSV-4	1.60	1.00	0.50	1.00	1.02	43.99
CSV-5	2.80	1.60	2.30	4.00	2.67	37.80
323 B	1.80	1.00	2.60	2.00	1.85	35.72
2077 B	2.40	1.00	2.30	3.30	2.25	42.08
2219 B	2.80	1.00	3.30	3.00	2.25	61.53
Mean	1.83	0.89	1.81	2.22		
C. D. (.05)	0.78	0.36	0.65	1.08		

Rust reaction of hybrids involving resistant and moderately susceptible tan pigmented parents is presented in Table 2. SPV-290 and CSV-4 were highly resistant while 296 B and 2219 B were moderately susceptible parents. Hybrids tended to range between highly resistant (0·31) to moderately susceptible (3·3). The mean rust score of CSV-4 × SPV-104, CSV-5 × SPV-104, CSV-5 × 323B, CSV-5 × 2077B, SPV-104 × SPV-232, SPV-104 × 296 B and SPV-104 × 2077 B, crosses was less than either of the parents. CSV-4 × SPV-290, SPV-104 × SPV-290, SPV-232 × SPV-290, SPV-290 × 296B and SPV-290 × 2077 B were some of the crosses intermediate in reaction to rust. The resistance was incompletely dominant in these crosses and recessive in the rest.

TABLE 2

Rust reaction of parents and hybrids in R × B diallel

Parent	Score 0—Highly resistant, 5—Susceptible								
	CSV 4	CSV 5	SPV 104	SPV 232	SPV 290	296 B	323 B	2077 B	2219 B
CSV–4	1.0	1.3	0.6	2.0	0.3	2.3	2.0	1.3	3.0
CSV–5		2.3	1.0	2.3	—	3.3	1.0	1.3	3.0
SPV–104			2.0	1.0	0.6	1.0	1.0	1.3	2.3
SPV–232				2.0	1.0	2.6	2.5	2.3	3.0
SPV–290					0.7	1.0	1.3	1.0	2.6
296 B						3.3	2.0	2.3	3.0
323 B							2.6	3.0	3.0
2077 B								2.0	3.3
2219 B									3.3
Mean over hybrids	1.6	1.88	1.09	2.08	1.11	2.18	1.98	1.98	2.90
C. V. %	55.6	51.6	48.2	35.1	65.7	38.5	41.4	43.9	10.6

The rust reaction studied in different cytoplasmic back ground using male sterile × restorer crosses is presented in Table 3. The male sterile (♀) parents were moderately susceptible while restorer parents varied from highly resistant to susceptible, SPV-290, SPV-291, SPV-312 and CSV-4 were highly resistant restorer parents while SPV-126, SPV-257 and SPV-307 also showed high tolerance to rust (score 1·0–1·3).

The susceptibility was dominant in the crosses of high resistant parents SPV-290 and SPV-291, when male sterile was one of the parent. The hybrids of other resistant parents such as SPV-126, SPV-257, SPV-307, SPV-312 and CSV-4 with 296A and 323A were intermediate in rust reaction. All the hybrids involving 2077A were relatively susceptible than the hybrids based on other females. About 43·7% T × T hybrids showed rust incidence equal (incomplete dominance) or less than mid-parental value (partial dominance). Some of the hybrids such as 296 A × SPV-104, 323A × SPV-228 and 323 A× SPV-265 were more resistant than either of the parents. The four hybrids, 323 A × SPV-312, 296 A × SPV-307, 296A × SPV-312 and 296 A × CSV-4 were intermediate in rust reaction. Resistance showed incomplete dominance in some of these crosses under tan genetic background.

TABLE 3

Rust reaction of parents and A × R hybrids

Parents (R)	Pigment	Male parent	Rust score of hybrids 296 A	323 A	2077 A	Mean of hybrids over females
SPV-104	T	2.5	1.6	2.3	3.0	2.3
SPV-126	T	1.0	2.0	1.0	2.0	1.9
SPV-225	T	2.6	3.3	4.0	3.0	3.4
SPV-226	T	5.0	3.6	3.6	3.6	3.6
SPV-228	T	2.6	2.3	1.0	3.0	2.1
SPV-232	T	2.3	3.3	2.6	4.0	3.1
SPV-257	T	1.3	2.6	2.0	3.3	2.6
SPV-265	T	2.3	3.3	1.3	3.0	2.5
SPV-290	T	0.0	3.0	2.3	3.0	2.8
SPV-291	T	0.0	2.0	3.0	3.0	2.6
SPV-307	T	1.0	1.6	1.6	2.6	1.9
SPV-311	T	2.0	2.0	2.3	3.3	2.5
SPV-312	T	0.6	1.0	1.3	2.6	1.6
CSV-4	T	0.5	1.6	2.0	1.6	1.7
CSV-5	T	2.3	4.0	2.6	3.0	3.2
PD 3-1-11	P	3.0	2.0	3.3	4.0	3.1
Mean of hybrids over						
Male parents			2.45	2.26	3.04	
Female parents (A)			3.34	2.6	2.3	

The rust reaction of high lysine parents and their all possible hybrids is presented in Table 4. The tan pigmented (T) parents ranged from moderately resistant to susceptible (score 2·67–3·50) while the purple pigmented (P) parents were highly susceptible (score 4·5–5·0). The hybrids varied from moderately resistant to highly susceptible. Among them, T × T hybrids were least susceptible ($\bar{X}$=2·88) as compared to T × P ($\bar{X}$=4·51) or P × P crosses ($\bar{X}$= 4·97). T × P crosses were as susceptible as P × P crosses. The coefficient of variability (CV) among T × T crosses was highest (CV=25·4%) and moderate

TABLE 4

Rust reaction of some tan and purple parents and hybrids among them

S. No.	Parent	Pigment	Score 0—Resistant, 5—Susceptible										
			N-49	N-55	N-59	N-93	N-94	N-82	P-721	IS 11167	IS 11758	Mean	C.V. %
1.	N-49	T	**2.83**	4.83	4.83	2.50	2.67	4.50	4.00	4.83	4.17	4.04	23.5
2.	N-55	T	3.17	**3.50**	3.00	3.17	3.50	4.50	4.83	4.83	5.00	4.00	21.7
3.	N-59	T	2.33	3.50	**2.67**	2.50	2.33	4.83	2.66	—	—	3.00	32.7
4.	N-93	T	2.50	3.33	2.17	**3.17**	2.00	4.83	3.33	—	5.00	3.31	36.6
5.	N-94	T	2.50	2.33	2.17	2.33	**3.50**	4.33	4.33	4.33	4.50	3.35	32.5
6.	N-82	P	4.83	5.00	4.17	4.50	4.83	**4.83**	4.83	4.83	5.00	4.62	9.1
7.	P-721	P	4.00	5.00	4.83	4.50	4.50	4.83	**4.50**	5.00	5.00	4.71	7.4
8.	IS 11167	P	—	5.00	—	4.83	4.83	5.00	5.00	**5.00**	5.00	4.94	1.8
9.	IS 11758	P	5.00	4.83	5.00	5.00	5.00	5.00	5.00	5.00	**4.83**	4.98	1.2
	Mean of hybrids		3.47	4.23	3.74	3.67	3.71	4.73	4.12	4.80	4.81		
	C. V. (%)		32.8	24.3	33.9	31.3	33.4	5.3	20.4	5.2	7.0		

— Crosses missing.

among T × P crosses (mean CV=5·8%). The variability among hybrids was least when susceptible variety was one of the parent. This would happen when susceptibility is dominant. N-93 × N- 94, N -59 × N-94, N-59 ×N-93, N-49 × N-93 and N-49 × N-94 were some of the reasonably tolerant hybrids.

The reciprocal differences in T × T crosses were marginal as indicated by overall mean ($\bar{X}_1=3\cdot13$, $\bar{X}_2=2\cdot63$) and coefficient of variability ($CV_1=31\cdot6\%$, $CV_2=19\cdot1\%$). Among T × T crosses N-55 × N-49, N-49 × N-59 and N-94 × N-55; among T × P crosses N-59 × P-721 and N-93 × P-721 were some of the specific crosses which showed reciprocal differences of rust reaction.

Discussion

The present emphasis on the development of leaf diseases resistant hybrids has lead to choose the tan (T) pigmented male sterile and restorer parents since the tan pigment imparts resistance to most of the leaf spot diseases (Rao *et al.*, 1978). However, in the present studies, tan varieties showed variability for rust reaction. Although, CSV-4 (CS 3541), its derivatives such as SPV-290, SPV-291, SPV-307, SPV-311, SPV-312 and mutant SPV-126 are fairly resistant to rust, CSV-4 and SPV-312 are only stable for resistance over locations. The male sterile lines (A) are also tan pigmented but show relatively more susceptibility. CSV-5, SPV-104 and SPV-232 in particular are hypersensitive in reaction and unstable at Dharwad where the environment is conducive to rapid fungal growth and inoculum load is high as earlier observed by (Indira *et al.*, 1982).

Purple pigmented (P) parents are susceptible and transmit susceptibility as a dominant character in direct and reciprocal T × P or P× P crosses. The variability among these crosses is low and mean rust score is as high as of susceptible parent indicating the complete dominance of susceptibility. Under variable genetic and cytoplasmic backgrounds, T × T crosses show different types of rust reaction in F_1. Earlier, (Rana *et al.*, 1976) have reported that the degree of susceptibility depends on the presence of one or two recessive genes, the inheritance being trigenic recessive character. However, CSV-4 × SPV-290, SPV-104 × SPV-290, SPV-232 × SPV-290, SPV-290 × 296B and SPV-290 × 2077B are some of the T × T crosses which are intermediate in rust reaction indicating incomplete dominance of susceptibility. Here one of the parent is highly resistant. Whereas CSV-4 × SPV-104, CSV-5 × SPV-104, CSV-5 × 323B, CSV-5 × 2077B, SPV-104 × SPV-232, SPV-104 × 296B, SPV-104 × 323B and SPV-104 × 2077 B are more tolerant than either of the parents. Both the parents are moderately susceptible here and at least one of the parent is hypersensitive in reaction. The increased resistance in these crosses appears due to complementary effect of rust resistance and hypersensitivity.

In T × T crosses based on male sterile (A), the susceptibility was dominant in some and partial dominance in others. Since cytoplasm of a male sterile is different than male parent (R) and B-line, there is possibility of cytoplasmic influence on rust reaction. This is further supported by the reciprocal differences observed in some of the T × T crosses.

Dominance of susceptibility (Patil-Kulkarni, 1972; Rana *et al.*, 1976) and dominance of resistance (Coleman and Dean, 1961; Bergquist, 1971) are earlier reported. Miller and Cruzado (1969) observed both situations of monogenic dominance of susceptibility in B-406 × PI-267474 cross and dominance of resistance in Combine Shallu × PI-267474 cross following a different scale of scoring. The present study elucidates incomplete to partial dominance of resistance in T × T crosses where one of the parent is highly resistant and superiority of F_1 where both the parents are tan and at least one of them is hypersensitive in rust reaction. Since T × T F_1 hybrids based on male steriles are variable in rust reaction, emphasis should be given to select hybrids with partial dominance of resistance. This can only be achieved in T × T crosses since tan pigment is monogenic recessive (Rana *et al.*, 1976). There is further need to develop resistant male steriles, so that both the parents of a hybrid are resistant to rust. The probability of recovery of rust resistance is higher in tan plant background as compared to purple type which confirms the earlier report by Rana *et al.* (1976). However, caution must be exercised while using the tan pigmented varieties since they show susceptibility to leaf blight elsewhere (Rana *et al.*, 1980).

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HOST PLANT RESISTANCE TO STALK-BORER, *CHILO PARTELLUS* SWIN., IN SORGHUM

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Abstract—Seventy cultivars of sorghum representing recently released varieties, hybrids, experimental varieties, lines bred for stalk-borer resistance and local resistant stocks were tested for stalk-borer resistance under artificial infestation during monsoon (July–October) season. There were significant differences among varieties for leaf-feeding injury, per cent 'dead hearts', number of holes and tunnels and per cent tunnelling. Released hybrids and local varieties were susceptible for different parameters. Thirteen varieties viz., SPV Nos. 35, 103, 107, 110, 135, 140, 192, 229, E 302, E 304, P 37, R 133 and CSV-8R were at par with resistant varieties for per cent tunnelling per plant. Long peduncle varieties were relatively susceptible.

Leaf-feeding injury, per cent 'dead hearts' and tunnelling parameters were not significantly correlated and independent of each and none of them could be related to grain yield. Number of holes, number of tunnels and per cent tunnelling were positively correlated. Thus, number of holes per plant or internode may be a good indicator of per cent tunnelling and can conveniently be used as a criterion for evaluating germplasm to stalk-borer (*Chilo partellus* Swin.) resistance. The varieties CSV-8R, SPV-35, SPV-103, SPV-140 and SPV-192 were identified as promising sources of resistance to stalk-borer.

Key Words: Stalk-borer, *Chilo partellus* Swin., sorghum, resistance parameters, host plant resistance

INTRODUCTION

THE SPOTTED stalk-borer, *Chilo partellus* Swin., is a pest of major economic importance in India and East Africa. The young larvae after feeding on leaf-lamina move into the whorl where they cause extensive leaf-feeding injury and can attack the growing tips causing 'dead hearts'. As the larvae grow older they burrow into the stem and cause extensive damage due to tunnelling.

The existence of resistance in sorghum to *Chilo* was first reported by Trehan and Butani (1949). Systematic screening of sorghum varieties from the World Germplasm Collection for Stem-borer Resistance was attempted by Singh *et al.* (1968) and Jotwani *et al.* (1971), under natural infestation conditions. By utilizing these sources, several varieties and hybrids of commercial value were bred which have better plant type compared to basic resistance stocks. There has been some ambiguity concerning the parameters for assessing borer resistance. Singh *et al.* (1968) evaluated the lines on the basis of 'dead hearts' caused by borer larvae. Jotwani *et al.* (1971) evaluated the varieties on the basis of leaf-feeding injury and stem tunnelling. There is some evidence to show that temperate and tropical varieties behave differently for these parameters (Rana and Murty, 1971).

In the present investigation, an attempt is made to ascertain the level of resistance in recently developed high yielding varieties and hybrids under artificial infestation conditions and to correlate the different resistant parameters with grain yield to find out the suitable criteria for assessing borer resistance.

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MATERIALS AND METHODS

Seventy cultivars included in these studies represented seven recently released varieties (CSV Nos. 1, 2, 3, 4, 5, 6 and 8R), four released hybrids (CSH Nos. 1, 5, 6 and 9), eight varieties bred for stalk-borer resistance (E 302, E 303, E 304, E 701, P 37, P 151, D 124 and R 133), two resistant stocks (IS 2312 and *Aispuri*), two local varieties (IS 4664 and PJ 8K) and the rest of the 47 experimental varieties (SPV Nos. 35, 59, 96, 97, 99, 100, 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 126, 135, 140, 141, 192, 220, 221, 223, 224, 225, 227, 229, 230, 232, 257, 289, 290, 291, 292, 304, 305, 306, 308, 309, 310, 311, 312, 313, 314, 315 and 316). The resistant stocks are also Indian local varieties grown in other provinces.

The cultivars were sown in two-row plots in a randomized complete block design with three replications. Sowing was done at 60 × 15 cm spacing with a row length of 2.4 m. A fertilizer dose of 40 kg N + 40 kg P_2O_5 per hectare as basal and 40 kg N as top-dressing was applied after 30 days of planting.

Cultures of *Chilo partellus* larvae were collected from the field and reared on the leaf-whorl pieces of the susceptible hybrid, CSH-1 under laboratory conditions at 25 ± 2°C and 65 ± 5% r.h.

Egg-masses at black-head stage were kept in small specimen tubes (7.5 × 2.5 cm) with a moistened cotton swab placed as a lid. Soon after the egg hatch, the larvae migrate towards the moistened cotton swab.

This promotes easy transferring of the larvae with camel hair brush to infest the test plants.

Thirty plants in a plot were artificially infested. Ten freshly hatched first instar larvae were infested on each plant in two applications i.e., five at the leaf-whorl stage (25th day) and five at the boot-leaf stage (55th day) of plant development. The resistance parameters studied were leaf-feeding injury, per cent 'dead hearts', number of holes, tunnels and per cent tunnelling. The latter three parameters were studied separately in the stalk, peduncle and whole plant. Per cent 'dead heart' was calculated as number of plants with 'dead hearts' ÷ total number of infested plants per plot × 100. Since all the plants in a plot were infested, the rest of the parameters were recorded on five random surviving plants.

The observations for lead-feeding injury were recorded on individual plants in each row with a rating scale of 0 (no damage) to 5 (severe damage) and the averages for each variety were calculated. The 'dead hearts' were counted after 15 days of artificial infestation. The number of holes in the stalk and peduncle were separately counted on five random plants at the time of harvest after completely removing the leaf-sheaths. The number of holes per internode was derived by dividing the total number of holes by total number of internodes per plant. The selected plants were split open from the base to earhead to count and measure the length of tunnels. Per cent tunnelling was calculated by dividing the length of tunnels by corresponding heights of stalk, peduncle or whole plant and was transformed in angle for statistical analysis.

In addition to resistant parameters, five varietal characters i.e., plant height, peduncle length, number of internodes, grain yield per plant and 100-seed weight were also studied on the same five plants. The mean values calculated for each observation were used in statistical analysis. Correlation coefficients were estimated among resistance and yield contributing characters.

The varieties were classified according to peduncle length into short (< 35 cm), medium (35–70 cm) and long (> 70 cm) types. Nine varieties i.e., SPV-35, CSV-8R, SPV-140, SPV-141, IS 2312, IS 4664, *Ai-spuri* and PJ 8K had short peduncles, nine varieties i.e., SPV-59, SPV-223, SPV-224, SPV-304, CSV-1, CSV-3, CSH-1, CSH-5 and CSH-6 had long peduncles and the rest of the 52 varieties had medium peduncle types.

RESULTS

Significant differences were observed among 70 varieties and hybrids tested under artificial infestation for leaf-feeding injury, per cent 'dead hearts', number of holes, tunnels and per cent tunnelling recorded in stalk, peduncle and plant. Between group differences for resistance parameters were highly significant among short, medium and long peduncle type varieties. The comparison of group means indicated that the long peduncle group was relatively more susceptible than short and medium peduncle groups for all the parameters except leaf-feeding injury and number of holes per stalk (Table 1).

Table 1. Group means over seventy varieties for resistant parameters in sorghum

Peduncle length	Number of varieites	Leaf-feeding injury rating	Percent 'dead heart'	No. of holes per: stalk	peduncle	plant	internode	No. of tunnels per: stalk	peduncle	plant	Percent tunnelling (angle) stalk	peduncle	plant
Short	9	0.38	12.75	8.21	2.06	10.46	0.80	1.93	0.37	2.30	13.33	9.19	12.59
Medium	52	0.21	20.76	5.00	5.11	10.60	0.90	1.81	0.69	2.50	18.73	22.54	20.96
Long	9	0.08	19.56	6.57	8.14	14.24	1.26	2.12	0.77	2.64	22.74	25.03	23.50

Peduncle length: short = < 35 cm, medium = 36–70 cm, long = > 70 cm.

Means of released varieties, hybrids, selected experimental varieties, resistant and local checks are given in Table 2. The mean leaf-feeding injury rating was 0.21 with a range of 0–1.67. The leaf-feeding injury on E 302, E 303, E 304, E 701 and SPV-105 was absent. It was also low on all the released hybrids. Varieties except CSV-5, CSV-6, the resistant check, *Aispuri*, and the local check, PJ 8K, SPV Nos. 100, 109, 141, 227, 292 and IS 4664 showed significantly more leaf-feeding injury than the local variety, PJ 8K.

Mean per cent 'dead heart' was 19.57 with a range of 2.38 to 76.67. No variety was free from 'dead heart' formation. The per cent 'dead heart' of local checks was 14.42 and 13.82. The varieties bred for resistance, released varieties, except CSV-4 and three released hybrids, CSH-1, CSH-6 and CSH-9 were at par with *Aispuri*, which showed least percentage 'dead heart'. SPV Nos. 105, 192, 223, 229, 305, 306, CSV-4 and CSH-5 were more susceptible than *Aispuri* for per cent 'dead hearts'.

Mean number of holes per stalk and peduncle were 5.60 and 5.50 with the ranges of 0–14.00 and 0–15.33 respectively. Significantly lower (2.3) number of holes per stalk than *Aispuri* were observed in CSV-8R, SPV-110, SPV-232, E 303, E 304, E 701 and P 37. Forty one other varieties viz., SPV Nos. 35, 100, 101, 103, 106, 107, 192, 225, 227, 229, 230, 257, 289, 291, 292, 304, 305, 306, 308, 309, 310, 311, 312, 313, 314, 315, 316, E 302, P 151, D 124, R 133, CSV Nos. 1, 2, 3, 4, 5, 6, CSH Nos. 1, 5, 6 and 9 were at par with *Aispuri*. The number of holes per peduncle were absent in the resistant check, IS 2312. Twenty-two varieties which were at par with IS 2312 for number of holes per peduncle are SPV Nos. 35, 100, 106, 107, 110, 135, 140, 141, 192, 229, 232, 257, 289, E 302, E 303, P 37, P 151, R 133, CSV-5, CSV-6, IS 4664 and *Aispuri*.

Mean number of holes per plant were 11.05 with a range of 1.40–20.20. The resistant checks (IS 2312 and *Aispuri*) exhibited 14.00 and 9.20 holes per plant respectively. Four varieties viz., CSV-8R, SPV-110, E 303, and R 133 with less than 2.9 holes per plant were significantly superior than *Aispuri* but two earliest maturing varieties, CSV-3 and CSH-6, showed significantly more damage than *Aispuri*. Mean number of holes per internode was 0.94. The range was from 0.18 to 2.08 The lowest number of holes per internode were observed in SPV-110 which is at par with 19 varieties viz., SPV Nos. 35, 100, 101, 192, 229, 232, 289, 291, 316, E 303, E 304, E 701, P 37, P 151, R 133, CSV-5, CSV-6, CSV-8R and *Aispuri*. Three released varieties (CSV-1, CSV-2, CSV-3), all released hybrids and the local check, PJ 8K were significantly more susceptible than SPV-110 and *Aispuri* for number of holes per internode.

Number of tunnels per stalk ranged from 0.27 to 5.87 with a mean of 1.86. Both the local checks, IS 4664 and PJ 8K showed 4.00 and 5.86 tunnels per stalk respectively which were significantly higher than resistant checks. The released varieties particularly CSV No. 3, 4, 5, 6 and 8R and six varieties bred for resistance (E 303, E 304, E 701, P 37, P 151 and R 133) were at par with resistant checks but CSV-2 and the released hybrids (CSH-5, CSH-6 and CSH-9) exhibited significantly more numbers of tunnels per stalk. The other 25 varieties which were at par with resistant checks for tunnels per stalk are SPV Nos. 35, 59, 99, 100, 101, 104, 105, 107, 110, 140, 192, 225, 227, 229, 232, 289, 290, 291, 305, 306, 309, 311, 312, 315 and 316. The number of tunnels was lowest in SPV-35 and SPV-110. The range of number of tunnels per peduncle was 0–1.40 with a mean of 0.66. There were no tunnels in the peduncle of IS 2312, but *Aispuri* showed 0.33 tunnel per peduncle. Local check, PJ 8K and released hybrids, CSH-5, CSH-6 and CSH-9 had significantly higher number of tunnels per peduncle as compared to resistant checks. Even the varieties bred for resistance exhibited significantly more number of tunnels per peduncle as compared to IS 2312. Only 10 varieties viz., SPV Nos. 35, 107, 110, 140, 192, 229, 309, R 133, CSV-1 and CSV-8R were at par with IS 2312 for number of tunnels per peduncle. The total number of tunnels per plant ranged from 0.33 to 7.27 with a mean of 2.53. The local check (PJ 8K) had a maximum number of tunnels per plant. CSV Nos. 4, 6 and 8R, E 303, E 304, E 701, P 37, P 151, R 133, SPV Nos. 35, 101, 105, 110, 140, 192, 225, 289, 309 and *Aispuri* were at par with IS 2312 for this parameter.

Per cent tunnelling (angles) per stalk ranged from 5.15 to 33.13 with a mean of 18.53. PJ 8K was significantly more susceptible for per cent tunnelling per stalk but SPV Nos. 35, 101, 103, 105, 108, 110, 140, 192, 225, 229, 289, E 302, E 303, E 304, E 701, P 37, P 151, D 124, R 133, CSV-4, CSV-6, CSV-8R and *Aispuri* were at par with IS 2312. Per cent tunnelling (angles) per peduncle varied from 0 to 37.08 with a mean of 21.14. There was no tunnelling in the peduncle of IS 2312. Only seven varieties i.e., SPV Nos. 35, 103, 107, 140, 192, R 133 and CSV-8R were at par with IS 2312 for this parameter. Per cent tunnelling per plant ranged from 5.60 to 31.68 with a mean value of 20.21. The resistant checks, IS 2312 and *Aispuri* showed 8.71 and 9.33 per cent tunnelling per plant respectively. Thirteen varieties viz., SPV Nos. 35, 103, 107, 110, 135, 140, 192, 229, E 302, E 304, P 37, R 133 and CSV-8R were at par with resistant varieties for per cent tunnelling per plant.

The correlation among resistance parameters are presented in Table 3. Leaf-feeding injury rating was positively correlated with number of tunnels per stalk but not with other resistant parameters. Per cent 'dead hearts' was also not significantly correlated with any resistant parameters. On the other hand, number of holes per peduncle or plant or internode were significantly and positively correlated with number of tunnels and per cent tunnelling per stalk, peduncle and plant and among themselves except number of holes per peduncle with number of holes per stalk. Positive and significant correlations of number of holes per stalk with number of tunnels per plant and stalk were also observed. However, number of holes per stalk were not significantly correlated with per cent tunnelling parameters. In addition to positive correlations among number of tunnel parameters themselves, they were also positively and significantly correlated with per cent tunnelling parameters, except the correlation between number of tunnels per stalk and per cent tunnelling per peduncle. Per cent tunnelling parameters were also positively correlated among themselves.

Table 2. Host plant reaction of released varieties and hybrids and some of the selected varieties to stalk-borer in sorghum

S. No.	Variety/ hybrid	Leaf-feeding injury rating	Percent 'dead heart'	No. of holes per: stalk	peduncle	plant	internode	No. of tunnels per: stalk	peduncle	plant	Percent tunnelling (angle) stalk	peduncle	plant
						Released varieties							
1.	CSV-1	0.09	12.22	7.67	5.66	13.33	1.06	1.86	0.40	2.26	23.13	20.14	21.12
2.	CSV-2	0.11	12.62	5.93	8.33	14.26	1.31	2.00	0.60	2.60	20.88	22.96	19.17
3.	CSV-3	0.12	8.82	3.60	15.53	19.13	2.08	1.60	0.80	2.40	21.31	19.07	18.76
4.	CSV-4	0.16	35.42	4.22	6.64	10.86	0.94	1.00	0.87	1.87	15.77	26.84	23.44
5.	CSV-5	0.40	29.67	2.83	2.73	5.56	0.56	1.47	0.66	2.13	25.16	18.67	24.39
6.	CSV-6	0.36	8.33	3.13	4.33	7.46	0.62	0.96	0.84	1.80	17.18	32.12	23.86
7.	CSV-8R	0.18	11.12	1.90	0.20	2.10	0.29	0.60	0.06	0.66	6.13	6.59	7.24
						Released hybrids							
8.	CSH-1	0.05	12.38	6.40	5.66	12.06	1.20	1.53	0.80	2.33	29.77	28.85	28.66
9.	CSH-5	0.12	39.23	4.60	10.00	14.60	1.08	2.06	0.87	2.93	23.58	28.61	26.28
10.	CSH-6	0.02	7.33	9.40	10.26	19.66	1.61	2.46	0.94	3.40	23.94	31.31	27.52
11.	CSH-9	0.18	19.18	8.93	5.80	14.73	1.13	2.66	1.00	3.66	25.76	37.08	28.58
						Promising varieties							
12.	SPV-35	0.08	6.91	4.00	0.00	4.00	0.36	0.26	0.07	0.33	6.05	1.21	6.01
13.	SPV-103	0.15	10.60	5.27	3.40	8.67	0.88	2.07	0.80	2.87	5.15	8.48	5.60
14.	SPV-110	0.28	13.08	1.33	1.07	2.40	0.18	0.47	0.47	0.93	9.97	19.95	13.25
15.	SPV-135	0.37	19.89	8.86	4.23	13.09	1.14	2.26	0.60	2.86	18.04	17.66	12.79
16.	SPV-140	0.36	14.98	10.00	2.66	12.66	0.91	0.60	0.07	0.67	9.45	0.00	8.72
17.	SPV-192	0.14	34.34	2.30	2.23	4.53	0.37	0.80	0.27	1.07	13.89	8.55	13.23
						Varieties bred for resistance							
18.	E 302	0.00	5.13	4.26	3.07	7.33	0.78	2.26	0.87	3.13	12.99	24.04	15.57
19.	E 303	0.00	24.44	0.00	1.40	1.40	0.29	1.33	0.67	2.00	14.92	17.23	17.83
20.	E 304	0.00	18.88	1.53	5.30	6.83	0.57	0.86	0.67	1.53	9.15	22.03	14.68
21.	E 701	0.00	12.09	1.40	5.67	7.07	0.64	0.73	0.74	1.47	11.30	24.72	17.34
22.	P 37	0.15	18.99	1.60	3.00	4.60	0.42	0.66	0.54	1.20	9.57	18.01	16.31
23.	P 151	0.06	16.30	3.86	2.40	6.26	0.56	1.00	0.53	1.53	11.97	27.47	18.99
24.	D 124	0.11	18.75	4.26	8.00	12.26	1.01	1.80	0.80	2.60	14.23	27.55	20.78
25.	R 133	0.15	16.59	2.86	0.00	2.86	0.33	0.80	0.33	1.33	7.05	9.69	12.42
						Resistant checks							
26.	IS 2312	0.07	11.49	14.00	0.00	14.00	1.36	0.67	0.00	0.67	9.23	0.00	8.71
27.	*Aispuri*	0.05	6.49	6.40	2.80	9.20	0.45	0.73	0.33	1.06	12.88	10.56	9.33
						Local checks							
28.	IS 4664	0.75	14.42	12.86	3.18	16.04	1.08	4.00	0.53	4.53	19.66	20.25	19.84
29.	PJ 8K	0.09	13.82	13.20	7.00	20.04	1.37	5.86	1.40	7.26	22.27	18.73	18.15
	Range	0–1.67	2.38–76.67	0–14.00	0–15.33	1.40–20.20	0.18–2.08	0.27–5.87	0–1.40	0.33–7.27	5.15–33.13	0–37.08	5.60–31.68
	Mean	0.21	19.57	5.60	5.50	11.05	0.94	1.86	0.66	2.53	18.53	21.14	20.21
	LSD (0.05)	0.386	23.77	4.09	1.58	6.30	0.52	1.26	0.48	1.41	8.20	10.44	7.45
	CV%	116.6	75.10	45.20	49.80	35.30	33.60	41.60	47.90	37.40	44.80	42.80	35.30

Table 3. Correlation coefficients among resistant parameters in sorghum

S. No.	Character	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
1.	Leaf-feeding injury rating	1.00	0.04	0.06	−0.21	0.06	0.40	0.25*	−0.14	0.19	0.18	−0.10	0.07
2.	Percent 'dead heart'		1.00	0.08	0.08	0.09	0.06	0.11	0.11	0.12	0.17	0.14	0.21
3.	No. of holes per stalk			1.00	0.06	0.45†	0.38†	0.43†	0.02	0.39†	0.12	−0.19	−0.09
4.	No. of holes per peduncle				1.00	0.71†	0.77†	0.41†	0.58†	0.50†	0.49†	0.49†	0.51†
5.	No. of holes per plant					1.00	0.94†	0.68†	0.35†	0.68†	0.66†	0.28*	0.51†
6.	No. of holes per internode						1.00	0.56†	0.36†	0.58†	0.63†	0.29*	0.49†
7.	No. of tunnels per stalk							1.00	0.41†	0.98†	0.60†	0.21	0.43†
8.	No. of tunnels per peduncle								1.00	0.59†	0.38†	0.73†	0.57†
9.	No. of tunnels per plant									1.00	0.62†	0.36†	0.51†
10.	Percent tunnelling per stalk										1.00	0.48†	0.84†
11.	Percent tunnelling per peduncle											1.00	0.77†
12.	Percent tunnelling per plant												1.00

*Significant at 5%.
†Significant at 1%.

The correlation among resistant parameters and yield components are presented in Table 4. Leaf-feeding injury rating was negatively and significantly correlated with peduncle length and positively correlated with number of internodes per plant and 100-seed weight. Per cent 'dead heart' did not show any significant correlation with yield components. Per cent tunnelling per plant, number of holes and tunnels per stalk and plant, were positively correlated with plant height, but per cent tunnelling per peduncle was negatively correlated with plant height. The positive and significant correlations of number of holes per peduncle and internode, number of tunnels per peduncle and all the three parameters of per cent tunnelling with peduncle length were observed. Number of holes and tunnels per stalk were positively and significantly correlated with number of internodes per plant, while all the three resistance parameters of peduncle were negatively and significantly correlated with number of internodes per plant. None of the resistant parameters concerning the stalk, peduncle or plant were significantly correlated with grain yield and 100-seed weight.

DISCUSSION

There was wide variability in host plant reaction of hybrids, improved and indigenous varieties for various resistance parameters to stalk-borer. Two of the four indigenous varieties, IS 2312 and *Aispuri* were found more resistant than the other two varieties. In fact, local variety, PJ 8K and released hybrids were more susceptible than some of the improved high yielding varieties for various parameters. Per cent 'dead heart' showed a continuous variation from 2.38 to 76.67 indicating that stalk-borer can cause serious damage in susceptible varieties at seedling stage. A number of improved varieties showed resistance for leaf-feeding injury rating and per cent 'dead hearts' and are at par with *Aispuri*, but when these parameters were considered together, only E 302, E 304 and E 701 showed resistance for both.

Number of holes, tunnels and per cent tunnelling which can be estimated on surviving plants are related parameters (Table 3). The varieties which show least damage for these parameters in both stalk and peduncle can be considered resistant. SPV Nos. 35, 107, 110, 229, 309, R 133 and CSV-8R show less number of holes, tunnels and per cent tunnelling per stalk as compared to resistant checks. SPV-101, SPV-225 and SPV-209 were at par with resistant checks for these stalk parameters. When peduncle parameters were considered together SPV Nos. 35, 107, 140, 192, R 133 and CSV-8R showed least damage as compared to resistant checks. However, no variety was immune to per cent tunnelling per plant. Even the resistant checks exhibited 8.71 to 9.33 per cent tunnelling per plant. Nine improved varieties such as SPV Nos. 35, 103, 107, 110, 135, 140, 192, 229, and CSV-8R and four varieties bred for resistance viz., E 302, E 304, P 37 and R 133 were comparable to resistant check for per cent tunnelling per plant.

Singh *et al.* (1968) screened germplasm on the basis of per cent 'dead hearts', while Jotwani *et al.* (1971) and Singh *et al.* (1980) screened on the basis of

Table 4. Correlation coefficients between resistant parameters and yield components in sorghum

Yield components	Leaf-feeding injury rating	Percent 'dead heart'	No. of holes per: stalk	No. of holes per: peduncle	No. of holes per: plant	No. of holes per: internode	No. of tunnels per: stalk	No. of tunnels per: peduncle	No. of tunnels per: plant	Percent tunnelling (angle): stalk	Percent tunnelling (angle): peduncle	Percent tunnelling (angle): plant
Plant height	−0.00	−0.16	0.50†	−0.10	0.23*	0.14	0.31†	−0.19	0.23*	−0.22	−0.30†	0.35†
Peduncle length	−0.37†	0.17	−0.20	0.55†	0.18	0.29*	0.05	0.46†	0.15	0.35†	0.58†	0.48†
No. of internodes per plant	0.28*	−0.00	0.33†	−0.31†	0.12	−0.14	0.27*	−0.24*	0.18	−0.03	−0.25*	−0.12
Grain yield per plant	−0.04	−0.07	0.03	0.15	0.01	0.01	0.07	−0.00	0.06	0.06	−0.15	−0.04
100-seed weight	0.24*	−0.06	−0.05	−0.11	−0.13	−0.19	−0.00	−0.14	0.04	0.05	−0.05	−0.03

*Significant at 5%.
†Significant at 1%.

leaf-damage and per cent stem tunnelling. The present study which included all these parameters, estimated the tunnelling parameters and number of holes elaborately in stalk, peduncle and whole plant. It is observed that when tunnelling parameters for stalk and peduncle were considered, only a few varieties viz., SPV-35, SPV-140, SPV-192 and CSV-8R qualified for resistance. The damage due to tunnelling in peduncle which results in breakage and premature drying of grain is more serious than the tunnelling damage in the stalk. Holes in the peduncle also cause mechanical damage and weaken the peduncle which often fails to sustain the weight of heavy heads of high-yielding hybrids and varieties. Therefore, estimation of tunnelling parameters on peduncle becomes more important.

The leaf-feeding injury rating and per cent 'dead hearts' were neither related among themselves nor with any of the stem tunnelling parameters. It shows that these parameters are independent. Based on a study of Indian tropical varieities, Jotwani *et al.* (1971) observed significant correlation between leaf damage and stem length tunnelled. The change in this relationship can be attributed to the greater genetic variability among varieties included in this study. These varieties were developed from temperate × tropical crosses (Rao and Rana, 1981) in which temperate varieties were more susceptible to peduncle or stalk tunnelling (secondary damage), while tropical varieties were more susceptible to leaf-feeding injury (primary damage) as earlier reported by Rana and Murty (1971). Due to the absence of correlation, it is however possible to choose certain varieties such as CSV-8R, SPV-35 and E 302 which have low stem-tunnelling and leaf-feeding injury.

Number of holes per plant is positively related with tunnelling parameters. Therefore, the higher the number of holes in a plant or peduncle, the more and longer will be the tunnels. Number of holes per internode also indicated a similar trend. Thus, number of holes per plant or internode was a good indicator of tunnelling parameters which can conveniently be used in screening programmes.

Neither the leaf-feeding injury, per cent stem-tunnelling nor number of holes could be related to grain yield in the present study. Starks and Doggett (1970) also found that leaf-feeding injury rating was a poor indicator of expected grain yield and the highest yielder consistently had the highest leaf-feeding injury rating. The lack of significant correlations between resistance parameters and grain yield indicates that, in spite of various degrees of damage, the recently bred varieties or hybrids are capable of yielding more due to their genetic potential. Starks and Doggett (1970) also observed that the hybrid showed less suppression of yield in the presence of the borer. In spite of this, there is a necessity to incorporate resistance in high yielding hybrids for stability of production.

The leaf-feeding injury was negatively correlated with peduncle length. Thus, varieties with longer peduncle will have low leaf-feeding injury rating. The positive correlations of peduncle length with number of holes per peduncle or internode, number of tunnels per peduncle and per cent tunnelling showed that the longer the peduncle, the higher will be the susceptibility. Correlation with plant height indicated that dwarf varieties have long but few tunnels. The identified resistant varieties in this study are better sources due to improved genetic background and can be used in breeding programmes.

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SOLUBLE PROTEIN PATTERNS AND ESTERASE ISOENZYME PATTERNS IN HIGH LYSINE SORGHUMS AND THEIR CROSSES

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ABSTRACT

Soluble protein pattern from parents (N 49 and P-721) differed quantitatively and qualitatively from back crosses. However, the crosses had greater homology with P-721. The soluble protein pattern of crosses indicated greater recombination.

Study of esterase isoenzyme pattern in parents and their crosses further confirmed the inheritance of major components with P-721, since the cross showed greater homology with P-721. Most of the crosses with high protein and high lysine had common features with respect to esterase isoenzymes. The distinct esterase isoenzyme pattern under high protein background would make it possible to use the pattern as markers in any future breeding programme.

SOLUBLE proteins are physiologically active proteins which constitute the bulk of enzymes involved in growth, development and differentiation. Several workers have used the soluble protein pattern and isoenzyme pattern to understand the genome relationships (Alam and Sandal, 1969; Schwartz, 1966; Siddiq, Nerker and Mehta, 1972). Tripathi, Mehta and Rao (1981) have characterised various cytoplasms on the basis of protein and isoenzyme patterns. The cytoplasmic and nuclear inheritance effects have also been observed in esterase isoenzyme patterns (Tripathi, Dongre, Mehta and Rao, 1981) and study of variation with respect to isoenzymes can help in identification and classification of cytoplasms. Dongre, Johari and Mehta (1979) have reported differences in soluble proteins and esterase isoenzyme pattern of esterase and peroxidase in the mature grains of CSV-5 and high lysine sorghum IS 11758, both by gelelectrophoresis and isoelectric focussing. Paulis and Wall (1979) observed distinct differences in the electrophoretic patterns and amino acid composition of alcohol soluble proteins from normal and high lysine sorghums. A fundamental knowledge of isoenzyme pattern in seeds of diverse genetic background and cytoplasmic characterisation would provide a better understanding of not only species relation, but also of any species characterisation with them. Therefore, the present studies of soluble protein and esterase enzyme patterns in parents having high protein content or high protein quality and in seeds derived from crosses of high lysine parents was taken up.

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Materials and Methods

Two plump parents (N 49 and P-721), three shrivelled parents (N 82, N 93 and N 94), one F_1, one F_2 and five back crosses made with the parents under study were taken for the study of soluble protein pattern and esterase isoenzyme pattern. N 49, N 93 and N 94 are the high lysine derivatives derived from the cross 148 × IS 11167, whereas N 82 was a derivative of IS 11758 × 370. P-721 is a pardue high lysine opaque mutant. The plump lines are moderately high in protein and lysine and the shrivelled lines are high both in protein and lysine. All the parents are photoinsensitive and agronomically desirable.

(a) *Soluble Protein Extraction:* Seeds were ground in chilled pestle morter with 50 m Mtris-cl buffer (pH 7·6) (1:2·5 W/V) containing 10 mm mercaptoethanol. All operations unless otherwise stated, were carried out at 4°C. The cell paste suspension was then centrifuged at 15,000 × g for 30 minutes at 0°C. The supernatant obtained was used immediately for soluble proteins and esterase isoenzyme studied.

(b) *Slab gel isoelectric focussing:* Analytical isoelectric focussing in thin layer of polyacrylamide gel for soluble protein and isoenzymes of esterase was carried out in 5 per cent acrylamide gel containing 2–3 per cent carrier ampholyte (pH 3·5–10·0) (W/V) using LKB Multiphor Unit. 1 M phosphoric acid and 1 M NaOH were respectively used as anodic and cathodic solutions. Samples were applied by soaking uniform rectangular filter paper (10 × 5 × 1 mm) pieces in soluble protein extracts. Run was carried out for 4 hours at 400 Volts 10 mA current. Water at 10°C was circulated for cooling of the plate during the run.

(c) *Detection of esterase isoenzyme:* The gel slab was incubated in 50 ml or 0·05 M phosphate buffer (pH 6·0) containing 1 ml of 1 per cent α-naphthyl acetate in 60 per cent acetone and 25 mg fast blue RR at room temperature till the bands developed.

(d) *Staining of gels for protein pattern:* At the end of the run, the plate was removed and fixed in sulphosalicylic acid (3·46%) in 10·5 per cent TCA for one hour. Thereafter, the proteins were stained in 1·15 per cent coomassie brilliant blue in 25% ethanol and 8% acetic acid solution. Excess of stain was removed by washing in 50% ethanol and 8% acitic acid. After development of bands gel were photographed. pH gradient was determined by cutting the blank gel after run in 2 mm pieces and extracting in 2 ml of distilled water. pH was measured by expanded scale pH meter.

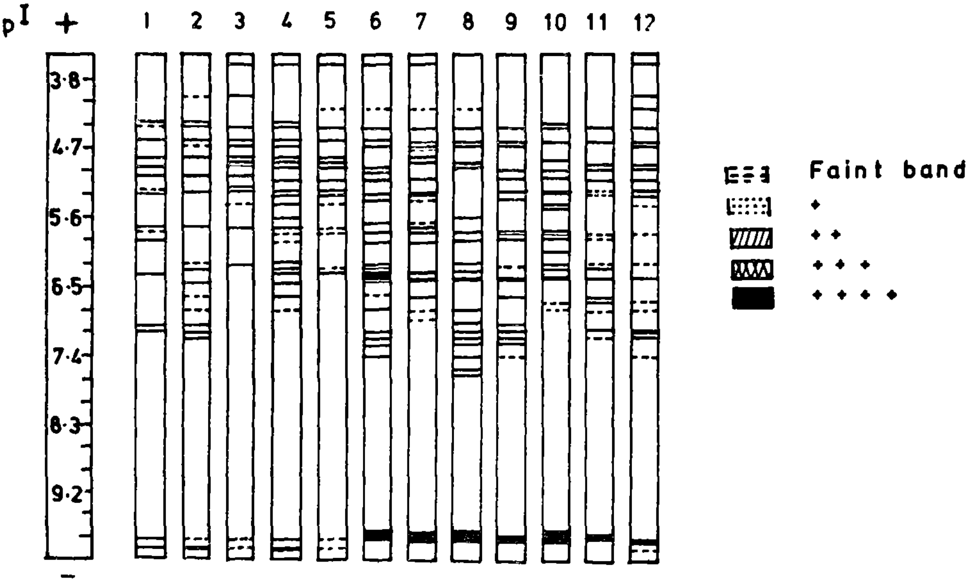

FIG_1 - SOLUBLE PROTEIN PATTERN.

RESULTS

(A) SOLUBLE PROTEIN PATTERN BY ISOELECTRIC FOCUSSING

Soluble protein patterns obtained in isoelectric focussing from seeds of parents F_1, F_2, BCF_1 and BCF_2 are illustrated in Figure 1. The isoelectric point (pI) of the bands along with their intensities are shown in Table 1. Both quantitative and qualitative differences were obtained in soluble protein pattern of parents and back crosses. Total number of bands ranged from 16 to 24. Maximum number of 24 bands were present in the parent N 93 and in the F_1 cross of N 82 × P-721. The back cross F_2 of (N 82 × P-721) × P-721 had 22 bands. An extra three bands were observed in the progeny of the back cross (N 82 × P-721) × P-721 (BCF_2), against its BC_2F_1 (N 82 × P-721) × P-721 and one against its second BC_1 F_1, where the number of bands were 19 and 21 respectively. When the F_1 pattern was compared with both of its back crosses, the number of bands were lesser, as F_1 had 24 bands and in the BCF_1s, there were 21 and 19. This may be due to increase in homogenity in the BCF_1 stage and due to further segregation and recombination in its BCF_2. Other back crosses (N 82 × P-721) × P-721, (N 93 × P-721) × P-721 and (P-721 × N 94) × P-721, had equal number of 19 bands. N 49 had the lowest number of bands; however, its back cross with P-721 had more bands i.e., 20 against 16 in N 49 and 19 in P-721. Similar changes in other back cross (N 82 × P-721) × P-721 and its F_2 were observed where the number of bands were more. It is thus clear that by using P-721 as a parent, there is a possibility of improving protein.

The bands at pI 4·45, 4·46 and 5·30 were not only common to most of the parents and their crosses, but also had similar intensity. However, at pI 5·30, there was no band in the back cross of (N 82 × P-721) × N 82. Two bands at pI 4·45 and 4·46 were present in all the parents, F_1, BCF_1 and BCF_2. It was also interesting to note that both the bands had more or less similar intensity, the latter having more intensity. The band at pI 5·80 absent in the parents and in the BCF_2 was present in BCF_1. This shift understandably may be due to the gene interactions and recombination effects. At pI 6·45 and 9·80, none of the parents had any band, but all F_1 and BCF_1s had prominent bands with similar intensity. The band at pI 9·80 was absent in BCF_2. Band at pI 9·85 and 9·95 present in all the parents had varied intensity. The band is also present in the BCF_2. Back crosses with P-721 had more similarities in the total distribution of bands indicating the utility value of P-721 in breeding programme.

Soluble protein pattern, when compared in the two plump lines N 49 and P-721 which are having a total number of 16 bands and 19 bands respectively revealed more similarities. The bands at pI 4·40, 4·45, 4·46, 4·90, 5·15, 5·30, 5·80, 7·05, 7·15, 9·85 and 9·95 were found to be common with more or less same intensity. P-721 had three extra bands. On comparison of the shrivelled parents N 82, N 93 and N 94, a similar trend of 11 common bands found at pI 3·65, 4·45, 4·46, 4·90, 4·95, 5·30, 5·50, 5·80, 9·85 and 9·95. However,

TABLE 1

Isoelectric focussing pattern for soluble proteins

pI	N 49	P-721	N 82	N 93	N 94	N 82 × P-721 F_1	(P-721 × N 49) × P-721 BC_1F_1	(N 82 × P-721) × N 82 BC_1F_1	(N 82 × P-721) × P-721 BC_2F_1	(N 93 × P-721) × P-721 BC_2F_1	(P-721 × N 94) × P-721 BC_1F_1	(N 82 × P-721) × P-721 BC_2F_2
3·65	—	—	+	+	+	+	+	—	—	—	—	+
4·05	—	—	+	—	—	—	—	—	—	—	—	+
4·10	—	F	—	—	—	—	—	—	—	—	—	—
4·25	—	—	—	—	F	—	F	F	—	—	—	+
4·40	+	+	—	++	—	F	—	—	—	++	—	—
4·45	F	+	+	++	++	+	+	++	+	+	+	+
4·65	++	++	+++	++	++	+	+	+	+	+	+	+
4·70	—	F	++	++	—	+	F	—	++	—	—	++
4·85	—	—	+	—	—	—	—	—	—	—	—	—
4·90	++	++	+	++	+	—	++	—	—	+	—	—
4·95	—	—	+	+	+	—	+	+	—	—	+	++
5·00	++	—	—	++	++	++	—	+	+	+	+	+
5·05	—	—	—	—	—	++	—	—	—	—	—	—
5·15	+	+	+	—	—	+	++	—	+	+	—	—
5·20	—	—	++	+	+	—	—	—	—	—	++	++
5·30	F	++	++	+	+	+	+++	—	+	++	F	++
5·35	++	—	—	++	+	—	—	—	—	—	++	++
5·45	—	—	—	—	—	++	F	—	++	—	—	—

TABLE 1 (*Contd.*)

pI	N 49	P-721	N 82	N 93	N 94	N 82 × P-721 F_1	(P-721 × N 49) × P-721 BC_1F_1	(N 82 × P-721) × N 82 BC_1F_1	(N 82 × P-721) × P-721 BC_2F_1	(N 93 × P-721) × P-721 BC_2F_1	(P-721 × N 94) × P-721 BC_1F_1	(N 82 × P-721) × P-721 BC_2F_2
5·50	—	—	F	++	F	—	—	—	—	++	—	F
5·65	—	—	—	++	—	—	—	+	—	++	—	—
5·75	—	—	—	—	—	++	F	—	—	—	—	—
5·80	++	++	+	++	F	—	+	—	+	++	—	—
5·85	F	—	—	F	F	++	++	+	+	+	F	F
5·90	—	—	—	—	—	—	—	—	++	+++	F	—
5·95	++	—	—	F	—	+	+	++	—	++	F	—
6·25	—	F	++	++	—	+	—	++	—	++	F	F
6·35	—	+	—	++	F	+	—	++	F	+	+	—
6·40	++	—	—	++	++	—	++	+	—	—	—	—
6·45	—	—	—	—	—	++++	+++	+++	+++	++++	+	+
6·50	—	++	—	++	—	+	—	—	—	—	—	—
6·70	—	F	—	+	—	F	++	—	+	—	++	—
6·75	—	—	—	—	—	—	—	—	—	F	++	F
6·85	—	F	—	F	—	++	F	++	—	F	F	F
7·00	—	—	—	—	—	—	F	—	—	—	—	—
7·05	++	++	—	—	—	—	—	+++	+	—	+	+
7·15	+	+	—	—	—	+	—	++	+	—	—	+

TABLE 1 —(*Contd.*)

pI	N 49	P-721	N 82	N 93	N 94	N 82 × P-721 F_1	(P-721 × N 49) × P-721 BC_1F_1	(N 82 × P-721) × N 82 BC_1F_1	(N 82 × P-721) × P-721 BC_2F_1	(N 93 × P-721) × P-721 BC_2F_1	(P-721 × N 94) × P-721 BC_1F_1	(N 82 × P-721) × P-721 BC_2F_2
7·25	—	+	—	—	—	+	—	+	+	—	F	—
7·30	—	—	—	—	—	+	—	++	++	—	—	—
7·45	—	—	—	—	—	+	—	+	F	—	—	F
7·65	—	—	—	—	—	—	—	++	—	—	—	—
7·70	—	—	—	—	—	—	—	++	—	—	—	—
9·80	—	—	—	—	—	++++	++++	++++	+++	++++	+++	F
9·85	++	F	F	++	F	—	—	—	—	—	—	—
9·95	+	+++	F	+++	F	—	—	—	—	—	—	+
Total	16	19	16	24	17	24	20	21	19	19	19	22

+Band present, —Band absent, F=Faint band.

the intensity among the bands differed. N 93 had the highest number of 24 bands followed by N 94 with 17 and N 82 with 16 bands respectively.

When the plump and shrivelled parents were compared together, 7 bands at pI 4·45, 4·46, 4·90, 5·30, 5·80, 9·85 and 9·95 were found to be common. The range of total bands varied from 16 to 24, N 93 with 24 and N 49 with 16 being the highest and lowest.

N-82 × P-721 F_1, when compared to its parental bands, six bands at pI 4·45, 4·65, 4·70, 5·15, 5·30 and 6·25 were found to be common. The bands at pI 4·40, 4·45, 4·65, 4·70, 5·15, 5·30, 6·25, 6·35, 6·50, 6·70, 6·85, 7·15 and 7·25 in case of P-721 and at pI 3·65, 4·45, 4·65, 4·70, 5.15, 5·30 and 6·25 were found to be common. This shows that the F_1 is more comparable with P-721, since there were 13 common bands as against 7 in N 82. The dissimilar bands (26) are more when compared to N 82 than P-721 (17). This could be attributed to the dominance and greater combining ability of P-721 which is of immense value.

The BCF_1s and BCF_2 compared to F_1 showed that there were eight common bands present at pI 4·45, 4·65, 5·00, 5·85, 6·45, 7.15, 7·45 and 9·80. Three additional common bands were found both in F_1 and its BCF_1s at pI 6·35, 7·25 and 7·30. The BCF_2 showed that at pI values 4·70 and 5·30, two more bands were common at all three stages (F_1, BCF_1 and BCF_2) when both the back crosses were compared together, there were similarities and dissimilarities. Twelve bands at pI 4·45, 4·65, 5·00, 5·85, 5·35, 6·45, 7·05, 7·15, 7·25, 7·30, 7·45 and 9·80 were common. However, the number of dissimilar bands were more. The BCF_1 of (N 82 × P-721) × N 82, when compared to its F_1 bands at pI 4·45, 4·65, 5·00, 5·85, 5·95, 6·25, 6·35, 6·45, 6·85, 7·15, 7·25, 7·30, 7·45 and 9·80 were common. On comparison with P-721 at pI 4·45, 4·65, 6·25, 6·35, 6·85, 7·05, 7·15 and 7·25, the bands were common. With N 82, only four bands at pI 4·45, 4·65, 4·95 and 6·25 were common. This again shows that P-721 had a greater contribution in the breeding programme. The BCF_1 of (N 82 × P-721) × P-721 had 11 common bands at pI 4·45, 4·65, 4·70, 5·15, 5·30, 5·80, 6·35, 6·70, 7·05, 7·15 and 7·25 with P-721 as against six common bands with N 82 at pI 4·45, 4·65, 4·70, 5·15, 5·30 and 5·80. This further confirmed that P-721 had a better combining capacity.

When the BC_1F_1 was compared to its F_1, at pI 4·45, 4·65, 5·00, 5·85, 5·95, 6·25, 6·35, 6·45, 6·85, 7·15, 7·25, 7·30, 7·45 and 9·80 the bands were common. BC_2F_1 showed at pI 4·45, 4·65, 4·70, 5·00, 5·15, 5·30, 5·45, 5·85, 6·35, 6·45, 6·70, 7·15, 7·25, 7·30, 7·45 and 9·80 bands were common. Extra three bands gained when the F_1 was back crossed with P-721.

The comparison of plump × plump back cross (P-721 × N 49) × P-721 showed that the number of similar bands were common with both the parents. The bands at pI 4·45, 4·65, 4·90, 5·15, 5·30, 5·80, 5·85, 5·95, and 6·40 and at pI 4·45, 4·65, 4·70, 4·90, 5·15, 5·30, 5·80, 6·70 and 6·85 with N 49 and P-721 were found to be common respectively. Bands at pI 4·45, 4·65, 4·90, 5·15, 5·30 and 5·80 were found to be common in both parents (N 49 and P-721) and in the back cross. There were three extra dissimilar bands found with P-721 when compared to N 49, which gives an idea that P-721 had greater ability of creating more recombinations under plump background.

(N 93 × P-721) × P-721 when compared to P-721 showed at pI 4·40, 4·45, 4·65, 4·90, 5·15, 5·30, 5·80, 6·25, 6·35 and 6·85 and with N 93 at pI 4·45, 4·65, 4·90, 5·30, 5·50, 5·80 and 6·35 similar bands. One extra band was observed when compared to P-721. The bands at pI 4·45, 4·65, 4·90, 5·30 and 5·80 were found to be common in both the parents as well as in BCF_1. The number of dissimilar bands in both the parents and BCF_1 was the same.

The other back cross (P-721 × N 94) × P-721 showed equal number of similar bands at pI 4·45, 4·65, 5·30, 6·25, 6·35, 6·70, 6·85, 7·05 and 7·25 with P-721 and at pI 4·45, 4·65, 4·95, 5·00, 5·20, 5·30, 5·35, 5·85 and 6·35 were *found to be common. Bands at pI 4·45, 4·65, 5·30 were common in both* the parents and back cross. The number of dissimilar bands were more when compared to P-721 than N 94. This reconfirmed the earlier part of the results indicating that P-721 can give more recombinations.

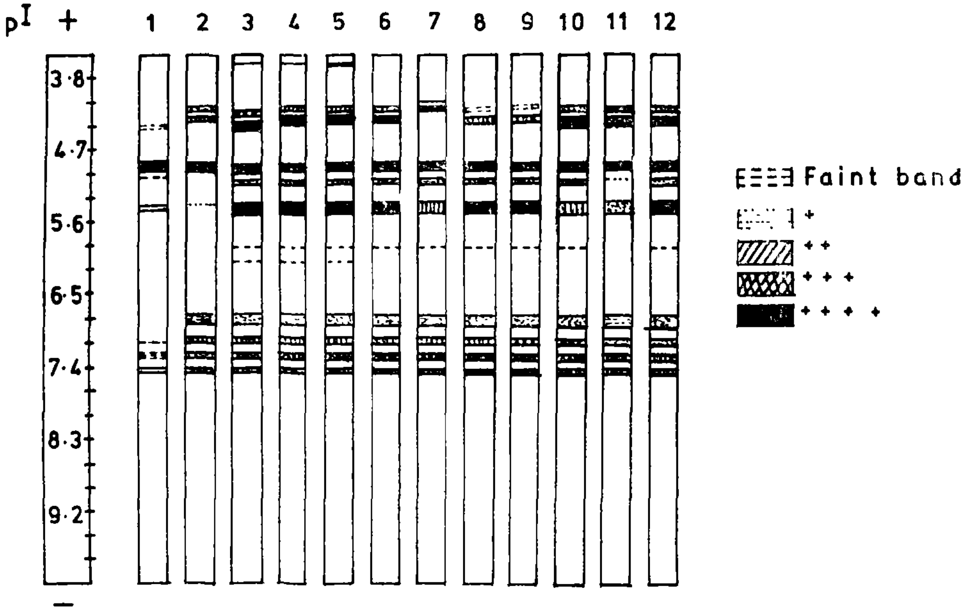

FIG. 2 – ESTERASE ISOENZYME PATTERN.

The total intensity of the bands in samples 6, 7, 8, 9 and 10 was greater than the parents. This indicates higher soluble protein concentration since equal amount of extracts was loaded. These results further indicated that by back cross programme, it is possible to improve protein concentrations. One of the characteristic feature of back cross programme is the presence of additional bands at pI 6·45 and 9·80 which are absent in the parents used in this study. Not only these protein bands were additional, but these bands had higher intensity indicating thereby a major swift in gene expression at certain loci under back cross programme.

(B) ESTERASE ISOENZYME PATTERN BY ISOELECTRIC FOCUSSING

Esterase isoenzyme patterns by isoelectric focussing in the same set of parents and crosses was examined and the pI values indicated in Figures 2 and the isoelectric point (pI) of the bands along with their intensities are shown in Table 2. Similarly, index values are given in Table 3. Esterase isoenzyme pattern of N 93 and N 94 was found to be similar. Esterase isoenzyme pattern of N 49 and P-721, the two plump lines differed and similar trend was observed in N 82 when compared with the other two shrivelled lines (N 93 and N 94). When the plump parents were compared with shrivelled parents, they differed significantly both in the number of bands as well as in their position. The two plump parents differed by a single extra band in P-721 and the number of total bands was same in all the three shrivelled parents. Maximum number of bands of 12 was found in the three shrivelled parents, whereas the plump P-721 and N 49 had 8 and 7 respectively.

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The number of isoenzymes in F_1, BCF_1s and BCF_2 was similar (10 bands); however, it was lesser than the isoenzymes in shrivelled parents (12 bands) and more than plump parents N 49 and P-721 which only had 7 and 8 isoenzymes respectively. This showed a recombination effect and stability in the number of bands in the back cross programme which is of definite breeding value. When the F_1 of N 82 × P-721 was compared with P-721, seven bands at pI values 4·20, 4·30, 4·90, 6·80, 7·10, 7·30 and 7·45 were found to be similar in intensity and at pI values 5·08, 5·38, 5·45 and 5·90, they were dissimilar. When compared with the other parents N 82, a similar number of seven bands were found, but they were at different pI values of 5·08, 5·45, 5·90, 6·80, 7·10, 7·30 and 7·45. In this case, the number of dissimilar bands is more when compared to P-721. This shows the dominance of N 82 in the cross. When only plump × plump × plump back cross was compared with the parent N 49, there were more number of dissimilar bands than the number of similar bands which are same when compared with P-721. At pI values 4·90, 5·08, 7·10, 7·30 and 7·45, the bands are common with N 49 and at pI values 4·30, 4·90, 6·80, 7·10, 7·30 and 7·45 with P-721 respectively. Similarly, when compared with N 49, the bands differed at pI values 4·10, 4·20, 4·47, 5·38, 5·45, 5·90

Table 2

Isoelectric focussing pattern for esterase isoenzymes

PI	N49	P-721	N82	N93	N94	N82 P-721 F_1	(P-721 × N49) × P-721 BC_1F_1	(N82 × P-721) × N82 BC_1F_1	N82 × P-721) × P-721 BC_2F_1	N93 × (P-721 × P-721 BC_2F_1	P-721 × N94) × P-721 BC_1F_1	(N82 × P-721) × P-721 BC_2F_2
3·65	—	—	++	++	++++	—	—	—	—	—	—	—
4·10	—	—	—	—	—	—	++++	—	—	—	—	—
4·20	—	F	—	++	++	F	++++	F	F	++	+	++
4·25	—	—	+++	—	—	—	—	—	—	—	—	—
4·30	—	++	—	++++	++++	++++	—	++	+++	++++	+	+++
4·35	—	—	++++	—	—	—	—	—	—	—	—	—
4·47	F	—	—	—	—	—	—	—	—	—	F	—
4·90	++++	++++	++++	++++	++++	++++	++++	++++	++++	++++	++++	++++
5·08	F	—	+	+	+	+	+	+	+	+	F	+
5·38	+	F	—	—	—	—	—	—	—	—	—	—
5·45	—	—	++++	++++	++++	++++	++	++++	++++	++	+	++++
5·90	—	—	F	F	F	F	F	F	F	F	—	F
6·10	—	—	F	F	F	—	—	—	—	—	—	—
6·80	—	F	+	+	+	+	+	+	+	+	F	+
7·10	F	++	++	++	++	++	++	++	+++	+++	+	+
7·30	F	+	+	+++	+++	+++	+++	+++	+++	+++	++	++
7·45	+	+++	++	+++	+++	+++	+++	+++	+++	+++	++	++
Total	7	8	12	12	12	10	10	10	10	10	10	10

+Band present, —Band absent, F=Faint band.

TABLE 3

Similarity index for esterase isoenzyme patterns

S. No.	Parent/cross	N 49	P-721	N 82	N 93	N 94	N 82 × P-721 F_1	(P-721 × N 49) × P-721 BC_1F_1	(N 82 × P-721) × N 82 BC_1F_1	(N 82 × P-721) × P-721 BC_2F_1	(N 93 × P-721) × P-721 BC_2F_1	(P-721 × P-721) × P-721 BC_1F_1	(N 82 × P-721) × P-721 BC_2F_2
1.	N 49		50	36	36	36	42	42	42	42	42	54	42
2.	P-721			25	46	54	64	50	54	64	64	64	64
3.	N 82				60	60	47	47	47	47	47	38	47
4.	N 93					100	84	69	84	84	84	69	84
5.	N 94						84	69	84	84	84	69	84
6.	N 82 × P-721 F_1							82	100	100	100	82	100
7.	(P-721 × N 49) × P-721 BC_1F_1								82	82	82	67	82
8.	(N 82 × P-721) × N 82 BC_1F_1									100	100	82	100
9.	(N 82 × P-721) × P-721 BC_2F_1										100	82	100
10.	(N 93 × P-721) × P-721 BC_2F_1											82	100
11.	(P-721 × N 94) × P-721 BC_1F_1												82
12.	(N 82 × P-721) × P-721 BC_2F_2												

and 6·80 and when compared with P-721, they differed at pI values 4·10, 4·47, 5·38, 5·45, 5·90 and 6·80.

The individual back crosses differed with their parents in isoenzyme band pattern. In back cross (N 82 × P-721) × N 82, the bands at pI values 4.20, 4·30, 4·90, 6·80, 7·10, 7·30 and 7·45 with P-721 and with N 82 at 5·08, 5.45, 5·90, 6·80, 7·10, 7·30 and 7·45 were found to be similar. At pI values 5.08, 5.38, 5·45 and 5·90 with P-721 and at pI values 3·65, 4·20, 4·25, 4·30, 4.35, 4·90, 5·00 and 6·10 with N 82, the bands were found to be dissimilar. The patterns from F_1 and both BCF_1 and BCF_2 were similar in this particular cross, but these differed with the parents. In another back cross (N 93 × P-721) × P-721, there was similarity with (N 82 × P-721) × N 82 and with (N 82 × P-721) × P-721, except the intensity of band at pI value 4·20. However, it differed with N 93 at pI values 3·65 and 6·10, where there were two extra bands in N 93 and at pI values 5·08, 5·38, 5·45 and 5·90, it differed with P-721. Rest of the isoenzyme bands were similar. The back cross (P-721 × N 94) × P-721 showed more isoenzymes than P-721 and less than N 94. The back cross showed similar bands when compared to both the parents at pI values 4·20, 4·30, 4·90, 6·80, 7·10, 7·30 and 7·45. In addition, bands with pI values 5·08 and 5·45 were similar in N 94. The bands at 4·47, 5·08, 5·38 and 5·45 in case of P-721 and at 3·65, 4·47, 5·90 and 6·10 were not similar with (P-721 × N 94) × P-721 back cross. The pattern in BCF_1 was almost similar with its F_2 and both back crosses with respect to the number of bands and pI values. However, the intensity of the band at pI 4·20, 4·30, 7·10, 7·30 and 7·45 differed with its F_1 and BCF_1s. When the BCF_2 is compared with P-721, the isoenzyme at values at 4.20, 4.30, 4.90, 6.80, 7.10, 7.30, and 7.45 were similar and at pI values 5·08, 5·38, 5·45 and 5·90, the bands were not similar. N 82 showed less similarity with BCF_2.

It is interesting to note here that most of the back crosses showed greater similarity in the number and intensity of isoenzymes except in back cross (P-721 × N 94) × P-721, where there was a slight change in the position of two bands. All the parents, F_1, BCF_1s and BCF_2 had a common set of bands with more or less same intensity at pI values 4·90, 7·10, 7·30 and 7·45. Similarly, except in N 49 and P-721, almost similar intensity band was present at pI value 5·45.

The above results show similarities and dissimilarities and reconfirm the earlier part of the results with sustained breeding effort, it will be possible to get recombinations with high nutritional quality under better endosperm background.

Discussion

In any breeding programme, it is important to use certain markers which could be associated with desirable character. Soluble proteins are physiologically active proteins which constitute the bulk of enzymes involved in growth, development and differentiation. Proteins which are the primary products of genes (Yanofsky and Lawrence, 1960) indicate direct measure of gene homology.

Based on this promise, various workers (Alam and Sandal, 1969; Schwartz, 1966; Siddiq *et al.*, 1972; Tripathi, 1979) tried to understand genome relationships using electrophoretic patterns of proteins and isoenzymes. On the basis of isoesterase pattern, nuclear inheritance effects have been observed in sorghum. Paulis and Wall (1979) compared the electrophoretic patterns and amino acid composition of alcohol soluble proteins from normal and high lysine sorghums and observed distinct differences.

In the present study, soluble proteins and esterase isoenzymes of parents with high lysine, F_1, F_2, BCF_1, BCF_2 having improved protein content have been examined. The soluble protein pattern showed qualitative and quantitative differences between not only parents, but also between F_1, BCF_1s and BCF_2. However, the soluble pattern from back crosses involving P-721 showed greater homology with P-721. Most of the bands in crosses could be traced to either of the parents, but the presence of a few prominant bands in crosses not found in parents indicate recombination. The predominance of protein band with pI 9·80 in most of the crosses is a result of such recombination. Greater homology between the crosses and parent P-721 indicate either a better combining ability or expression of genetic component derived from P-721 resulting in the crosses. In back crosses involving a second dose of P-721, the homology was even greater. The similarity index values of P-721-are higher for all crosses.

The esterase isoenzyme band pattern of high lysine plump seeds in the crosses was strikingly more or less similar. The shrivelled seeds showed the presence of an esterase isoenzyme band at pI 6·10. In all the crosses, most of the isoenzymes were similar to the pattern of P-721. The additional bands as compared to P-721 were restricted to one to two bands. These results further indicate better combining ability of P-721. On comparing the esterase isoenzyme pattern of high lysine sorghum strains and crosses (Jaya Mohan Rao, 1980) with isosterile sorghums (Tripathi, 1979), major differences were noticed. The majority of the bands in isosterile sorghums were found to be between pI 5·54 and 8·42 most of the bands had an isoelectric point higher than pI 5·78, while in high lysine sorghums, we find a much wider variation with isoelectric point of esterase isoenzymes. The increased intensity of isoenzyme on further crossing may indicate either additive effects or increased synthesis of particular enzyme. Conversely, the decrease in intensity of esterase band indicate decreased synthesis of enzymes. It is therefore, interesting to see the different biogenetic behaviour of high lysine strains. Siddiq *et al.* (1972) studied soluble protein pattern of *Oryza sativa* and found marked variability in soluble protein pattern between and within varietal groups. Protein and isoenzyme variations are known to provide an additional clue to an understanding of phylogenetic relationships in plants. The characteristic soluble protein and esterase isoenzyme pattern from seeds of sorghum strains with different degrees of plumpness and protein quality thus may help in monitoring inheritance of specific genetic traits and gene homology between crosses and parents.

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Soluble Proteins and Isoenzymes from Seeds of Diverse Male Steriles of Sorghum, (*Sorghum bicolor* (L.) Moench)

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Summary. A comparison of soluble protein, esterase, GDH and ADH isoenzyme patterns in seeds of different steriles, maintainers and restorer lines exhibited similarities as well as differences. Soluble protein patterns from sterile and maintainer lines differed both qualitatively and quantitatively. Based on the esterase patterns, male steriles with different cytoplasms could be separated into three groups (i) Ck 60A and B; Nagpur A and B, (ii) M 35-1A and 1 B, M 31–2A and 2B, (iii) G1A and B, VZM 2A and 2B. Each group could further be differentiated on the basis of minor differences in esterase isoenzyme patterns within each group. ADH and GDH patterns in general were similar in both sterile and maintainer lines.

Key words: Isoenzyme – Male sterile (A) – Maintainer (B) – Restorer (R) – Apomict – *Sorghum bicolor* (L.) Moench – Gel electrophoresis

Abbreviations

ADH Alcohol dehydrogenase
GDH Glutamate dehydrogenase
NAD Nicotinamide adenine dinucleotide

Introduction

Soluble proteins are the physiologically active fractions which constitute the major bulk of enzymes involved in plant metabolism. Yanofsky and Lawrence (1960) reported the existence of a direct relationship between genes and enzymes. In studying evolutionary mechanisms and species relationships it has been felt that conventional methods such as morphological variations, chromosome behaviour, etc., are not discriminatory enough. Theoretically, proteins which are the primary product of genes probably provide a direct measure of gene homology. Based on this premise attempts have been made by many workers to understand genome relationships using the electrophoretic patterns of proteins and isoenzymes (Alam and Sandal 1969, Schwartz 1966, Siddiq et al. 1972). Payne and Koszykovski (1978) used esterase differences as an aid in identifying soybean cultivars.

In the present study soluble protein and isoenzyme patterns in seeds of sorghum male steriles with different cytoplasms and their maintainer lines have been studied.

Materials and Methods

Mature seeds of six male steriles (Ck 60A, Nagpur A (both *milo*), G1A, VZM 2A, M 35-1A, M 31-2A), their maintainers (B lines), three fertility restorer lines (Nandyal, GM1-5, K.Local) and two apomictic lines (R 473, 302) were used for analysing soluble protein and isoenzymes patterns.

Soluble Protein Extraction

Seeds were ground in chilled pestle mortars with 50 mM Tris-Cl buffer (pH 7.6; 1 : 2.5 w/v) containing 5 mM β-mercaptoethanol and 5 mM EDTA for solubilizing protein and isoenzymes of alcohol dehydrogenase (ADH), glutamate dehydrogenase (GDH) and esterases. All operations were carried out at 4 °C. The cell paste suspension was then centrifuged at 15,000×g for 30 min at 0 °C. The supernatant obtained was used immediately in gel electrophoresis.

Separation of Proteins

Polyacrylamide gel electrophoresis was used to separate soluble proteins and various isoenzymes. The anionic system of Davis (1964) and Ornstein (1964) was adopted for separation of proteins and isoenzymes. Samples containing 200–225 μg protein were layered above the spacer gel. Electrophoresis was conducted in the cold (about 4 °C). Initially 2 mA were applied (for 15 min); this was increased to 3 mA current per gel tube until the tracking dye (bromophenol blue) entered into the running gel tube. After the completion of electrophoresis, which was indicated by the movement of tracking dye to the bottom of gels, the gels were stained for 30 min in 0.1% amido black (in 7% acetic acid) and destained by diffusing out excess stain in 7% acetic acid.

Esterase and ADH Isoenzyme Detection

Esterases were detected by incubating gels in 50 ml phosphate buffer (0.05 M; pH 6.0), containing 1 ml of 1% α-naphthyl-acetate in 60% acetone and 25 mg Fast Blue RR, at room temperature for 10–30 min. ADH gels were incubated at 37 °C for 20 min in a reaction mixture containing Tris-Cl, 0.05 M; EtOH, 0.05 ml; phenazine methosulphate (PMS), 1.0 mg; Nitro-bluetetrazolium (NBT), 10.0 mg; NAD, 40 mg; NaCN, 0.002 M, 2.0 ml, with a final volume of 20 ml at pH 8.0.

GDH Isoenzyme Detection

For GDH detection, gels were incubated at 37 °C until visible bands developed in the reaction mixture containing sodium glutamate, 100 mg; nicotinamide adenine dinucleotide (NAD), 12.0 mg; NBT, 10.0 mg; PMS, 1.0 mg; $MgCl_2$, 8.0 mg, 0.05 M phosphate buffer to a final volume of 20 ml; pH 6.7.

As a control, a blank gel for each enzyme was incubated in the mixture. For dehydrogenases, two control gels were incubated, one in a reaction mixture not containing NAD; the second was a blank gel. In such controls no bands were observed. At least two independent extractions were made for all the material examined. For each group of enzymes, triplicate runs were made. The relative migration (Rm) of each band with respect to the front formed by the tracking dye was calculated. Densitometer tracings of the gels were obtained on a Joyce-Loebl chromoscan.

Results

The soluble protein patterns obtained from different male steriles along with maintainers, restorers and two apomictic lines are shown in Fig. 1. The Rm values for protein bands are given in Table 1. The comparison of protein patterns indicate that patterns in *milo* Ck 60A, Ck 60B, Nagpur A and Nagpur B, are different qualitatively from those of G1A, VZ M-2A, M 35-1A and M 31-2A. In general, the soluble protein pattern of the M 35-1A and M 35-1B lines were similar to those of M 31-2A and M 31-2B. The protein pattern of restorer and apomictic lines differed considerably from other sterile lines and those of maintainer lines. The protein patterns of GM1-5 and K.Local showed considerable similarities. A maximum number of bands were found in Nagpur A while a minimum number were found in GM1-5. In general, restorers and apomictic lines had a fewer number of bands than the A and B lines. Nagpur A, G1A and VZM 2A had more bands compared to their maintainers, whereas the maintainers Ck 60B and M 35-1B had more bands when compared to respective male sterile lines. Bands with Rm 0.01, 0.19, 0.41, 0.45 were common to all male steriles and their maintainers. Bands with Rm 0.29 and 0.57 were common to all except that the former band did not appear in G1 B and the latter did not appear in M 31-2B. Bands with Rm 0.71 were common to only *milo* and were absent in other male steriles. Bands with Rm 0.73 were absent in *milo* and present in other male steriles, as well as in their maintainers.

Characteristic differences were evident between lines of different cytoplasmic origin with respect to protein bands with low electrophoretic mobility. Bands with Rm 0.04 and 0.33 were present in the M 35-1B and M 31-2B lines but absent in other A and R lines with *milo*, G1A and VZM 2A. These protein bands appear to be characteristic of this group (M 35-1B and M 31-2B). Bands with Rm 0.41 and 0.46 were not only common to all male sterile A and B lines but also showed greater intensities in all. Intensity of protein bands with low electrophoretic mobility was greater in Ck 60B, G1B, M 35-1B and M 31-2B.

A Versus B Lines

Comparing protein patterns of Ck 60A with Ck 60B, it was found that bands at Rm 0.25, 0.31, 0.61 and 0.83 were present only in Ck 60B, while bands with Rm 0.11 and 0.51 were present in Ck 60A but absent in Ck 60B. The remainder of the bands were common for both lines. Bands with Rm 0.07, 0.11, 0.13, 0.53 and 0.81, present in Nagpur A, were absent in Nagpur B, and the remainder of the bands were common to both. Protein bands with Rm 0.17 and 0.29 were additional bands in G1A compared to G1B. Most bands are common, except for Rm 0.25 and 0.37 present only in VZM 2A, and Rm 0.63, present in VZM 2B. In the cases of M 35-1A and B, bands with Rm 0.11 and 0.25 were present only in M 35-1A and protein bands with Rm 0.13, 0.15 and 0.27 were present in M 35-1B. Protein patterns from M31-2A and B differed from each other with respect to protein bands with Rm 0.01, 0.09, 0.15, 0.53, 0.57 and 0.67, present in M31-2A and absent in M31-2B. Instead new protein bands with Rm 0.17, 0.51, 0.59, 0.63, and 0.65 were present in M31-2B.

Esterase Isoenzyme

Esterase isoenzyme patterns from the seeds of A, B, R and apomictic lines are shown in Fig. 2; Rm values are given in Table 2. Three distinct patterns were evident between A and B lines. The patterns of Ck 60A and B were in general similar to Nagpur A and B. Patterns in G1A and B were similar and resembled closely the isoenzyme patterns found in VZM 2A and B. The patterns of M 35-1A and B showed greater resemblance to isoenzymes in M 31-2A and B.

The comparison of A and B lines indicated some differences in the relative intensity of bands. In the case

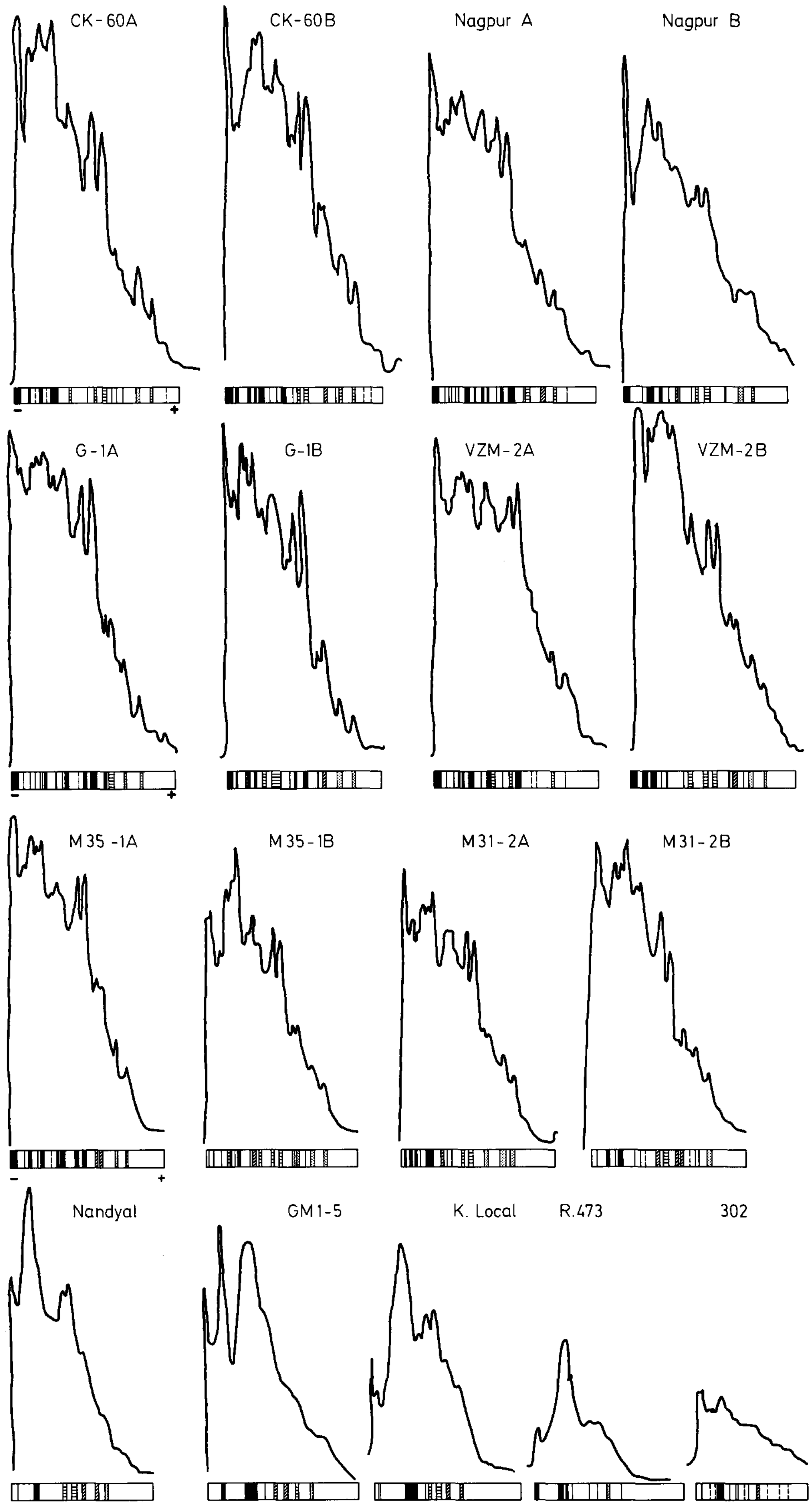

Fig. 1. Densitographs of soluble protein patterns in sorghum seeds

Table 1. Rm values of soluble protein bands found on polyacrylamide gel electrophoresis from seeds of different sorghum strains

Rm	CK 60A	CK 60B	NagA	NagB	GlA	GlB	VZM 2A	VZM 2B	M 35-1A	M 35-1B	M 31-2A	M 31-2B	Nand	GM 1-5	K.l	R · 473	302
0.01	+	+	+	+	+	+	+	+	+	+	+	–	–	–	–	–	–
0.03	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
0.04	–	–	–	–	–	–	–	–	+	+	+	+	–	–	+	–	+
0.07	+	+	+	–	+	+	+	+	–	–	+	+	+	+	+	+	+
0.09	–	–	+	+	–	–	–	–	+	+	+	–	–	+	–	–	F
0.11	F	–	+	–	+	+	+	+	+	–	–	–	–	–	–	–	F
0.13	+	+	+	–	+	+	+	+	–	+	+	+	–	–	–	–	–
0.15	–	–	+	+	+	+	+	+	–	+	+	–	–	–	–	–	+
0.17	F	+	–	–	+	–	–	–	+	+	–	+	+	–	–	–	–
0.19	+	+	+	+	+	+	+	+	+	+	+	+	–	–	–	–	–
0.21	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	+
0.25	–	+	+	+	+	+	+	–	F	–	–	–	–	–	+	+	+
0.27	–	–	–	–	–	–	–	–	–	+	–	–	–	+	–	–	+
0.29	+	+	+	+	+	–	+	+	+	+	+	+	–	–	–	+	–
0.31	–	+	+	+	+	+	+	+	–	–	–	–	–	–	–	–	F
0.33	–	–	–	–	–	–	–	–	+	+	+	+	–	–	+	–	+
0.35	–	–	–	–	–	–	–	–	–	–	+	F	–	–	–	–	–
0.37	+	+	+	+	F	+	+	–	–	–	–	–	+	+	+	–	–
0.39	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	+
0.41	+	+	+	+	+	+	+	+	+	+	+	+	–	–	–	–	–
0.43	–	–	–	–	–	–	–	–	–	–	–	–	+	+	+	–	–
0.46	+	+	+	+	+	+	+	+	+	+	+	+	–	–	–	+	F
0.49	–	–	–	–	–	–	–	–	–	–	–	–	+	+	+	–	–
0.51	+	–	–	–	–	–	–	–	–	–	–	+	–	–	–	+	–
0.53	+	–	+	–	+	+	F	+	+	+	+	–	–	–	–	–	–
0.55	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–
0.57	+	+	+	+	+	+	F	+	+	+	+	–	+	+	–	–	–
0.59	–	–	–	–	–	–	–	–	–	–	–	F	–	–	–	–	F
0.61	–	+	–	–	–	–	–	–	–	+	–	–	–	–	–	+	–
0.63	+	+	–	–	–	–	–	+	–	–	–	+	–	–	–	–	–
0.65	–	–	+	+	+	+	+	+	+	+	–	+	+	–	–	–	–
0.67	–	–	–	–	–	–	–	–	–	–	+	–	+	–	–	–	–
0.71	+	+	+	+	–	–	–	–	–	–	–	–	–	–	+	–	–
0.73	–	–	–	–	+	+	+	+	F	+	+	+	–	–	–	–	–
0.79	F	F	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
0.81	–	–	F	–	–	–	–	–	–	–	–	–	–	–	–	–	–
0.83	–	F	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Total	16	17	18	13	17	15	16	15	15	17	16	16	8	7	8	8	13

+ – band present; – band absent; F – faint band; Nag – Nagpur; Nand – Nandyal; K.l – K.local

of *milo* cytoplasm bands in sterile lines had greater intensities compared to the corresponding bands in their B lines. The patterns in G1A and B were similar but the intensity of bands in G1B was slightly less compared to those of G1A. Three bands at Rm 0.56, 0.59 and 0.61, present in G1A and B, were similar to bands present in VZM 2A and B. M 35-1A, B and M 31-2A, B showed more isoenzymes than the *milo*, VZM 2 and G1 lines.

The esterase patterns of restorer lines were found to be different from those of the A and B lines. The pattern in Nandyal was similar to that of K.Local but differed from that of GM1-5. Apomictic lines also showed characteristic and distinct isoenzyme patterns which were different from the patterns in R, A and B lines.

Esterase isoenzyme with a Rm 0.56 in Ck 60B had a greater intensity than the other lines. Bands with Rm 0.59 and 0.61 were exclusively present in G1A and B, VZM 2A and B lines. Bands with Rm 0.13, 0.28, 0.43 and 0.49 were present in M 35-1A and B and M 31-2A and B. Bands at Rm 0.60 were common to M 35-1A and B, M 31-2A and B, Nandyal, GM1-5, K.Local and R.473. The band at Rm 0.49 in M 35-1A and B and M 31-2A and B had a greater intensity than any other band.

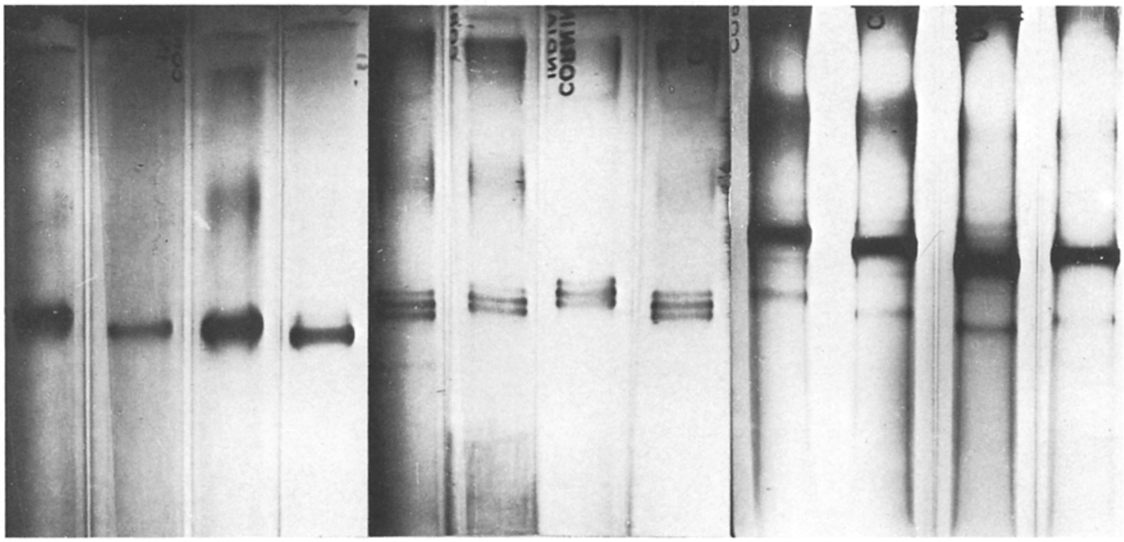

Fig. 2. Esterase isoenzyme from sorghum seeds. *1* Ck 60A; *2* Ck 60B; *3* Nagpur A; *4* Nagpur B; *5* G1A; *6* G1B; *7* VZM 2A; *8* VZM 2B; *9* M 35-1A; *10* M 35-1B; *11* M 31-2A; *12* M 31-2B

GDH Isoenzyme

Two GDH isoenzymes (Rm 0.14 and 0.26) were present in male steriles of Indian origin (M 35-1A & B, M 31-2A and B, VZM 2A and B and G1A and B) whereas one band at Rm 0.16 was detected in Ck 60B and Nagpur A and B. Ck 60A also had major band at Rm 0.16 in addition to a faint band at Rm 0.30.

ADH Isoenzyme

Three ADH isoenzymes were present in all A and B lines. Bands in all A and B lines, except for M 35-1A and B, had similar enzyme patterns with Rm values of 0.27, 0.29, and 0.31. In M 35-1A and B, the Rm of the isoenzymes was 0.25, 0.27 and 0.29. The intensity of ADH isoenzymes was greater in Ck 60A, Nagpur A and M 31-2A in comparison to their maintainer lines. Isoenzymes in remaining strains showed similar intensities. The R lines Nandyal, GM1-5, K.Local and apomictic line R 473 also showed an ADH isoenzyme pattern similar to that of the *milo* lines.

Discussion

Proteins which are the primary product of genes (Yanofsky et al. 1960) are a direct measure of gene homology. Based on this premise, various workers (Alam and Sandal 1969; Schwartz 1966; Siddiq et al. 1972) haved tried to understand genome relationships by using electrophoretic patterns of proteins and isoenzymes. In the present study biochemical differences among sorghum strains with diverse cytoplasmic and nuclear factors have been studied by examining soluble protein and isoenzyme patterns of esterase, ADH and GDH from seeds, employing the gel electrophoresis technique. Soluble protein patterns from diverse cytoplasmic sources differed qualitatively and quantitatively. General comparisons of protein patterns show some basic similarities and differences among male sterile lines. The *milo* cytoplasmic steriles CK 60A and B and Nagpur A and B pattern differed qualitatively from that of G1A, VZM 2A, M 35-1A and M 31-2A. In general, a similarity in soluble protein pattern of M 35-1A and B to that M 31-2A and B indicates some common genomic relationship between these groups. A protein band with Rm 0.71 was present only in *milo* and absent in other male steriles, whereas a protein band with Rm 0.73 was absent in *milo* and present in other male steriles as well as their maintainers. Protein bands with Rm 0.04 and 0.33 were present only in M 35-1B and M 31-2B.

No major differences were observed in the ADH and GDH isoenzyme patterns of seeds from A, B and R lines. The esterase isoenzyme pattern from sorghum seeds with different cytoplasm showed characteristic and distinct differences among *milo* steriles, G1A and B, VZM 2A and B, M 35-1A and B. Nagpur A and B had greater homology with Ck 60A and B while the G1A and B esterase patterns resembled more closely those of VZM 2A and B. M 35-A and B patterns also resembled closely that of M 31-2A and B. Esterase patterns not only showed differences with different cytoplasmic background but also showed minor but con-

Table 2. Rm values and intensity of esterase isoenzyme bands found on polyacrylamide gel electrophoresis from seeds of different sorghum strains

Rm	CK 60A	CK 60A	NagA	NagB	GIA	GIB	VZM2A	VZM2B	M35-1A	M35-1B	M31-2A	M31-2B	Nand	GM1-5	K.l	R · 473	302
0.04	–	–	–	–	–	–	–	–	+	+	+	+	–	+	–	+	+
0.06	–	–	+	–	+	+	+	+	–	–	–	+	+	–	+	–	–
0.08	–	–	–	–	–	–	–	–	+	+	+	–	–	+	–	–	–
0.10	–	–	–	–	–	–	–	–	–	+	+	+	–	–	–	–	–
0.13	–	–	–	–	–	–	–	–	+	+	+	+	–	–	–	–	–
0.17	+	–	–	–	–	–	F	F	–	–	–	–	–	–	–	–	+
0.23	–	–	–	–	–	–	–	–	–	+	–	–	–	F	–	–	–
0.25	–	–	–	–	–	–	–	–	+	+	–	+	–	–	–	–	–
0.28	–	–	–	–	–	–	–	–	+	+	+	F	–	–	–	+	–
0.31	–	–	–	–	–	–	–	–	+	–	+	–	–	–	–	–	–
0.33	+	–	F	–	+	+	–	F	–	+	–	F	–	–	–	–	–
0.43	–	–	–	–	–	–	–	–	F	F	+	+	–	–	–	–	–
0.48	–	–	–	–	–	–	–	–	+	+	–	–	–	–	–	–	–
0.49	–	–	–	–	–	–	–	–	++++	++++	++++	++++	–	–	–	–	–
0.50	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	+	+
0.53	–	–	–	–	–	–	–	–	+	+	+	–	–	–	–	–	–
0.54	–	–	–	+	–	–	–	–	–	–	–	–	+	+	+	–	+
0.55	–	–	–	–	–	–	–	–	+	+	–	–	–	–	–	–	–
0.56	++++	++++	++++	++++	+	+	+	+	–	–	–	–	–	–	+	+	–
0.59	–	–	–	–	++	++	++	++	–	–	–	–	–	–	–	–	–
0.60	–	–	–	–	–	–	–	–	++	++	++	++	+	+	+	+	–
0.61	–	–	–	–	++	++	++	++	–	–	–	–	–	–	–	–	–
0.67	–	–	–	–	–	–	–	–	–	–	–	–	+	+	–	–	–
0.69	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	+
0.71	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–
Total	3	1	3	2	6	5	5	6	12	14	10	10	4	7	4	6	5

+ band present; – band absent; F – Faint band; Nag – Nagpur; Nand – Nandyal; K.l – K.local
NB: Increasing no. of + indicate increasing intensities

sistent differences between A and B lines. In general, intensity of esterase isoenzymes in B lines was less when compared to A lines in *milo* steriles. VZM 2A and B differed from G1A and B with respect to low and medium electrophoretic mobility (Rm 0.17, 0.33) bands. Similarly, M 31-2A and B esterase isoenzymes with low electrophoretic mobility had lesser intensities than corresponding bands in M 35-1A and B. Based on esterase isoenzyme patterns, the different sorghum lines studied could be classified into three major groups: first, represented by Ck 60A and B, Nagpur A and B; second, represented by G1A and B, VZM 2A and B, and third, represented by M 35-1A and B, M 31-2A and B. These individual classes could further be subdivided into two classes, each representing A and B lines, by comparing intensities and minor isoenzyme band patterns. Esterase isoenzyme band patterns from Nandyal and K.Local were similar while that of GM1-5 and two apomictic lines differed. The esterase patterns are clearly distinguishable in different cytoplasms.

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INHERITANCE OF STEM BORER RESISTANCE IN SORGHUM

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ABSTRACT

A 17x17 F_1 diallel was evalutated for stem borer resistance under artificial infested conditions. Number of holes per internode and peduncle showed 36.6 and 44.2% heritability respectively. Tunneling parameters were poorly heritable (6.4—16%). Correlated response of number of holes per peduncle and per stalk were relatively higher. Selection for number of holes can therefore improve other resistance parameters. Derived resistant lines, E 302 and SPV 135 were better general combiners than the basic resistant stocks for % tunneling per stalk. IS 2312 and CSV 8R were good general combiner for resistance parameters of peduncle. Among high yielding derivatives, SPV 104 was best combiner while SPV Nos. 103, 105, 140 and CSV 4 were average combiners.

Temperate and tropical varieties, which represent the diversity of genes for plant type and resistance, form the essential part of breeding programme in India and elsewhere (Rao and Rana, 1982). The tropical varieties particularly from Indian sub-continent furnish the source of stem borer and shoot fly resistance in whole germplasm collection (Rao, Rana and Jotwani, 1978). By utilizing the basic genetic stocks and temperate varieties, a number of high-yielding varieties for *kharif* and *rabi* seasons and improved sources of resistance were developed. Earlier, Rana *et al.* (1975) reported heritability and selection procedure for shoot fly resistance. The inheritance of stem borer resistance is studied in the present investigation.

MATERIALS AND METHODS

Seventeen varieties comprising two basic resistant stocks (IS 2312 and IS 4664), three improved resistant sources (E 302, R 133 and SPV 135), three high-yielding *rabi* varieties (CSV 8R, SPV 140 and SPV 141) and rest of the nine high-yielding *kharif* varieties were selected for a diallel without reciprocal crosses. All the varieties except basic resistant stocks were developed from temperate x tropical crosses. The resulting 136 hybrids along with 17 parents were

Part XXXV of Genetic Analysis of some Exotic x Indian crosses in sorghum.

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planted in 3 metre rows in RCBD with three replications during *kharif* season. The row to row and plant to plant distance were 60cm and 15cm respectively. The recommended dose of fertilizer was given.

The screening for stem borer resistance was done under artificial infestation. The data on number of holes, number of tunnels and % tunneling were recorded separately in stalk, peduncle and whole plant. The larvae and pupae per plant were also counted. The number of holes per internode were computed.

Diallel analysis was done following Griffing (1956) Model I Method 2. The correlated response of a character Y when X is selected was computed as $CR_Y = K.r\sqrt{h_x^2.\sigma^2A_Y}$ where K= selection differential (2.06 at 5% selection intensity), r=correlation between X and Y characters, h_x^2=heritability of character X and σ^2A_Y=Additive genetic variance of character Y.

RESULTS

Nature of gene action : Mean squares of general *(gca)* and specific *(sca)* combining ability effects were significant for all the resistance parameters except number of tunnels and % tunneling per peduncle. The σ^2 *gca*/σ^2 *sca* ratios varied from 0.1 to 1.0 (Table 1). The σ^2 *gca*/σ^2 *sca* ratios of peduncle parameters for number of tunnels and % tunneling were higher than the parameters of stalk or plant. The degree of dominance varied from 1.5 to 2.45 for whole plant parameters, 1.08 to 1.64 for stalk parameters and 0.71 to 1.16 for peduncle parameters indicating that the additive genetic variance was slightly more for the resistance parameters of peduncle and equal or moderately low for stalk and whole plant parameters.

Estimates of heritability (h^2) varied from 11.6 to 44.2% for number of holes, 13 to 16% for number of tunnels and 6.4 to 14.7% for tunneling. Heritability for number of holes was higher than other parameters. Number of tunnels, % tunneling and number of larvae+pupae per plant were low heritable (6.4—16%) characters and mainly governed by non-additive genes.

General combining ability effects : The negative *gca* effects were desirable (Table 2). The pattern of parental *gca* effects for number of holes, number of tunnels and % tunneling per stalk was different from peduncle. However, SPV Nos. 103, 104, 105 and 135 showed negative *gca* effects for number of holes per stalk and peduncle. Both the basic stocks, IS 2312 and IS 4664, were better general combiners for number of holes per peducle than the derived resistant lines, E 302 and R 133. The *rabi* varieties, CSV 8R and SPV 140, were good combiners for holes per peduncle but not for holes per stalk. *gca* effects of SPV 105 and SPV 135 were negative for number of tunnels per peduncle, stalk and plant.

TABLE 1

Estimates of combining ability variances for resistant parameters

Source	No. of holes				No. of tunnels			% tunneling			No. of larvae and pupae
	Plant	Stalk	Peduncle	Inter-node	Plant	Stalk	Peduncle	Plant	Stalk	Peduncle	
σ^2 gca	0.23	0.29	0.51	0.13	0.02	0.03	0.001	1.20	1.34	0.70	0.01
σ^2 sca	1.97	0.50	0.94	0.35	0.09	0.07	0.001	4.43	7.19	1.87	0.02
σ^2 gca/σ^2 sca	0.12	0.58	0.54	0.37	0.22	0.43	1.000	0.27	0.19	0.37	0.50
σ^2 A	0.46	0.58	1.02	0.26	0.04	0.05	0.002	2.40	2.68	3.62	0.02
σ^2 D	1.97	1.00	0.94	0.35	0.09	0.07	0.001	14.43	7.19	3.09	0.02
$\sqrt{\sigma^2 D/\sigma^2 A}$	2.07	1.31	0.96	1.16	1.50	1.18	0.71	2.45	1.64	1.16	1.00
h^2 (%)	11.60	23.50	44.20	36.60	16.00	13.00	15.00	6.40	14.70	10.20	10.00

TABLE 2

General combining ability effect of basic resistant stocks, improved resistant lines and high yielding rabi *and* kharif *varieties for resistance parameters*

Paresents	No. of holes				No. of tunnels			% tunneling			No. of
	Plant	Stalk	Pedun-cle	Inter-node	Plant	Stalk	Pedun-cle	Plant	Stalk	Pedun-cle	larvae & pupae
Basic resistant stocks											
IS 2312	—0.19	0.10	—0.35**	—0.30**	0.09**	0.17**	—0.08*	—0.66	0.62	—4.37**	—0.08
IS 4664	0.38**	0.49**	—0.13**	0.74**	0.15**	0.20**	—0.05	0.34	0.83	0.41	0.02
Improved resistant lines											
E 302	0.46**	—0.31**	0.70**	0.61**	—0.04**	0.09**	0.03*	—1.42	—1.81**	0.37	—0.12**
R 133	0.64**	0.87**	—0.02	—0.22**	0.25**	0.35**	0.01	2.23	2.54**	—0.77	0.20**
SPV 135	—0.30**	—0.25**	—0.09**	0.11**	—0.26**	—0.23**	—0.03*	—2.69*	—1.19*	—1.32*	- 0 08
High-yielding rabi varieties											
CSV 8R	0.72**	0.58**	—0.23**	—0.19**	0.21**	0.24**	—0.02*	—0.46	0.65	—2.21**	0.11
SPV 140	0.91**	0.89**	—0.05*	—0.21**	0.12**	0.14**	0.01	0.32	0.88	—1.07	0.19**
SPV 141	0.46**	0.44**	—0.02	—0.28**	0.16**	0.19**	—0.04*	0.30	0.85	—0.45	0.17**
High-yielding kharif varieties											
CSV 4	—0.55**	—0.70**	0.09**	0.41**	—0.26**	—0.27**	0.01	2.87*	—0.78	0.85	—0.03
SPV 35	0.24*	0.22*	—0.05*	—0.27**	0.09**	0.07**	0.01	2.78*	1.14*	0.50	0.04
SPV 97	—0.03	0.15	0.03	0.54**	0.08**	0.10**	—0.02*	0.20	1.27*	—0.42	0.01
SPV 99	0.15	0.37**	—0.003	—0.25**	0.09**	0.05**	0.04*	—0.16	0.42	0.82**	—0.04
SPV 103	—0.71**	—0.51**	—0.03**	0.20**	—0.13**	—0.15**	0.02*	—2.03	—1.72**	0.68	—0.05
SPV 103 dw	—0.23*	—0 85**	0.57**	—0.31**	—0.26**	—0.32**	0.05*	0.50	—2.02**	3.92**	—0.17**
SPV 104	—1.09**	—0.93**	—0.19**	0.02*	—0.23**	—0.24**	0.01	—2.27	—1.71**	—0.08	—0.12**
SPV 105	—0.68**	—0.57**	0.21**	—0.31**	—0.06**	—0.05**	—0.01	—1.36	—0.57	—0.46	—0.02
SPV 110	—0.17	—0.27**	0.03	—0.30**	0.01	—0.05**	0.07*	1.50	0.61	2.60**	—0.04
SE (g_i)	0.11	0.09	0.02	0.006	0.008	0.006	0.0006	1.28	0.53	0.65	0.04
SE ($g_i—g_j$)	0.18	0.15	0.04	0.01	0.012	0.01	0.001	2.16	0.89	1.11	0.06

* Significant at 5% ** Significant at 1%.

The derived resistant lines, E 302 and SPV 135, were better general combiners for % tunneling per stalk than the basic stocks, IS 2312 and IS 4664. But IS 2312 and CSV 8R were good combiners for peduncle resistance. Among high yielding varieties, SPV 103 and SPV 104 were good general combiners for % tunneling per stalk and number of larvae and pupae per plant. E 302 was also a good combiner for latter character.

Direct and correlated responses : The response due to direct and indirect selections of resistance parameters of peduncle is given in Table 3. Response to direct selection of holes per peduncle was higher than the correlated response through number of tunnels or % tunneling per peduncle. On the other hand, direct response of number of tunnels *per se* or % tunneling *per se* was less than the response due to indirect selection of number of holes per peduncle.

TABLE 3

Direct (diagonal values) and correlated response for resistance parameters of peduncle

Character under Selection (X)	Correlated response of Y: Number of holes	Number of tunnels	% tunneling
No. of holes	**0.920**	0.018	0 834
No. of tunnels	0.234	**0.014**	0.834
% tunneling	0.172	0.016	**0.374**

The direct and indirect responses to the resistance parameters of stalk are given in Table 4. In general, correlated responses were higher than the response due to direct selection. However, correlated responses due to indirect selection of number of holes per stalk were higher than the response due to direct selection of tunnels per stalk, % tunneling per stalk or larvae+pupae per plant. Therefore, selection for least number of holes could be more effective to improve the overall resistance to stem borer.

DISCUSSION

The resistance to stem borer in sorghum involves antixenosis, tolerance and antibiosis mechanisms (Singh and Rana, 1984). While antixenosis is determined by ovipositional non-preference, tolerance and antibiosis depend on the capability of host plant to affect the biology and insect growth. Ovipositional

TABLE 4

Direct (diagonal values) and correlated response for resistance parameters of stalk

Character under selection (X)	Correlated response of Y			
	No. of holes	No. of tunnels	% tunneling	Larvae & pupae
No. of holes	**0.369**	—0.162	1.047	0.079
No. of tunnels	—0.374	**0.065**	0.392	0.033
% tunneling	0.385	0.124	**0.495**	0.057
Larvae & pupae	0.278	0.096	0.543	**0.029**

Correlated responses of peduncle parameters to these characters were negligible and thus not presented

antixenosis does not operate under artificial infestation. The extent of damage estimated in terms of number of tunnels, % tunneling, number of exit holes and larvae+pupae per plant, depends on the interaction between host plant and insect. (Singh *et al.*, 1983). This furnishes a measure of antibiosis and tolerance mechanisms only.

Differences due to *gca* and *sca* effects were significant for all the resistance parameters of stalk and peduncle except specific combining ability effects for number and % tunneling per peduncle indicating that the genetic control of resistance in stalk and peduncle differ for tunneling parameters. While non-additive gene action was more prominent than additive gene action for resistance parameters of stalk, both additive and non-additive gene actions were important for peduncle parameters. The heritability of tunneling parameters of stalk and peduncle were very low (10—15%). The advance from selection for tunneling parameters in particular will therefore be fairly low. The proportion of genetic variances were not reflected by heritability estimates for number of tunnels and % tunneling per peduncle obviously due to higher environmental variability for peduncle components. Heritabilty of number of holes per peduncle (44.2%) was moderately high and greater than holes per stalk (23 5%). These data confirm to earlier observations of Rana and Murty (1971) that both additive and non-additive gene actions are important for secondary damage in sorghum. The genetic basis of resistance to borer in maize is also not simple and both *gca* and *sca* are significant for second brood resistance (Jennings, Russell and Guthrie, 1974) as observed in sorghum, though other reports in maize indicates predominance of additive gene action in conditioning resistance (Scott, Guthrie and Pesho, 1967; Jennings *et al.*, 1974).

The improved high yielding varieties such as SVP Nos. 103, 104, 105, 135 and E 302 provide a better choice of parental material for resistance parameters than the basic genetic stocks. The resistance breeding for shoot fly (Rana *et al.*, 1975; 1981) elucidates the effectiveness of pedigree breeding method under reasonable level of infestation. As an alternate, backcross method was not successful in transferring resistance to susceptible inbred lines in maize (Brindley *et al.*, 1975). These data showed that desired genotypes could not be identified in the segregating generations; when more than two backcrosses were used, the needed level of resistance was lost.

The selection for a large number of parameters at a time is difficult and therefore minimum number of effective characters can be chosen to realize correlated response in related parameters. Indirect selection can be expected superior to direct selection when secondary character has a substantially higher heritability than the desired character and genetic correlation between two is high. Threshold characters are likely to repay a search for a suitable correlated character (Falconer, 1960) as in case of stem borer resistance. Based on the heritability and correlated response, number of holes both in stalk and peducle provide the selection criteria for resistance breeding.

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BREEDING OPTIMUM PLANT TYPES IN SORGHUM*

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ABSTRACT

A set of 107 varieties representing a wide range of variation for plant height and maturity were classified into 16 possible combinations of 4 height and 4 maturity groups. Increased plant height and days to flower contributed positively to the fodder yield. Increased vegetative growth in terms of leafiness and height was desirable only in early genotypes. Days to flower accounted for 72% of the variation in grain yield and 82% of the variation in leaf number. Early flowering and low leaf number was correlated with higher yield. The relationships among plant height, flowering, time and grain yield were non-linear. The optimum plant type is quantified to be combining 68 days to flower and 175 cm plant height assuming fixed number of leaves and panicle branches. The model imposes restriction on the vegetative phase by controlling plant height and time to flower and consequently improves the grain-straw ratio. The model also permits prediction of new character combinations.

Ideotype approach to crop breeding has generated considerable interest in models and model characters (Donald, 1968; Mock and Pearce, 1975; Hodges *et al.*, 1979). Sorghums (*Sorghum bicolor* L.) are ancient to tropics. Following selection of dwarf forms and exploitation of heterosis, their agronomic advancement has been more rapid in the temperate regions, where sorghums were later introduced. The characterization of tropical and temperate sorghums with respect to flowering behaviour, plant height, dry matter distribution, adaptation responses, insect pest and disease reactions *etc.*, has been attempted by Rao and Rana (1978, 1982). The use of diverse tropical×temperate crosses is now more or less universal in all sorghum improvement programmes. The handling of such crosses provides opportunities for considerations of optima with respect to plant type. This paper is an attempt to quantify optimum plant type in sorghum and to provide for predictions with changes in selection criteria.

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Materials and Methods

Temperate sorghums are generally early maturing and short statured while tropical Indian cultivars are late maturing and tall. Advanced generation progenies were developed from crosses involving temperate and tropical parents. The seventy nine most productive advance generation derivatives in different height and maturity combinations together with their twenty eight parents (nine temperate, 11 tropicals, two commercial hybrids and six released varieties furnished material for the present study.

Four height categories (H_1 to H_4) were delimited on the basis of group means. Height group H_1 included dwarf material shorter than 150 cm. The rest of the classes were delineated with a class interval of 53 cm (4σ). Simultaneously for maturity groups (M_1 to M_4) were formed. Maturity group M_1 included the earliest flowering entries (<66 days). The class interval between different maturity groupe,was 10 days (4σ = 9.52 days).

The 107 entries were planted in a randomized complete block design with three replications. The plot size was 9 m^2 consisting of 4 rows, 45 cm apart, 15 distance between plants, resulting in a plant density of 148,000 plants/ha. The experiment was grown during the rainly season (July-Nov.) at high fertility level of 100 kg N, 60 kg P_2O_5 and 40 kg K_2O per hectare. Plant protection and irrigation as and when rcquired were furnished to ensure full phenotypic expression.

Data on days to 50% flowering, plant height, number of leaves, panicle branches, grain yield, 100 seed weight and dry fodder weight were recorded on 25 contiguous plants sampled from the middle two rows to represent entry performance. The number of leaves was recorded at harvest and this must have resulted in neglection of seminal and early formed leaves. Days to 50% flowering were recorded on a plot basis.

The following multiple regression model containing all the interaction terms was adopted.

$$Y_j = \beta_o + \sum_{i=1}^{n} \beta_i X_{ij} + \sum_{i=1}^{n} \beta_{ii} X_{ij}^2 \sum_{i<k} \beta_i^k X_{ij} X_{kj} + e_j$$

Where Y stands for dependent variable (grain yield) and X_i for independent variables (i=1...n). The subscript- j=1......v. v denotes the number of varieties. The term ej is the error associated with th observation. For the final regression all the linear and interaction terms whose t-statistic was greater than 1 were retained. Such a low value of 't' was selected to avoid erroneous deletion of linear or interaction terms. All quadratic terms corresponding to linear terms were also included in the final regression. Numerical methods are used to evaluate optimal plant types. Standard methods were adopted for computing all other statistics.

Results

Comparison of group means : The null hypothesis of equivalence of the 107 varieties had to be rejected for all the characters (Table 1). When these varieties were grouped into height and maturity classes, between group variation was larger than within group variation for all the characters except panicle branches. The effect of days to flower on yield within each height group was notable. As maturity was delayed within each of the height groups, the yield sharply declined. The high yielding groups were H_2M_1 followed by H_3M_1,

TABLE 1

Group means and ANOVA for between and within group variation

Group	Number of entries	50% flowring (days)	Plant height (cm)	Number of leaves	Panicle branches	Yield/plant (g)	Dry fodder weight/ plant (g)	100 seed weight (g)
(a) *Group means* :								
H_1M_1	9	63.6	121.1	14.1	69.5	52.7	124.78	2.76
H_1M_2	7	71.4	135.5	15.5	73.5	62.7	175.50	2.76
H_1M_3	6	81.3	132.7	16.6	70.6	48.3	198.50	2.46
H_1M_4	3	90.2	131.3	17.2	71.4	37.5	195.77	2.28
H_2M_1	10	62.0	179.5	13.5	70.4	69.5	164.25	2.84
H_2M_2	10	72.5	165.7	15.6	75.7	61.7	203.06	2 64
H_2M_3	5	81.9	182.0	18.1	81.0	42.7	275.58	2.37
H_2M_4	4	90.3	169.5	18.3	70.0	36.7	240.17	2.31
H_3M_1	3	63.1	218.9	12.4	65.6	62.6	220.10	2.59
H_3M_2	9	74.1	233.8	16.5	73.9	56.6	306.70	2.70
H_3M_3	20	80.6	231.9	17.4	75.7	50.2	330.17	2.60
H_3M_4	2	88.0	228.8	17.2	83.7	47.3	293.30	2.38
H_4M_1	3	65.0	283.9	14.7	79.9	61.6	392.00	3.14
H_4M_2	5	73.6	277.5	14.4	74.2	44.9	407.32	3.04
H_4M_3	7	79.9	289.2	18.2	73.3	43.0	364.28	2.74
H_4M_4	4	90.8	269.3	19.5	70.0	36.3	437.65	3.01

(b) *ANOVA*

Source	d.f.	Mean squares						
Bet. group	15	1571.1**	61097.9*	63.8*	268.8*	1911.0**	9226**	0.21*
Within group	91	22.7**	1181.9*	4.7**	278.4*	328.9**	36043**	0.59**
Genotypes	106	241.6**	10063.0**	13.1**	271.5**	552.0*	32248**	0.54**

** Significant at 1%; * Sigificant at 5%

Height : H_1 (<150 cm), H_2 (151-203 cm), H_3 (204-256 cm), H_4 (>257 cm)

Days to 50% flowering : M_1 (<66 days), M_2 (67-76 days), M_3 (77-86 days), M_4 (>87 days)

H_4M_1, H_1M_2 and H_2M_2. Very early and dwarf genotypes (H_1M_1) and all the height groups of M_3 and M_4 were low yielding. The highest yielding group possessed 13 leaves, 70 panicle branches and high grain : straw ratio. Group H_4M_4 was lowest yielding but highest in dry fodder yield.

Variation associated with the height and maturity classes was significant for number of leaves, grain yield, fodder weight and 100 seed weight (Table 2). The height × maturity interactions were not significant for any of the characters. Grain yields of H_3, M_1 and M_2 groups were high. Delay in maturity was associated with gradual decrease in grain yield and an increase for number of leaves. The variation in maturity alone accounted for 72% of the variation in grain yield and for 82% of the variation in leaf number. The contribution of increased height towards fodder yield and 100 seed weight was greater than towards grain yield.

Relationship among yield and other characters in different height and maturity groups : Table 3 shows the degree of linear relationships of seven characters to yield within each height and maturity groups. The number of days to 50% flowering was negatively correlated with yield in different height groups. Relatively early genotypes were more productive in all the height groups. Plant height was positively associated with grain yield in the early maturing group (M_1). This relationship was negative in other groups indicating that relatively dwarf genotypes were more productive in the M_2 and the M_3 groups. The correlation between leaf number and grain yield was negative except in dwarf genotypes (<150 cm).

The genotypic correlations between panicle length and grain yield were positive in different maturity groups but the magnitude decreased with delay in the maturity. Grain and fodder yields were generally negatively correlated except in dwarf and early groups as well as for M_4. These negative correlations were more pronounced in height groups compared to maturity groups.

Figure 1 and Table 4 show the relationships of individual characters with yield. They are significant and curvilinear for days to 50% flowering, plant height and number of leaves and fodder weight. Variation in flowering date and leaf number contributed most to variation in grain yield, as indicated by the high values of R, the multiple correlation coefficient.

The multiple regression : The multiple regression analysis showed that among all the characters initially regressed against grain yield, days to flowering (X_1), plant height (X_2), number of leaves (X_3) and panicle branches (X_4) had t-value greater than 1.0 (Table 5). The linear coefficients of days to 50% flowering and plant height were significant but not those of X_3 and X_4. The quadratic term of days to flower (X^2_1) and the interaction terms $X_1.X_2$, $X_1.X_3$ and $X_2.X_3$

TABLE 2

ANOVA and means for different height and maturity groups

Source	d.f.	Mean squares: 50% flowering (days)	Plant height (cm)	Number of leaves	Panicle branches	Yield/ plant (g)	Dry fodder wt/plant (g)	100 Seed wt (g)
Height vs maturity groups	3							
Height (H)	3	1.51	6037.21**	2·25*	10.39	611.49*	35180**	0.30**
Maturity (M)	3	485.47**	52.57	16 13**	10.68	2151.65**	8527**	0.32**
H×M	9	2.77	42.11	0.45	30.37	140.75	807	0.04
Error	212	5.99	221.83	1.43	71.58	123.87	3383	0.07
Percent contribution (SS/TSS×100)								
Height		0.30	99.02	11.41	9.30	8.31	76.26	57.20
Maturity		90.02	0.29	81.80	9.50	71.92	18.49	29.55
H×M		1.68	0.69	6.79	81.20	19.77	5 25	13.25
Height groups								
H_1		76.6	130.2	15.85	71.25	50.3	173.63	2.52
H_2		76.7	167.4	16.27	74.27	52.6	220.76	2.54
H_3		75.8	227.6	15.87	74.73	54.2	312.24	2.57
H_4		77.3	285.5	17.45	74.35	46.5	383.65	2.98
S.E.		0.81	4.96	0.39	2.82	3.71	19.39	0.09
Maturity groups								
M_1		63.4	200.9	13.57	71.36	61.6	208.60	2.83
M_2		72.9	202.4	16.25	74.32	56.5	273.17	2.74
M_3		80.9	209.1	17.57	75.10	46.9	292.13	2.54
M_4		89.2	285.5	18.05	73.77	39.4	316.39	2.49
S.E.		0.81	4.96	0.39	2.82	3.71	19.39	0.09

** Significant at 1%, * Significant at 5%

TABLE 3

Relationship between yield and other charaters in different height (H) and maturity (M) groups

Character	Correlation coefficients								
	All genotypes	H_1	H_2	H_3	H_4	M_1	M_2	M_3	M_4
(a) *Penotypic*									
50% flowering	—.467**	—.361**	—.637**	—.250*	—.480**	—.082	—.167	—.245	—.120
Plant height	—.202*	.109	.107	—.244*	—.174	.223*	—.368**	—.146	—.043
Number of leaves	—.321**	.088	—.582**	—.300**	—.735**	—.293*	—.081	—.246*	—.001
Panicle length	.176	—.364**	.331**	.152	.164	.401**	.141	.241*	.160
Panicle branches	.044	.123	—.035	.020	.104	—.004	.011	.158	.377*
Dry fodder weight	—.280**	.076	—.313**	—.184	—.393**	.003	—.267**	—.159	.074*
100 seed weight	.098	.167	.324**	.124	.001	.053	.002	—.053	.021
(b) *Genotypic*									
50% flowering	—.664	—.623	—.883	—.393	—.624	—.021	—.498	—.393	—.164
Plant height	—.266	.162	—.033	—.599	—.149	.331	—.733	—.216	—.003
Number of leaves	—.664	.233	—.811	—.537	—.907	—.422	—.699	—.548	—.022
Panicle length	.253	—.577	.605	.190	.131	.531	.407	.386	.164
Panicle branches	—.012	.112	—.226	.002	.305	—.016	—.185	.208	.866
Dry fodder weight	—.474	—.022	—.464	—.546	—.643	—.017	—.819	—.262	.074
100 seed weight	.218	.537	.513	.316	—.106	.173	.116	—.098	.132
Number of varieties	107	25	29	34	19	25	31	38	13

**Significant at 1%, *Significant at 5%

TABLE 4

Quadratic regression of grain yield on other characters

Character	Equation	Mean squares		R
		Regression	Deviation	
50% flowering	$Y = 7.2676 + 2.1686\ X - 0.01993\ X_2$ (1.81) (2.51)	9979.4**	207.7	.48
Plant height	$Y = 40.109 + 0.1889\ X - .000578\ X_2$ (2.06) (2.72)	2690.1**	253.6	.25
Number of leaves	$Y = 82.098 + 0.1514\ X - .0991\ X_2$ (0.038) (.803)	9668·1**	209.7	.47
Panicle branches	$Y = 10.979 - 1.3786\ X - .00957\ X_2$ (1.92) (2.01)	603.7	266.7	.12
Fodder weight	$Y = 62.9144 - 0.03738\ X - .0000057\ X_2$ (1.22) (.115)	3517.6**	248.4	.29
Seed weight	$Y = 14.0182 - 25.4199\ X - 3.98838\ X_2$ (1.53) (1.33)	688.1	266.2	.01

**Significant at 1%; S.E. in parentheses; d.f. for deviations=318

TABLE 5

Multiple regression analysis for grain yield

Variable	Regression coefficient (Yield)	t-value
50% flowering (X_1)	4.1713*	2.90
Plant height (X_2)	0.2525*	2.07
Number of leaves (X_3)	-5.5699	1.11
Panicle branches (X_4)	-0.6074	1.00
X_1^2	-0.0543**	4.10
X_2^2	-0.0002	1.13
X_3^2	-0.0564	0.27
X_4^2	0.00437	1.09
$X_1.X_2$	0.00468*	2.18
$X_1.X_3$	0.1625*	3.74
$X_2.X_3$	-0.0323*	2.01
Intercept	-29.3683	
S.E. (Y)	13.43	
Regression M.S.	2751.6** (11 d.f.)	
Residual M.S.	180.4 (309 d.f.)	
R_2	0.5931	

*Significant at 5%; **Significant at 1%

were also significant. While the linear terms of days to 50% flowering and of plant height were positive, their quadratic terms were negative. Hence the positive liner contributions of later flowering and greater plant height to grain yield were progressively neutralized by their negative quadratic terms. The magnitudes of the linear and quadratic terms of height imply that height contributes moderately to yield through out the sampled range. However, both linear and quadratic terms of number of leaves were negative indicating that reduction of leaf number enhances grain yield within the entire range of sample values. The negative coefficient of the $X_2.X_3$ interaction term revealed that simultaneous increase in plant height and leaf number reduces grain yield.

As shown in Fig. 1, height and days to 50% flowering are strongly related. It will be difficult to vary them independently. Fig. 2 therefore, shows predictions for joint variation of height and days to 50% flowering. It also shows the interval of two standard deviations around the prediction. At a leaf number of 15 and panicle branches of 105, the optimum lies at 68 days of flowering and 175 cm plant height, when linear, quadratic and interaction terms were considered together. Recently developed hybrid, CSH 5, may possess 105 panicle branches and thus such high value used in the equation.

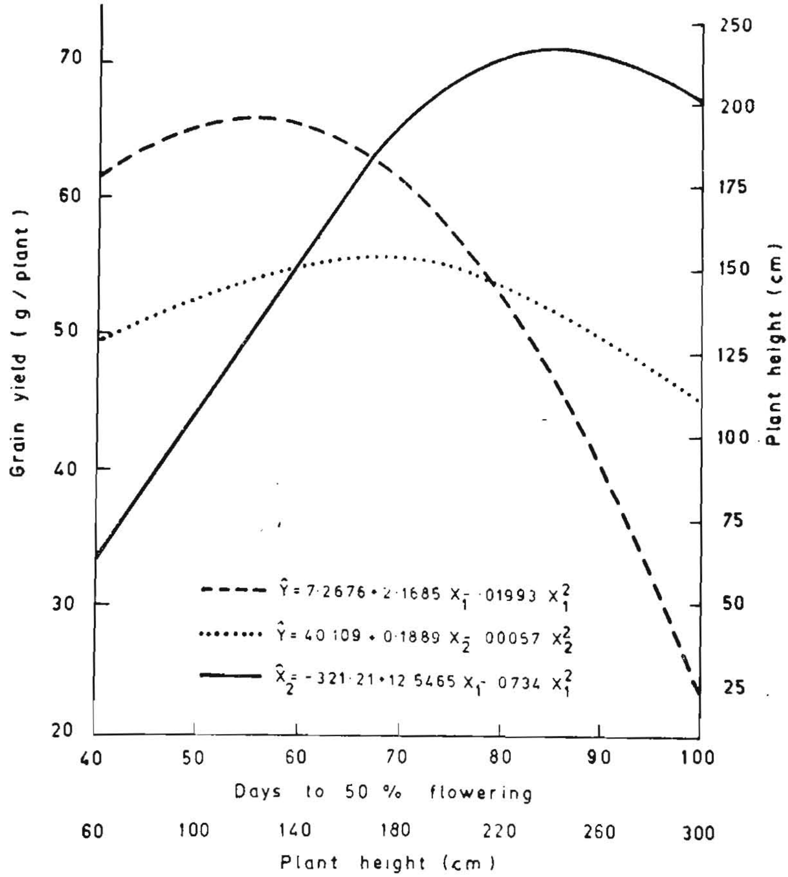

Fig. 1. Relationships among grain yield (Y), flowering (X_1) and plant height (X_2) in sorghum.

Expected yields : Table 6 shows expected yields for various combinations of height, maturity and leaf numbers assuming 90 panicle branches. Because a higher number of panicle branches always leads to higher yield we hold panicle branches at the value of 105 of the highest yielding genotype, CSH 5 and present predicted yields in Fig. 3.

Table 6 shows various interesting breeding options. It shows that regardless of height and leaf number the highest yields are expected in the 60 to 70 days range. Beyond the optimum number of days to flowering, yield declines sharply. Fig. 3 and Table 6 show that at the lowest plant height of 75 cm, yield decline with number of days to flowering is the sharpest. This means that late dwarfs are lowest yielding and therefore offer an unattractive breeding option. In

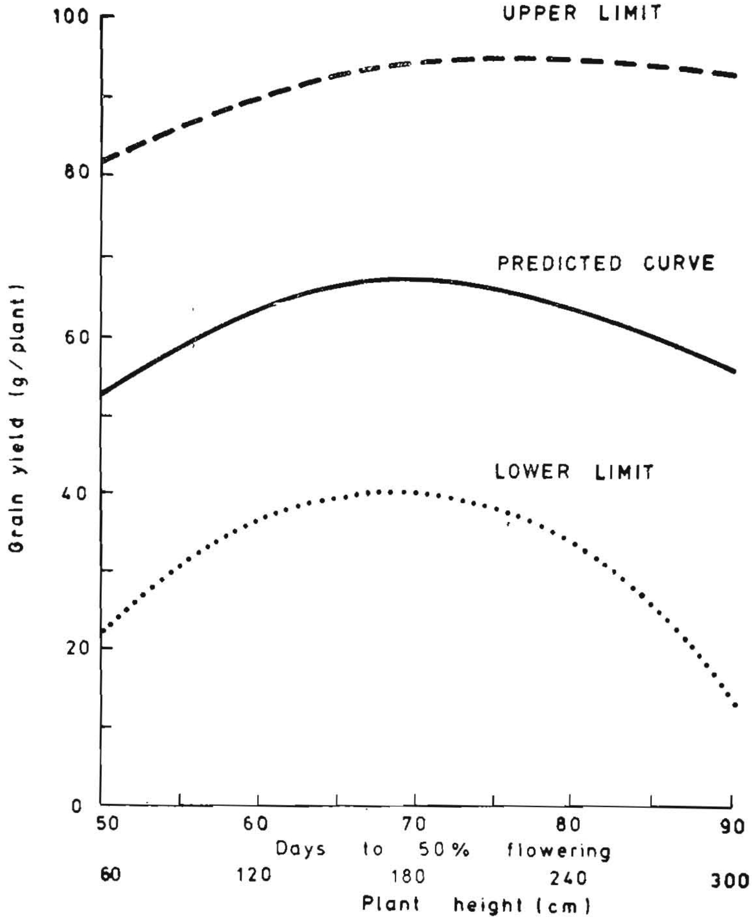

Fig. 2. Optimum phenotype as related to plant height and days to flowering.

early genotypes a smaller leaf number contributes higher grain yield. But the opposite is the case for the late genotypes. Therefore, a high leaf number is a disadvantage in early tall varieties.

Fig. 3 shows that the development of high yielding genotypes with 75 cm height and 54-64 days to flowering; 125 cm height and 56-66 days to flowering; mid-tall 225 cm height and 60-71 days to flowering and 275 cm height and 62-73 days flowering is feasible by manipulating the character leaf number in different height groups.

TABLE 6

Expected grain yield (g) for different combinations of height, leaf number and maturity (panicle branches number 90)

Plant height (cm)	Number of leaves)	Days to 50% flowering				
		50	60	70	80	90
75	8	57.0*	55.5	43.1	19.9	—14.2
75	10	55.2	57.0*	47.9	27.7	— 3.0
75	12	53.0	58.0*	52.1	35.4	7.8
75	15	48.8	58.7*	57.7	45.9	23.2
125	8	66 4	67.2*	57.2	36.3	4.6
125	10	61.4	65.5*	58.7	41.1	12.6
125	12	56.0	63.3*	59.8	45.4	20.1
125	15	46.9	59.1	60.5*	51.0	30.6
175	8	74.8	78.0*	70.3	51.7	22.3
175	10	66.6	73.0*	68.9	53.3	27.1
175	12	57.9	67.6*	66.4	54.3	31.4
175	15	44.0	58.6	62.3*	55.1	37.1
225	8	82.2	87.7*	82.4	66.2	39.1
225	10	70.8	79.5*	77.4	64.5	40.6
225	12	58.8	70.9	72.0*	62.3	41.7
225	15	40.1	57.0	63.1*	58.2	42.5
275	8	88.6	96.5*	93.5	79.6	54.9
275	10	73.9	85.0	85.3*	74.7	53.2
275	12	58.8	73.1	76.6*	69.3	51.0
275	15	35.2	54.5	62.8*	60.3	47.0
325	8	94.0	104.2*	103.5	92.0	69.6
325	10	76.1	89.5	92.1	83.9	64.7
325	12	57.7	74.4	80.3*	75.2	59.3
325	15	29.3	50.9	61.6*	61.5	50.5
375	8	98.4	111.0	112.6*	103.4	83.4
375	10	77.3	93.1	98.0*	92.0	75.2
375	12	55.7	74.7	82.9*	80.2	66.7
375	15	22.4	46.3	59.4	61.6*	52.9
425	8	101.8	116.7	120.7*	113.9	96.2
425	10	77.5	95.6	102.8*	99.2	84.8
425	12	52.6	74.0	84.5*	84.2	73.0
425	15	14.5	40.8	56.2	60.7*	54.4

*Highest yield in a row

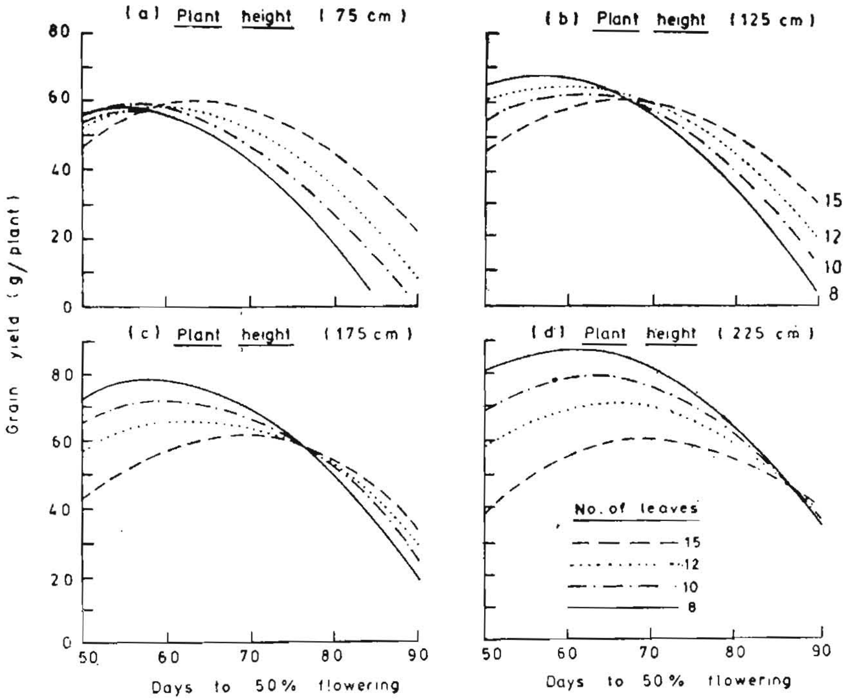

Fig. 3. Expected grain yield in relation to leaf number in different height groups.

Discussion

Examination of the degree of linear relationships in different height and maturity groups show that increase in height was advantageous only in the M_1 maturity group but not in the other maturity groups. Excessive vegetative growth in terms of leafiness and fodder weight was in general disadvantageous for grain yield. It is however the flowering period which accounted most for the variation in grain yield (72%) and in the number of leaves (82%). Earliness and low leaf number were related to higher grain yield. The contribution of plant height was more towards fodder and 100 grain weight. The highest yielding group possessed 13 leaves, 70 panicle branches and a high grain straw ratio.

The relationships among height, maturity and grain yield are actually nonlinear. Thus some of the specific combinations such as H_1M_2, H_2M_1, H_2M_2, H_3M_1, and H_4M_1 are more productive than others. These combinations do not represent either temperate (H_1M_1) or tropical (H_4M_4) parental groups but represent the recombination between the two extremes. Since increase in height and maturity contribute mainly to the fodder yield, the first genotypic correction to be made in tropical sorghums is to rectify their excessive height and maturity to find an optimum.

Donald (1968) used the term ideotype to describe an optimum plant type and defined ideotype as a plant with model characteristics known to influence photosynthesis, growth and grain yield in cereals. To obtain an ideal combination in sorghum Rao *et al.* (1973) postulated that one should preferably deal with dwarf derivatives in which a certain degree of lateness and of tallness are incorporated, with tall derivatives in which a certain degree of earliness and of dwarfness are introduced. They further observed that such intermediate selections represent "intermediate productive peaks" and possess yield potential much above that of the checks. The present study specifies the combination of desirable attributes and quantifies the optimum. The optimum plant type is characterized by 68 days to flowering and 175 cm plant height (Fig.2). Such a plant type is expected to be of high efficiency relative to its environmental resources (Rao *et al.* 1982).

The model imposes restriction on the vegetative phase by controlling height and flowering date and consequently enhancing the grain-straw ratio. Control of plant size and leaf number by maturity genes was also reported by Quinby (1972). Harvest indices of height groups (0.23, 0.19, 0.16, 0.13, for H_1 to H_4 respectively) systematically get reduced as height and fodder weight increased. This shows negative relationship of the harvest index with plant height and fodder weight.

The present model can be utilized for calculating the expected yield of new combinations of flowering time, plant height, number of leaves and panicle branches. Calculations based on leaf number show that reduction to 8-10 leaves contributes to higher grain yield in early genotypes. Of the sorghum grain yield, 93% is due to assimilation by the panicle and upper four leaves, the flag leaf being the most efficient contributor per unit area (Fischer and Wilson, 1971). The leaf number of tropical varieties can therefore be substantially reduced without sacrificing grain yield.

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GENETIC ANALYSIS OF CYTOPLASMIC SYSTEMS IN SORGHUM

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ABSTRACT

F_1 studies on pollen sterility, pollen shedding and seed set enabled the classification of the cytoplasmic sources into three groups : (1) CK60A and Nagpur-A based on milo-A_1 ; (2)M 35-1A and M31-2A-A_2 (Tentative) ; (3) VZM2A and G1A - A_3 (Tentative). The correspondence of the A_2 with A_2 steriles reported from USA is yet to be established. These studies provided evidence for the seasonal (temperature) interaction for pollen fertility and seed set, the M35-1A and M31-2A steriles, exhibiting greater levels of fertility during summer season. In some crosses, evidence for the operation of self-incompatibility was available.

A diallel set of crosses including reciprocals with nine parents (six B lines and three R lines) enabled cytoplasmic characterisation of the B and R lines. Reciprocal differences for pollen sterility and seed set were significant. The cytoplasms of G1B and Nandyal tended to exhibit greater levels of pollen sterility while those of CK60 B and Karad local tended to promote greater levels of male fertility. Based on these studies, three cytoplasmic groups have been characterized : (1) CK 60 B and Karad local-B_1 ; (2) M35-1 and VZM2B-B_1 ; (3) G1B and Nandyal-B_3. 'B_1' is the most fertility inducing, whereas 'B_3' induces greater levels of sterility. The cytoplasmic and nuclear effects in A and B lines are in opposite directions.

The present status of diverse cytoplasmic-genetic male sterility systems in sorghum has been reviewed by Schertz and Pring (1982). Quinby (1982) analysed the role of gene-cytoplasm interactions in sex-expression. The sterility inducing cytoplasms (A) have generally received greater attention compared to the fertility inducing (B) systems. In the present study, we attempt a genetic analysis and characterization of diverse cytoplasmic systems in sorghum.

MATERIALS AND METHODS

Six male steriles, their maintainers (B-lines) and three fertility restorer lines were chosen for characterization of the cytoplasm, to study the genetics of fertility restoration and combining ability of diverse cytoplasmic male steriles. The description of the parents is given below :

Description of male steriles and restorers used in the study

S. No.	Parent	Origin	Distinguishing characters
*Male steriles**			
1.	CK60A	Texas (USA)	Dwarf and early, chalky grain, purple glumes, semicompact elongated head
2.	Nagpur-A	Maharashtra (India)	Semi-dwarf, midlate, creamy-white, bold seed compact head, derived from Kafir × Indian variety cross.
3.	G1A	Andhra Pradesh (India)	Tall midlate, thin stem, narrow leaves, small seed with yellow pericarp, glumes yellow, semi-lax round panicle.
4.	VZM2A	Andhra Pradesh (India)	Tall, late, big panicle, pearly white and bold grain, straw colour glumes.
5.	M35-1A	Maharashtra (India)	Tall, late, pearly white, bold grain, straw glume with tip, *rabi* variety.
6.	M31-2A	Raichur (India)	Tall, very late, *rabi* variety, pearly white, bold seed, straw colour.
*The counterparts of male steriles (B-lines) were used for crosses where needed.			
Fertility restorers			
7.	Nandyal	Karnataka (India)	Tall *Kharif* variety with pearly white small but hard seed.
8.	GM1-5	Karnataka (India)	Comparatively shorter variety among Indian types. Cultivated in parts of Karnataka.
9.	Karad loeal	Maharashtra (India)	Tall, late *kharif* variety, long panicle, pearly white small seed. Cultivated in Southern parts of Maharashtra.

The three restorers restore fertility not only on *milo* based steriles but also on some of the other cytoplasmic sources of sterility where fertility restoration is relatively difficult.

All the six male sterile lines were crossed with all 'B' and restorer lines resulting in 54 crosses. A set of all possible crosses among the six B lines and the three restorer parents resulting in 72 crosses were also made.

The experiments were laid out in randomized complete block design at IARI Regional Station, Hyderabad, during *rabi* with four replications. The line × tester experiment was replicated four times and the diallel three times. Three rows in line × tester, one row in F_1 diallel per replication were planted. Five metre row length was uniformly maintained at 60 cm distance. Plant to plant distance was 15 cm. A fertilizer dose of 100 kg N, 60 kg P_2O_5 and 60 kg

K_2O per hectare was given. Nitrogen was applied in two split doses, half as basal and another half at knee-high stage. Recommended plant protection measures were adopted for the control of shootfly and stem borer. Irrigation and other cultural operations were done as and when required.

All plants were carefully selfed with paper bags. Following characters pertaining to male sterility were studied :

Pollen shedding : Presence or absence of pollen shedding was examined in the field by tapping the earhead. Plants were classified into shedders or non-shedders accordingly.

Pollen sterility (%) : Mature pollen grains were collected and stained with 2% iodine solution to distinguish sterile and fertile pollen grains unaer microscope. Completely stained pollen grains were classified as fertiles and the pollen grains stained brownish, half-stained or with stained outer wall only were classified as sterile. Number of sterile and fertile pollen grains out of a sample of two hundred pollen grains were counted and sterility per cent was calculated. Pollen steritity counts were taken on individual plants of F_1's and parents. Three to four branches from different parts of each panicle were sampled and dusted on a single slide. Counts were taken after mounting the slide with coverslip.

Selfed earheads were observed for seed set at the time of maturity. Clear-cut cases of fertile (full seed set) and sterile (no seed set) heads were counted. Partially fertile earheads towards fertility and towards sterility were separately counted.

RESULTS

CYTOPLASMIC-GENIC INTERACTIONS IN A×B AND A×R CROSSES :

(a) *Pollen fertility* : B and R lines were fertile, with the percentage of fertility ranging from 76-94%. Pollen development in females was variable. Anthers of CK60A and Nagpur-A were abortive and few sterile pollen grains were produced. Pollen production in other *ms* lines was normal but pollen grains were completely sterile. Pollen grains of crosses among A-B lines of each cytoplasmic group were sterile (Table 1).

All other B lines and R lines restored pollen fertility on CK60A and Nagpur-A. Percentage of fertile pollen grains in crosses of Nagpur-A with VZM2B1, G1B and restorer lines was lower compared to CK60A.

M35-1B, M31-2B and VZM2B did not restore pollen fertility on M35-1A and M31-2A. CK60B and Nagpur-B restored slight (6-12%) fertility on M35-1A and 42-79% fertility on M31-2A. But inspite of the fact there was 42-79% pollen fertility with CK60B, there was no seed set on M31-2A. Thus, per cent fertile pollen grains on crosses with restorers was lower on M35-1A compared to M31-2A.

TABLE 1

Cytoplasmic-genic interaction for pollen fertility (%) in A×B and A×R crosses (F_1)

Female parents (ms)	Male parents: Maintainer lines (B)						Restorer lines (R)		
	CK60B	Nagpur B	M35-1B	M31-2B	VZM2B	G1B	Nandyal	GM2-5	K. local
CK60A	NP	a	98	99	86	74	91	86	76
Nagpur-A	a	NP	62	100	49	60	52	54	64
M35-1A	6	12	0	0	0	‡	55	47	64
M31-2A	79*	42*	0	0	0	67	68	72	73
VZM2A	3	1	1	6	0	0	21*	21*	53*
G1A	0	3	0	0	0	0	6	0	1
Parents	94	90	91	—	92	87	76	80	94

NP=No pollen formation-empty anther sacs; ‡=Fertile in summer; *=No seed set inspite of pollen fertility; a=Abortive anthers

TABLE 2

Cytoplasmic-genic interactions for pollen shedding in A×B and A×R crosses (F_1)

Female parents (ms)	Male parents: Maintainer lines (B)						Restorer lines (R)		
	CK60B	Nagpur B	M35-1B	M31-2B	VZM2B	G1B	Nandyal	GM1-5	K. local
CK60A	—	—	+	+	+	+	+	+	+
Nagpur-A	—	—	+	+	+	+	+	+	+
M35-1A	—	—	—	—	—	+*	+	+	+
M31-2A	F	F	—	—	—	+	+	+	+
VZM2A	—	—	—	—	—	‡	+	+	+
G1A	—	—	—	—	—	—	—	—	—
Parents B/R	+	+	+	+	+	+	+	+	+

—=Nonshedding; +=Shedding of fertile pollen; ‡=Sterile pollen dust; *=Pollen shedding in summer season only; F=Pollen fertile but no shedding

Pollen fertility restoration on VZM2A and G1A by any of lines was negligible (1-6%) or absent. Interactions of VZM2A and G1A cytoplasms were, therefore, alike with respect to B-lines reaction. Crosses of VZM2A with restores exhibited some pollen fertility (21-53%) but without seed set whereas crosses with G1A were nearly sterile.

Differential fertility restoration on M35-1A and M31-2A lines by CK60B and Nagpur-B and differential reaction of VZM2A and G1A with R lines indicated that there were some genetic differences for restoration between M35-1A and M31-2A as well as between VZM2A and G1A. The sterility system of M35-1A as compared to M31-2A and G1A as compared to VZM2A were relatively stronger.

It was interesting that inspite of 79% pollen fertility in M31-2A × CK60B and 42% pollen fertility in M31-2A × Nagpur-B and 21-53% fertility in VZM2A × R line crosses, seed set was completely absent. Failure of seed set inspite of pollen fertility in M31-2A ×CK60B and M31-2A × Nagpur-B was due to non-dehiscençe of fertile pollen while failure of seed set inspite of some pollen fertility in VZM2A crosses with R lines may be attributed to incompatibility.

(b) *Pollen shedding* : In B and R lines, pollen shedding was normal (Table-2). Pollen shedding in *ms* lines was completely absent in winter season inspite of the fact that M35-1A, M31-2A, VZM2A and G1A produced sterile pollen grains. Seasonal interaction was observed in case of VZM2A and G1A which shed sterile pollen dust during summer season.

Pollen shedding was absent in all the crosses of G1A whileVZM2A crosses with G1B and R-lines shed pollen. However, pollen shedding behaviour of VZM2A in crosses appeared to be similar to the *maldandi* group. Pollen of VZM2A × G1B was sterile while G1B produced fertile pollen in M35-1A and M31-2A crosses. VZM2A reaction with G1B was, therefore, different from M35-1A and M31-2A lines.

(c) *Seed set* : The data on seed set are presented in Table 3. B and R parents were completely fertile. All the four crosses of CK60A and Nagpur-A with their 'B' lines were sterile. CK60B and Nagpur-B, therefore, maintained sterility on each other and the rest of the male steriles. Other B lines and all the restorer lines produced fertile or partial fertile F_1s on CK60A and Nagpur-A. Thus, while the sterility system of CK60A and Nagpur-A is the same, their cytoplasm differs from the rest of the male steriles.

M35-1A and M31-2A formed another distinct group since all the B-lines except G1B maintained sterility. Fertility restoration of M35-1A with G1B is influenced by the environment as revealed from seed set during summer and lack of it during winter. All the R-lines restored fertility.

None of the B-lines or R-lines restored fertility on VZM2A and G1A steriles inspite of the fact that G1B and R-lines restored fertility on other cytoplasms. Non-restoration by any of the B or R-lines basically differentiated the G1A and VZM2A cytoplasms from other cytoplasmic sources.

The range of pollen fertility and seed set of hybrids 'segregating' in F_1 is given in Table 4. The seed set was not proportionate to pollen fertility. It is

TABLE 3

Cytoplasmic-genic interactions for seed set in A×B and A×R crosses (F_1)

Female parents (ms)	Male parents								
	Maintainer lines B						Restorer lines (R)		
	CK60B	Nagpur-B	M35-1B	M31-2B	VZM-2B	G1B	Nandyal	GM1-5	K. local
CK60A	S	S	F	F	F	F/PF	F	F/PF	F/PF/S
Nagpur-A	S	S	F	F	F/PF/S	PF/S	F	F	PF/S
M35-1A	S	S	S	S	S	S*	F	F	F
M31-2A	S	S	S	S	S	F	F	F	F
VZM-2A	S	S	S	S	S	S	S	S	S
G1A	S	S	S	S	S	S	S	S	S
Parents B/R	F	F	F	F	F	F	F	F	F

S=Sterile (no seed set); F=Fertile (full seed set); PF=Partial fertile
*=Fertile in summer

TABLE 4

Range and mean for pollen sterility and seed set in F_1s

Crosses (F^1)	Pollen sterility (%) Range	Pollen sterility (%) Mean	Pollen fertility (%) Range	Pollen fertility (%) Mean	Seed set (%) Range	Seed set (%) Mean
CK60A×G1B	11-59	30.00	41-89	70.00	5-100	78.10
CK60 A×GM1-5	5-30	18.20	70-95	81.80	25-100	75.50
CK60 A×K. local	7-32	20.50	68-43	79.50	0-100	26.70
Nagpur-A×G1B	36-95	63.60	5-64	36 40	0-50	23.00
Nagpur-A×VZM2B	32-75	53.20	25-68	46.80	5-100	49.20
Nagpur-A×K. local	22-64	41.70	36-78	58.30	0-100	19.50
M35-1A×GM1-5	17-61	42.25	39-83	57.75	60-100	91.00
M35-1A×K. local	8-52	37.70	48-92	62.30	100	100.00
M35-1A×Nandyal	10-87	39.90	13-90	60.10	10-100	95.50

clear that inspite of minimum 36% pollen fertility, seed set in CK60A × G1B, CK60A × K. local and Nagpur-A × K. local was quite low. Such interactions in K. local crosses were higher than other parents.

Based on the three characteristic cytoplasmic-genetic interactions for seed set, pollen fertility and pollen shedding behaviour, it is concluded that these six male steriles represent three distinct cytoplasmic groups. Cytoplasmic source-1 (*milo*) included CK60A and Nagpur-A; cytoplasmic source-2 included M35-1A and M31-2A and cytoplasmic source-3 included VZM2A and G1A.

Restorer lines interacted differently with different sources of cytoplasm and hence may differ from the sterile cytoplasmic sources. This will be examined later.

CYTOPLASMIC-GENIC INTERACTIONS IN B×B, B×R AND R×R CROSSES :

(a) *Pollen shedding and seed set* : Pollen shedding and seed set was normal in all the B and restoreri lnes., Normal pollen shedding and full seed set were also observed in all possible B×B, B×R and R×R crosses.

(b) *Pollen sterility* : Parents exhibited 12.6-29.8% pollen sterility. VZM2B, M35-1B and Karad local showed minimum sterility (12.6-15.66%) while the highest sterility was observed in case of Nandyal. In general, several hybrids showed higher sterility as compared to parents. It was quite high (47.4%) in G1B crosses when G1B was used as female, Similarly, mean sterility (41%) for the crosses involving Nagpur-B as male parent was the highest.

Among B×B crosses, G1B × Nagpur-B showed highest sterility (66%) followed by G1B × M35-1B (52%). Sterility in CK60B × Nagpur-B and

TABLE 5

Mean pollen sterility % (transformed values) of parents and reciprocal crosses (F_1)

Female parents	Male parents								
	Maintainers (B)					Restorers (R)			
	CK60B	Nagpur	M 35-B	VZM2B 1B	GIB	Nandyal	GM1-5	K. local	Mean
CK60B	20.5	38.2	14.5	13.2	32.3	15.1	19.2	15.5	21.1
Nagpur-B	37.9	21.3	37.6	42.3	46.2	35.2	39.0	33.0	36.5
M35-1B	24.6	39.6	13.3	13.9	34.6	12.7	10.8	12.7	20.3
VZM2B	14.6	38.8	16.4	12.7	37.5	11.9	13.9	14.7	20.1
G1B	40.4	66.4	52.4	46.7	22.0	44.0	55.7	51.4	47.4
Nandyal	28.5	43.9	14.2	14.2	39.4	29.8	33.1	10.5	26.7
GM1-5	15.6	39.2	11.5	14.9	43.9	10.8	23.0	46.3	25.7
K. local	12.8	40.7	14·4	11.0	41.1	13.3	15.5	15.7	20.6
Mean	24.3	41.0	21.8	21.1	37.1	21.6	26.3	25.0	27.3

SE±2.30 CD (5%)=6.38 CD (1%)=8.38

Parental values underlined.

G1B × VZM2B was significantly higher than their respective parents. Sterility in CK60B, VZM2B and M35-1B crosses with all the B-lines except Nagpur-B and G1B was reasonably low (10.7-19.2%).

Among R×R crosses, pollen sterility was quite high in Nandyal × GM1-5 (33.0%) and GM1-5×K. local (46.3%) crosses. In other crosses, sterility was lower than parental sterility.

(c) *Grain yield*: Parental yield varied from 23 g/plant to 56.6 g (Table 6). Yields of VZM2B, Nandyal and GM1-5 were highest among parents. Some of B-lines crosses (CK60B × VZM2B, CK60B × M31-2B, VZM2B × M35-1B) and M35-1B × M31-2B crosses were higher yielding than their respective parents. In general, M31-2A, VZM2B and K. local crosses were high yielding when they were used as females.

TABLE 6

Mean grain yield (g/plant) of parents and reciprocal crosses (F_1)

	Male parents									
	Maintainers (B)						Restorers (R)			
Females	CK60B	Nagpur-B	M35-1B	M31-2B	VZM-2B	G1B	Nandyal	GM1-5	K. local	Mean
CK60B	27.3	31.7	45.9	87.7	64.7	47.7	48.4	63.0	53.6	52.2
Nagpur-B	27.1	23.1	43.1	48.3	50.5	18.5	42.9	67.0	30.7	39.0
M35-1B	39.7	27.1	44.9	70.7	66.5	39.3	67.4	50.9	74.9	53.5
M31-2B	85.7	55.0	59.3	51.0	48.3	30.7	80.0	94.3	59.0	62.6
VZM23	71.1	67.8	61.3	49.9	56 6	40.8	85.4	49.2	65.3	60.8
G1B	69.6	15.2	18.1	13.0	35.3	33.2	31.3	15.1	21.7	28.1
Nandyal	12.2	20.9	69.9	64.3	67.9	34 8	54.0	26.4	71.3	47.0
GM1-5	41.1	66.5	56.5	72.3	58.1	30.0	60.7	50 6	34.8	52.3
K. local	58.0	46.5	65.3	68.0	69.6	38.1	69.5	66.1	41.3	58.0
Mean	48.0	39.3	51.6	58.4	57.5	34.7	60.0	53.6	50.4	50.4

SE±7.16   CD (5%)=19.83   CD (1%)=26.06

Parental values underlined.

The cross Nagpur-B × G1B (reciprocals) is generally low yielding. The reciprocal differences with regard to the crosses Nandyal × CK60B and Nandyal × Nagpur-B were significant. It, therefore, appears that the cytoplasm of Nandyal reduced yield levels in these two crosses.

Among R×R crosses grain yield of Nandyal × GM1-5 and GM1-5 ×K. local crosses was also lower than parents as well as reciprocal crosses.

CYTOPLASMIC EFFECTS

(a) *Analysis of means* : ANOVA for within and between B×B, R×R and B×R crosses was done to determine the cytoplasmic differences among B and R lines (Tables 7 and 8). Since within group differences among all possible crosses involving reciprocals could be attributed to both genic and cytoplasmic differences, total effects were partitioned in ($B_i \times B_j$) and ($B_j \times B_i$) genotypic effects

TABLE 7

Group means of B-R crosses

Group	Pollen sterility (Angle)	Grain yield (g/pl)	Panicle weight (g)	Panicle length (cm)	No. of primary branches	100-grain weight (g)	Plant height (cm)	50% bloom (days)
$B_i \times B_j$	33.9	45.7	64.1	17.8	65.2	4.3	200.2	82.8
$B_j \times B_i$	34.8	49.5	66.8	18.8	62.7	4.0	197.2	84.0
$R_i \times R_j$	30.0	44.5	62.1	20.2	69.0	3.4	191.6	82.9
$R_j \times R_i$	13.2	65.4	86.1	21.4	76.1	2.9	166.8	87.1
B×R	25.7	55.6	77.3	10.4	72.5	2.6	188.8	84.5
R×B	25.7	52.2	74.6	19.6	73.8	3.5	188.4	86.5

B=Maintainer line, R=Restorer line

NB=First parent represents female, second parent as male in a cross and i, j represent parental sequence in crosses.

and ($B_i \times B_j$) *vs* ($B_j \times B_i$) reciprocal effects which arise due to cytoplasmic differences. Similar partitioning was done for R×R and B×R crosses.

Significant differences were observed for all the characters within B×B crosses. These differences were mainly accounted for by genotypic differences within $B_i \times B_j$ and $B_j \times B_i$ crosses. Reciprocal effects were also significant for panicle length and 100-grain weight.

Within group differences in R × R crosses were significant for all the characters. When further partitioned, $R_i \times R_j$ crosses exhibited differences for all the characters but when sequence of parent was changed in crosses, differances for pollen sterility, grain yield, panicle weight, number of primary branches and 50% bloom disappeared in $R_j \times R_i$ crosses. This shift was due to the change in cytoplasm in crosses and, therefore, reflected the cytoplasmic-genic interactions. Reciprocal effects in R × R crosses were significant for all the characters except panicle length and number of primary branches. Cytoplasm, therefore, contributed for the determination of all these characters. Change

TABLE 8

ANOVA for cytoplasmic effects

Source	df	Pollen sterility (Angle)	df	Grain yield (g/pl)	Panicle weight (g)	Panicle length (cm)	No. of primary branches	100-grain weight (g)	Plant height (cm)	50% bloom (days)
BxB Crosses	19	205.7**	29	405.7**	480.4**	9.6**	104.1**	0.44**	805.6**	53.4**
(1) $B_i \times B_j$	9	208.0**	14	421.9**	400.7**	5.9**	88.2**	0.14**	863.6**	44.5**
(2) $B_j \times B_i$	9	225.9**	14	410.6**	624.5**	13.5**	124.2**	0.73**	798.5**	65.3**
Reciprocal (1) vs (2)	1	3.6	1	110.0	58.7	7.5**	46.4	0.60**	64.6	11.6
R×R crosses	5	218.1**	5	378.4**	618.2**	9.5**	124.9**	0.11**	583.4**	28.1**
(1) $R_i \times R_j$	2	528.5**	2	598.0**	1019.9**	17.6**	210.3**	0.07*	358.2**	53.6**
(2) $R_j \times R_i$	2	5.6	2	19.4	93.6	4.9**	63.7	0.40**	639.8**	3.4
Reciprocal (1) vs (2)	1	422.3**	1	657.2**	864.2**	2.2	76.2	0.15**	921.1**	26.8*
BxR+RxB crosses	29	212.9**	35	400.9**	603.7**	5.9**	110.2**	0.18**	570.3**	58.0**
(1) B×R	14	248.7*	17	474.6**	605.3**	6.7**	115.0**	0.17**	625.9**	40 7**
(2) R×B	14	192.3**	17	344.9**	634.2**	5.4**	111.5**	0.20**	548.1**	76.6**
Reciprocal (1) vs (2)	1	0.0	1	100.4	62.1	0.3	6.0	0.01	1.3	37.6**
Error	160	5.3	160	51.3	77.1	1.0	34.1	0.02	65.3	5.73

B—Maintainer line, R—Restorer line

* —Significant at 5%, **—Significant at 1%

NB. First parent represents female, second parent as male in a cross and i, j represent parental sequence in crosses

TABLE 9

Reciprocal differences in general combining ability effects

Parent	A line cyt. group	Pollen sterility (Angle)	Grain yield (g/pl)	Panicle weight (g)	Panicle length (cm)	No. of Primary branches	100-grain weight (g)	Plant height (cm)	50% bloom (days)
CK60-B	1	−3.21**	4.25	6.08*	−0.41	3.85*	0.31**	−1.40	−1.93*
Nagpur-B	1	−4.46**	−0.26	1.56	0.30	0.78	0.27**	1.40	0.60
M35-1B	2	−1.50	1.87	2.67	−0.33	1.76	0.04	2.41	−0.52
M 31-2B	2	—	4.23	−2.22	0.62	−5.00**	0.03	−5.03	−1.89*
VZM2B	3	−1.04	3.32	4.18	−0.34	0.60	0.11*	2.93	1.37
G1B	3	10.26**	−6.67*	−7.00*	−0.04	−3.55	−0.56**	0.33	1.03
Nandyal		5.05**	−12.99**	−16.55**	−0.19	1.02	0.06	2.66	0.61
GM1-5		−0.61	−1.32	−3.74	0.04	−0.89	−0.19**	5.15	2.30**
K. local		−4.41**	7.54**	13.04**	−0.59	1.44	−0.06	−8.52*	1.19
SE ±		0.53	1.59	1.95	0.21	1.29	0.03	1.79	0.26
Significant standardized range at 5%		1.74	5.24	6.42	0.67	3.36	0.10	5.89	0.86

**Significant at 1%, *Significant at 5%.

from $R_i \times R_j$ to $R_j \times R_i$ crosses resulted in reduction of pollen sterility, 100-grain weight, plant height and increase in yield, panicle weight and flowering time.

Differences were significant among B × R and R × B crosses for all the characters. Reciprocal crosses were significant only for 50% bloom. Cytoplasmic difference due to change in sequence of parental combination delayed blooming by two days.

(b) *Reciprocal differences* : Reciprocal differences in *g.c.a.* effects are presented in Table 9. CK60B cytoplasm (Kafir) induced earliness by two days, and enhanced pollen fertility (3%), panicle weight, number of primary branches and 100-grain weight while Nagpur-B cytoplasm contributed to 100-grain weight and reduced pollen sterility.

G1B cytoplasm promoted pollen sterility and reduced grain yield, panicle weight and 100-grain weight; cytoplasmic effects of Nandyal were similar to G1B for pollen sterility, grain yield and panicle weight, Karad local cytoplasm increased grain yield and panicle weight but reduced pollen sterility and plant height.

Cytoplasmic differences of CK60B and Nagpur-B; G1B and VZM2B; M35-1B and M31-2B were dissimilar for different characters. Cytoplasmic effects of G1B and Nandyal, VZM2B and M35-1B and CK60B and Karad local were similar.

(c) *Reciprocal effects of individual crosses* : Differences for pollen sterility were significant in reciprocal crosses of G1B × Nagpur-B; G1B × VZM2B; G1B × M35-1B, G1B × GM1-5; G1B × K. local, Nandyal × GM1-5 and GM1-5 × K. local indicating the presence of cytoplasmic-genetic interactions (Table 10).

TABLE 10

Reciprocal effects for pollen sterility (angular transformed values)

Female/Male	CK60B	Nagpur-B	M35-1B	VZM2B	G1B	Nandyal	GM1-5	K. local
CK60B	0.00	0.15	—5.04*	—0.70	—4.04	—6.69*	1.80	1.34
Nagpur-B	—0 15	0.00	—1.00	—1.71	—10.11**	—4.30	—0.12	—3.87
M35-1B	5.04*	1.00	0.00	—1.25	—8.89**	—0.70	—0.37	—0.84
VZM2B	0.70	—1.72	1.24	0.00	—4.63*	—1.14	—0.51	1.86
G1B	4.04	10.11**	8.89**	4.63	0.00	2.33	5.91**	5.13*
Nandyal	6.66**	4.30	0.70	1.14	—2.33	0.00	—11.16**	1.42
GM1-5	—1.80	0.12	0 38	0.51	—5.91**	—11.16**	0.00	15.44**
K. local	—1.34	3.87	0.84	—0.86	—5.13*	1.42	—15.44**	0.00

**Significant at 1%, *Significant at 5%.

Even G1B × CK60B effect was sufficiently large but significant only at 10% level. Cytoplasm of G1B promoted maximum sterility and appeared to be different from all the B-line and R-line cytoplasms. Reciprocal effects of CK60B × M35-1B and CK60B × Nandyal crosses were also significant indicating that cytoplasms of M35-1B and Nandyal were different from the cytoplasm of CK60B and, therefore, non-kafir type. It was already stated that G1B cytoplasm was different from CK60B and other B and R lines.

Reciprocal differences for grain yield among B × B crosses were absent (Table 11). CK60B × Nandyal cross was significant indicating that yield was reduced when Nandyal was used as female parent. Nandyal cytoplasm, therefore, modified the genotypic effect of CK60B.

Reciprocal effects among R × R crosses, viz., GM1-5 × Nandyal and GM1-5 × K. local were significant and quite pronounced confirming cytoplasmic differences between GM1-5 and Nandyal. While Nandyal increased the yield in GM1-5 cytoplasm, K. local decreased the yield.

Discussion

Characterization of "sterile" (A) cytoplasmic sources

Observations on seed set, pollen fertility and pollen dehiscence in A×B and A×R crosses clearly established three different types of reactions. In the *milo kafir* group represented by CK60B and Nagpur-A there is restoration of fertility for pollen and seed set with the B lines M35-1B, M31-2B, VZM2B and G1B. In case of the *maldandi* group while VZM2B fails to restore fertility, G1B restores fertility in summer season on M35-1A and in both seasons on M31-2A. The three lines Nandyal, GM1-5 and K. local restore fertility on the two steriles of this group. With VZM2A and G1A none of the B lines nor R lines restore seed set. Thus, the three group viz., CK60A and Nagpur-A represent the *milo* cytoplasm; M35-1A and M31-2A represent as second group and VZM2A and G1A a third group.

However, there are differences for environmental interaction for pollen fertility and pollen shedding. Pollen dehiscence is influenced by temperature in case of M31-2A. Hybrids of VZM2A with R lines shed fertile pollen but there is no seed set indicating the opration of self-incompatibility. The *milo* (A1) × R crosses and VZM2A × R crosses also appear to be confounded by self-incompatibility in addition to male sterility.

Quinby (1982) felt that M35-1A might represent A2 cytoplasm, but the absence of a known parent representing the A2 source of cytoplasm (Schertz and Ritchey, 1978) in this study, correspondence between A2 and any of these

TABLE 11

Reciprocal effects for grain yield (g)

Male/Female	CK60B	Nagpur-B	M35-1B	M31-2B	VZM2B	G1B	Nandyal	GM1-5	K. local
CK60B	0.00	2.30	3.10	1.00	—3.20	—10.95	18.10	10.97	—2.18
Nagpur-B	—2.30	00.0	8.03	—3.33	—8.63	1.68	11.03	0.23	—7.88
M35-1B	—3.10	—8.03	0.00	5.67	2.20	10.58	—1.27	—2.82	4.80
M31-2B	—1.00	3.33	—5.67	0.00	—0.80	8.83	7.83	11.00	4.50
VZM2B	3.20	8.63	—2.60	0.80	0.00	2.77	8.77	—4.45	—2.17
G1B	10.95	—1.68	—10.58	—8.83	—2.77	0.00	—1.77	—7.47	—8.17
Nandyal	—18.10*	—11.03	1.27	—7.83	—8.77	1.77	0.00	—17.17	1.43
GM1-5	—10.97	—0.23	2.82	—11.00	4.45	7.47	17.17*	0.00	—15.63*
K. local	2.18	7.88	—4.80	4.50	2.17	8.17	—1.43	15.63*	0.00

		SE±
R(I, J)	=	5.06
R(I, J)—R(K,L)	=	7.16

*Significant at 5%.

sources has to wait. But our studies clearly establish existence of at least three diverse sources of cyto-genetic sterility. This is further confirmed by amino acid composition, soluble protein patterns, isoenzymes, differences in pollen grain shape, size, exine sculpture and internal structure (Tripathi *et al.*, 1981a, 1981b, 1982a, 1982b, 1983).

CHARACTERIZATION OF B AND R CYTOPLASMS

Quinby (1982) assumes the presence of female-inducing (A1 and A2) and male-inducing (B1 and B2) cytoplasms. The *kafir B* type of cytoplasm is designated as B1 and studies on cytoplasmic characterization of other B and R lines still needs critical analysis.

In this study, some of the B×B and R×R crosses exhibited high levels of pollen sterility compared to their parents. The B×B crosses, G1B×Nagpur-B, G4B×M35-1B, CK60B×Nag-B and G1B×VZM2B exhibited significantly higher levels of sterility compared to their parents. Amongst the R×R crosses, the Nandyal×GM1-5 cross exhibited significantly higher levels of sterility (Table 5).

The analysis of variance revealed that overall reciprocal differences were more prominent between the R×R crosses compared to B×B or B×R crosses. Individual crosses, however, in each group did show significant reciprocal differences. Based on reciprocal differences for general combining ability effects, it gets established that the cytoplasmic effects can broadly be classified into the negative and positive categories. The cytoplasms of G1B and Nandyal tend to induce sterility and also reduce grain yield. Further, association analysis between reciprocal effect for pollen sterility and yield indicates G1B as the extreme sterile inducing type followed by Nandyal. On the other hand, Karad Local and CK60B represent the most 'fertility inducing' type cytoplasms, while Nagpur-B and GM1-5 tend to induce some sterility. The differences amongst them are significant.

It thus appears that there are clearcut cytoplasmic differences for induction of sterility or fertility. Based on the analysis, the following categories may be recognised :

	Cytoplasmic type	Example
1.	High male sterility inducing	G1B and Nandyal
2.	Male sterility inducing	Nagpur-B and GM1-5
3.	Male fertility inducing	VZM2B and M35-1B
4.	High male fertility inducing	Karad Local and CK60B

A question that arises is that even if certain amount of pollen sterility is induced due to cytoplasmic differences, reciprocal yield differences should not be significant since there is adequate pollen available for fertilizing all stigmas within a head under the bag. Inspite of this, there is a corresponding fall in yield levels also which needs explanation.

Rao *et al.* (1971) reported the existence of self-incompatibility in sorghums. Crosses on CK60A and Nagpur-A with Karad local have high per cent of pollen fertility but seed sets were only partial. Similarly, VZM2A crosses with the R lines like GM1-5, K. local and Nandyal had 20-50% fertile pollen, but seed set was absent. Both these cases, may be explained only on the basis of partial to complete self-incompatibility. Like cytoplasmic-genetic male sterility, the origin of self-incompatibility may also have a cytoplasmic genetic basis. It will, therefore, be necessary to establish the precise relationships between these two phenomena. There is need to re-examine these crosses so that a precise characterization becomes feasible.

The present studies clearly establish cytoplasmic differences among normally fertile lines represented by B and R categories which may be classified into 2 or 3 groups as follows :

Cytoplasmic effects of A, B and R lines

	A lines	*B/R lines*	
increasing sterility	↓ CK60A	G1B, Nandyal	↑ increasing sterility
	M 35-1A	Nag B, GM1-5	
	VZM2A	M35-1, VZM2B	
	G1A	CK60B, Karad local	

In A lines, the degree of sterility increases from A1 > A2 > A3 and consequently fertility restoration also becomes increasingly difficult in the same order.

Similarly in B/R lines also, the cytoplasms do exhibit similar differences. But what is of significance is the *milo* cytoplasm of Kafir A (A1) induces sterility whereas the Kafir B cytoplasm (B1) is most fertility promoting, while B2 and B3 types tend to induce increasing levels of sterility. Cytoplasmic factors in A and B lines appear to be in opposite directions.

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BREEDING SORGHUMS FOR HIGH PROTEIN CONTENT AND QUALITY

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ABSTRACT

Considerable variability exists in sorghum for protein content (%), 100-seed weight, DBC values, DBC/Protein and protein per grain. Interesting cross combinations were observed where simultanous improvement in protein quantity and quality traits could be achieved. In breeding programmes aimed at protein improvement, it is essential to select parents with high protein synthesizing ability instead of choosing parents solely on protein pereentage. The methodology of DBC per unit protein used in the present investigation is likely to be useful in identifying high lysine lines.

The nutritionally superior sorghums of Ethiopian origin IS 11758 and IS 11167 (Singh and Axtell, 1973) have shrivelled grains and in practice the transference of the high lysine trait from shrivelled to plump grains could not be accomplished so far. The P-721 opaque sorghum mutant (Mohan, 1975) even though plump is reported to be unstable (Riley, 1980) and its transference to a corneous endosperm type is yet to be achieved. The main reason for a lower yield in high lysine genotypes has been the reduction in grain weight (Mehta, Dongra, Johari, Lodha and Naik, 1978; Bansal, Shrivastava, Eggum and Mehta, 1977). The results presented in this study indicate the possibility of combining high protein and high lysine against plump seeded background in grain sorghum.

MATERIALS AND METHODS

The experimental material comprised two released varieties; two high lysine Ethiopian lines and one high lysine Purdue mutant; three plump and three shrivelled seeded derivatives from cross combinations of Ethiopian high lysine sorghums; F_1's, F_2's, BC F_1's and BCF_2's of crosses with P-721 mutant. One gram of wholegrain meal from each of the materials, ground in Udy Cyclotec Mill, was used for protein estimations (N×6.25) by the macrokjeldahl method on the Tecator Kjeltec system II. DBC (mg dye bound/g sample) analysis were done on the ground samples using the Udy protein analyser according to Mossberg (1969). Standard statistical procedures were followed for analysis of the data.

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RESULTS

The seeds of F_1, F_2, BC F_1 and BC F_2 as well as parents were analyzed for protein and DBC. The mean and range is presented in Table I. The parents, CSV-3, CSV-5, N 49, N 55 and N 59 had plump seed and IS 11758, IS 11167, N 82, N 93 and N 94 had shrivelled seeds. The 100-seed weight was the highest for N 55 and the lowest for the high lysine parent, N 82. Protein (%) varied among parents. The parents, P-721, IS 11758, IS 11167, N 82, N 93 and N 94 had more than 10 percent protein, while CSV-5 and CSV-3, N 49, N 55 and N 59 had less than 10 percent protein. The protein content on percent basis was quite high in ,IS 11758, N 82 and N 93. On comparing the protein content per grain, a different pattern was obtained. IS 11758 had the highest protein content of 4.17 mg protein per grain, while the protein content per grain of N 82 was much lower even though protein expressed as percentage was very high. Parent, N 55 had about 4 mg protein per grain. Protein content was lower in N 93, N 49 and P 721 than the rest. The higher protein percentage in parents, N 82 and N 93 with shrivelled seeds was mainly due to a reductlon in starch since protein content per grain was lower as compared with many plump seeded varieties.

The DBC value furnishes an estimate of protein content and basic amino acids which were higher in parents, IS 11758, IS 11167, N 82, N 93 and N 94 and lower in CSV-5, CSV-3, N 49, N 55, N 59 and P-721. DBC per protein unit indicates protein quality and was found to be higher in CSV-5, N 49, N 55, IS 11758, IS 11167 and N 94. CSV-5 and N 49 had less DBC/g flour but on per unit protein basis the values were much higher indicating better protein quality in seeds with plump background.

On comparison, the protein percentage in F_1, BC F_1 and BC F_2 exhibited wide variation in protein content as well as seed weight. In F_1, protein varied from 8.23 to 9.45%; in F_2 from 8.75 to 9.80%; in BCF_1 from 7.14 to 16.46% and in BCF_2 from 8.16 to 13.13%. There was consistent improvement in protein percentage in backcrosses. The scatter diagram (Fig. 1) shows the relationship between seed weight and protein per gram. Distinct improvement in protein content over parent was observed. Figure 2 shows the relationship between protein percent and DBC value. A linear relationship was noticed but there were certain deviates which had higher DBC at the same protein level and these were the strains which shows improvement in protein quality.

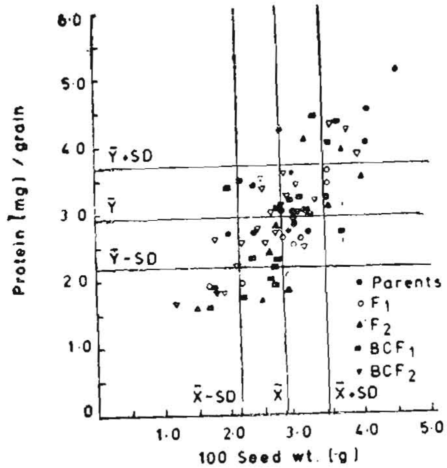
The DBC values of F_1 seeds ranged from 24.80 to 27.90; for F_2 from 27.15 to 27.90 and for BCF_1 from 23.35 to 44.10. The DBC per unit protein also varied between F_1, F_2. BCF_1 and BCF_2. The mean DBC/g protein for BCF_2 was higher than parental mean. However, in BCF_2, certain strains

TABLE 1

Mean and range of some of the materials taken up for biochemical studies

S.No.	Generation		100 Seed wt (g)	Protein (g)	DBC Value	DBC/Protein × 100	Protein (Mg/grain)
1	Parents	Mean	2.87±0.18	11.46± 0.69	31.74± 1.73	278.61± 6.28	3.20±0.17
		Range	1.91—4.13	8.40—14.70	24.95—40.85	242.53—314.29	2.70—4.17
2	F_1	Mean	3.20±0.18	9.02± 0.27	26.75± 0.68	296.87± 1.58	2.88±0.20
		Range	2.81—3.49	8.23— 9.45	24.80—27.90	294.18—301.34	2.46—3.30
3	F_2	Mean	3.25±0.34	9.10± 0.25	27.38± 0.20	301.33± 6.39	2.93±0.25
		Range	2.67—4.05	8.75— 9.80	27.00—27.90	284.69—313.71	2.42—3.54
4	BC F_1	Mean	2.99±0.18	10.36± 0.89	28.44± 1.83	281.05± 9.76	3.03±0.24
		Range	2.04—4.11	7.14—16.46	23.35—44.10	232.28—329.74	1.92—4.45
5	BC F_2	Mean	3.03±0.14	10 86± 0.37	27.00± 0.52	250.95± 6.87	3.27—0.16
		Range	2.23—3.92	8.16—13.13	23.00—28.85	218.58—287.20	2.56±4.32
6	Overall	Mean	3.01±0.08	10.55± 0.32	28.59± 0.71	274.68± 4.43	3.12—0.02
		Range	1.91—4.13	7.14—16.46	23.00—44.10	218.58—329.74	1.92—4.45

which had high protein showed low DBC values there by indicating lower basic amino acid content in those strains. Protein content per grain also varied



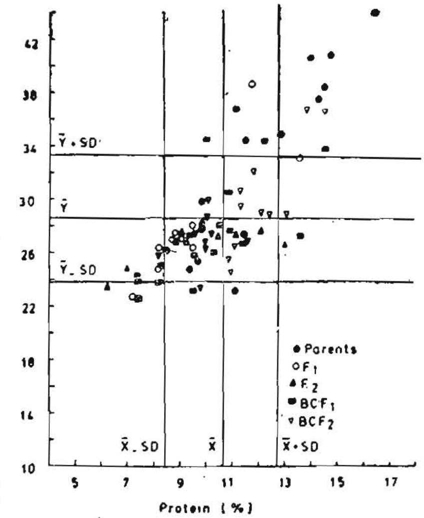


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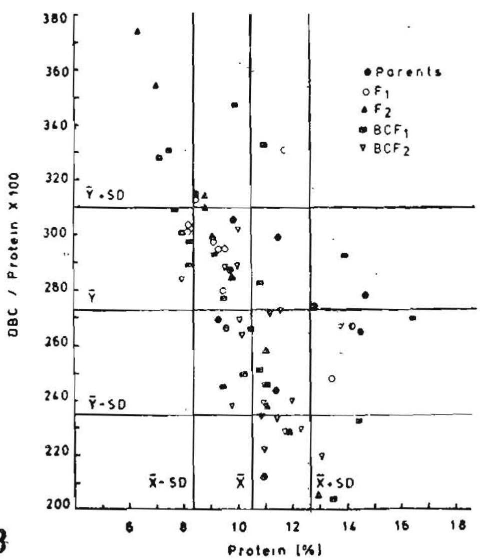
Fig. 1. Relationship between 100 seed weight (g) and protein (mg)/grain.
Fig. 2. Relationship between protein % and DBC values.



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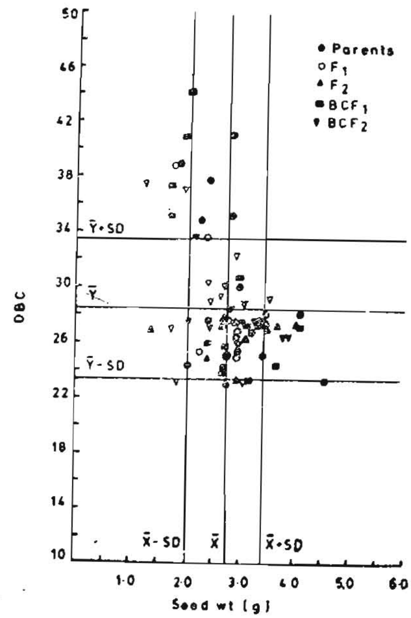

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Fig. 3. Relationship between protein % and DBC protein × 100.
Fig. 4. Relationship between seed weight (g) and DBC values.

in F_1, F_2, BC F_1 and BC F_2. In F_1, it ranged from 2·46 to 3.30mg; in F_2 from 2·42 to 3.54 mg; in BCF_1 from 1.92 to 4.45 mg and in BC F_2 from 2.57 to 4.32 mg. Compared to the mean protein percentage and the protein per grain of parents, the F_1's have shown a decrease. There was improvement in DBC/g of protein in F_2 and BCF_2 seeds which was indicative of protein quality improvement.

The variation in DBC per unit protein was quite marked. The results indicate major differences with respect to protein quality. Some of the BC F_1's such as (N 49×P-721) × N 49 and (P-721×N 55) × N 55 in a plump background had high DBC/unit protein indicating higher lysine/basic amino acid content. It has been earlier observed that DBC/protein is positively correlated with lysine content. Therefore, higher DBC value per unit protein in some of these crosses was indicative of the improvement in protein quality in sorghum. Out of the 20 BC F_2's (P-721×N 93) × N 93, (P-721×N 49) × P-721, (N 93× P 721) × P 721 and (N 49×P-721) × P-721 had high DBC per unit protein and hence better protein quality (Table 2). The relationship of protein (%) with DBC/protein is shown in Fig. 3 and of the seed weight with DBC in Fig. 4. In general, with increasing protein % there has been a decrease in DBC/protein. However, there are many deviates where at some protein level DBC/protein has registered increase.

Discussion

Protein content in cereal grains has been shown to be negatively associated with grain yield. Cereal grains are nutritionally poor mainly on account of deficiency of lysine. In several laboratories, efforts are being made to combine high yields with increased protein content and quality (Bansal and Bhaskaran, 1976; Bhatia, Desai and Suseelan, 1978; Johnson, Mattern, Wilhelm and Kuhr, 1978; Bansal, Singh, Bhaskaran, Santha and Murty, 1980; Jaya Mohan Rao, 1980; Jaya Mohan Rao and Rao, 1981; Jaya Mohan Rao, Deosthale, Vidyasagar Rao and Rao, 1983; Jaya Mohan Rao, Deosthale, Rana, Vidyasagar Rao and Rao, 1983; Jaya Mohan Rao, Reddy, Rana and Rao, 1983; Jaya Mohan Rao, Rana, Reddy, and Rao, 1983; Jaya Mohan Rao, Santha, Mehta and Rao, 1983. Among cereals, the nutritional quality of sorghum is the least and people subsisting on sorghum diet develop pellagra mainly on account of high leucine/isoleucine ratio (Gopalan and Srikantia, 1960). The poor nutritional quality in these grains is mainly due to the predominance of prolamine which is known to be extremely low in lysine and rich in leucine. The development of high lysine strains like IS 11758 and IS 11167 (Singh and Axtell, 1973) and P-721 Opaque (Mohan, 1975) in sorghum, Hiproly, Notch-2, Riso 1508 in barley and Opaque-2 in maize (Mertz, Bates and Nelson, 1964) raised hopes of combining nut tritional quality

TABLE 2

Some of the promising segregants identified from the biochemical analysis

Breeding line	Pedigree	100-seed weight (g)	Protein (%)	DBC value	DBC protein × 100	Protein (mg/grain)	Seed type	Generation
125—27	N 93×P 721	1.45	11.38	26.85	235.94	1.65	Seg. P	F_2
171—6	P 721×N 93	2.83	12.08	27.60	228.48	3.41	Seg. P	F_2
150—11	N 94×P 721	3.71	10.50	27.15	258.57	3.89	Seg. P	F_2
275—10	P 721×N 94	3.15	12.95	26.55	205.02	4.07	Seg. P	F_2
23—1	(N 49×P 721) × N 49	3.68	7.43	24.50	329.74	2.73	P	BC F_1
158—4	(P 721×N 55) × N 55	2.69	7.14	23.35	327.03	1.92	P	BC F_1
166—6	(P 721×N 82) × N 82	2.76	9.45	25.75	272.49	3.06	Seg. P	BC F_1
124—4	(N 93×P 721) × P 721	1.95	14.04	40.85	290.95	2.73	Seg. P	BC F_1
312—1	(P 721×N 93) × N 93	2.35	10.29	25.60	248.79	2.41	Seg. P	BC F_1
174—11	(P 721×N 94) × N 94	3.37	13.49	27.30	203.37	4.46	Seg. P	BC F_1
18—1	(N 49×P 721) × P 721	3.16	8.16	23.00	281.86	2.57	P	BC F_2
131—1	(P 721×N 49) × P 721	3.31	9.61	27.60	287.20	3.18	P	BC F_2
86—2	(N 93×P 721) × P 721	3.05	9.98	28.60	286.55	3.04	P	BC F_2
258—1	(P 721×N 93) × N 93	2.74	9.95	29.90	300.50	2.72	Seg. P	BC F_2
96—1	(N 94×P 721) × N 94	2.47	11.27	30.55	271.07	2.78	Seg. P	BC F_2
112—3	(N 94×P 721) × P 721	2.92	11.76	32.00	272.11	3.43	Seg. P	BC F_2
292—1	(P 721×N 94) × N 94	1.81	9.84	23.35	237.30	1.78	Seg. P	BC F_2

P=Plump; S=Shrivelled; Seg. P=Segregating but plump seed taken for analysis.

with yield. This has not been possible mainly because of reduction of starch content in the grain (Mehta *et al.*, 1978; Bansal *et al.*, 1977; Sen and Mehta, 1981; Batra, Bansal and Mehta, 1981). Grain weight, being an important yield attribute, has been encountered to be a constraint in breeding barley for improved nutritional quality and productivity (Doll and Koie, 1978; Weish, 1978). In sorghum also, the high lysine strains of Ethiopian source have shrivelled and dented seeds. It has been suggested that some high protein or high lysine genes may be linked to factors that impair endosperm development (Bhatia and Robson, 1976; Doll and Koie, 1978). In addition, high lysine lines, IS 11758 and IS 11167 are photosensitive and are of long duration.

In the present study, utilizing parents with improved quality, it has been possible to incorporate high protein and high lysine characters in plump seeds in some segregants. It has also been possible to get seed weights to the extent of 4.05 g. In BC F_1 and BC F_2, the improvement in the protein content was accompanied with an improvement in protein quality in some of the lines. The improvement in the protein quality is reflected in higher mean DBC value per unit protein in BC F_2's as compared to the parents. Some of the segregants had much higher DBC value per unit protein than the respective parents used in the crosses. This indicates that it is possible to combine and get additive effects both in protein quantity and quality by following a suitable breeding programme. Although in many of the segregants such as (N 82×P721) × N 82 and (N 82×P—721) × P—721 protein percent obtained was high but on comparing the absolute level of protein these segregants had much lower protein content per grain. In other words, the higher protein per cent observed in such segregants was not due to high protein content in the grains as their seeds were shrivelled. Thus, in a plant breeding programme aimed at protein improvement, it is absolutely necessary to select parents on the basis of their absolute protein synthesizing ability rather than solely on protein percentage basis.

In barley, Bansal *et al.* (1977) and in wheat, Jain, Singhal and Austin (1976) demonstrated that for breeding purposes protein per grain or protein yield per unit area should be taken into consideration for selecting high protein types. The present study brings out very clearly that improvement in both seed weight and protein content could be obtained by using parents with improved protein and lysine content. The material raised in this study is being further used in breeding programme, so that improved protein quantity and quality traits can be stabilized under high yield potential.

Acknowledgements

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ULTRA STRUCTURAL STUDIES OF HIGH LYSINE SORGHUMS

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ABSTRACT

Endosperm structure in high lysine sorghums and their crosses was examined by scanning electron microscopy. The high lysine trait was associated with adherence of protein to large starch granules, surface granularity of the starch granules and the number of smaller starch granules present.

High lysine sorghums identified or induced so far have improved nutritional quality but the yields are lower as compared with commercial varieties (Singh and Axtell, 1973; Mohan, 1975). Studies conducted so far indicated that improvement in protein quality has been mainly due to a decrease in prolamine (Jambunathan, Mertz and Axtell, 1975; Guiragossian, Chibber, Van Scoyoc, Jambunathan, Mertz and Axtell, 1978). It has also been suggested that the protein bodies which predominantly contain prolamine are smaller and fewer in high lysine sorghums than in normal sorghums (Rooney and Sullins, 1976). In high lysine barley and maize genotypes, yield reduction has been mainly on account of decrease in starch (Mehta, Dongre, Johari, Lodha and Naik, 1979; Sen and Mehta, 1980). In the high lysine barley mutant Notch-2, scanning electron microscopy indicated changes in size and morphology of starch granules. Yield reduction was partly contributed by the smaller size of the starch granules (Sood, 1982). Electron microscopic investigations of starch and protein grains of endosperm of high lysine sorghums and their derivatives were undertaken to provide guide lines on the selection of nutritionally superior genotypes.

MATERIALS AND METHODS

Large number of crosses were made using the high lysine sorghum lines. IS 11167 and IS 11758, both as male and female parents. During the course of selection, only three plump

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(N 49, N 55 and N 59) and three shrivelled (N 82, N 93 and N 94) derivatives were selected and were used in subsequent crossing programme along with P 721, the Purdue high lysine opaque mutant. N 49, N 55, N 59, N 93 and N 94 were derived from the cross 148CSV-5×IS 11167, whereas N 82 was a derivative of IS 11758×CSV-3 370. The plump lines are moderatelyhigh in protein and lysine whereas the shrivelled lines were high both in protein and lysine. All the parents were photoinsensitive and agronomically desirable.

The experimental material was grown during summer, 1980 at the National Research Centre for Sorghum, Hyderabad under normal (about 60-80 kg N/ha) fertility. Based on amino acid and electrophoretic studies out of a total 72 samples in parents, F_2, BCF_1 and BCF_2 generations (Jaya Mohan Rao, Mehta and Rao, 1983), only 7 parents, one F_1 and 5BCF_1' s and one BCF_2 (Table 1) were selected for scanning electron microscopy. Seeds at maturity were taken for scanning electron microscopy. Single seeds were cut by rajor blade at room temperature and the sections after mounting on the stubs with a colloidal silver solution were coated with a thin carbon film in a vacuum coating unit and were later coated with gold. The mounted stubs were rotated while being coated. The sections were examined in Cambridge Stereoscan S 4-10 scanning electron microscope for their endosperm structure at 10 KV and photographs taken. The seeds were not fixed because there was no problem of moisture removal.

RESULTS

PROTEIN CONTENT AND QUALITY

Protein content, 100 seed weight and lysine content of parents and crosses are given in Table 1. The seed weight of parent, N 49 was the highest and of N 82 the lowest while seeds of different crosses had seed weights varying from 1.20 to 2.38 g. Crosses involving parent, N 82 had lesser seed weight than those derived from N 94 or N 49. Protein content expressed as percentage was higher in IS 11758 and N 82 among parents and in crosses (P 721×N 49) × P 721, (N 93×P 721) × P 721, (P 721 × N 94) × P 721 BCF_1' s than others. However, protein content per grain which is a better index of protein synthesizing ability was higher in IS 11758 and IS 11167 than other parents. On comparing the protein content per grain of crosses with that of parents both parental performance and interactions were observed. One of the parents, P 721 had less protein and yet its crosses with N 49 had higher protein in BCF_1. This indicates interaction effects since both the parents had lower protein per grain than the cross (P 721×N 94) × P 721 while the cross of P 721 with N 82 in all cases resulted in a decrease in protein content. In cross (P 721×N 94) × P 721 BCF_1, the protein followed its parent N 94. Lysine content in most crosses N 82×P 721, (P 721×N 49) × P 721 BCF_1, (N 82×P 721) × N 82 and (N 82×P 721) × P 721 was higher than other crosses. In BCF_1 (P 721×N 49) × P 721 high lysine was achieved with high protein content per grain and high protein percentage. The decreased grain weight in this cross derivative is, therefore, mainly due to reduced synthesis of starch.

TABLE 1

Protein and lysine content in high lysine sorghum grains

Parent/Cross	Seed type	100 Seed weight (g)	Protein (g%)	Lysine g/100 g protein	Protein (mg. grain)
IS 11167	S	2.88	12.78	3.51	3.68
IS 11758	S	2.84	14·70	3.06	4.17
P 721	P	2.40	11.38	2.59	2.73
N 49	P	3.23	8.40	2.44	2.71
N 82	S	1.91	14.18	3.00	3.43
N 93	S	2.42	11.55	3.26	2.70
N 94	S	2.34	11.42	3.15	3.35
N 82×P 721 F_1	S	1.65	11.73	3.90	1.93
(P 721×N 49) × P 721 BCF_1	P	2.04	16.46	3.70	3.35
(N 82×P 721) × N 82 BCF_1	S	1.71	9.97	3.55	1.70
(N 82×P 721) × P 721 BCF_1	S	1.75	11.09	3.55	1.94
(N 93×P 721) × P 721 BCF_1	Seg. P	1.95	14.04	3.40	2.73
(N 721×N 94) × P 721 BCF_1	Seg. P	2.38	14.53	2.90	3.45
(N 82×P 721) × P 721 BCF_2	P	1.20	13.79	2.70	1.65

S=Shrivelled; P=Plump: Seg. P=Segregating on the panicle but only plump seed taken for analysis

SCANNING ELECTRON MICROSCOPY

(a) *Parents* : Plate 1 shows the internal endosperm structure of parents and cross derivatives. Starch granules of IS 11167 were bigger as compared to IS 11758 (1-A and B). The size ranged in the former from 0·10 μ to 0.25 μ and in the latter 0.09 μ to 0.20 μ. The starch grains showed small surface granularities in both these parents. The granularity was more prominent in IS 11167 which had higher lysine content.

The starch granules in the plump high lysine mutant, P 721 were the biggest ranging from 0.20μ to 0·29μ. The surface granularities on the granules is quiet prominent (1-C). The starch granules were sandwitched with amorphous material. In the moderately high lysine derivative, N 49 the starch grains were smooth, the size ranging from 0·14 μ to 0.27 μ (1-D). More amorphous material was present in this case. The average number of bigger granules was 84% in P 721 and 87% in N 49 compared to 57% in IS 11167 and 67% in IS 11758.

In the high lysine shrivelled derivatives (1-E and F) the size of the granules ranged from 0.18 μ to 0.36 μ in case of N 93 and from 0.09 μ to 0.30 μ in N

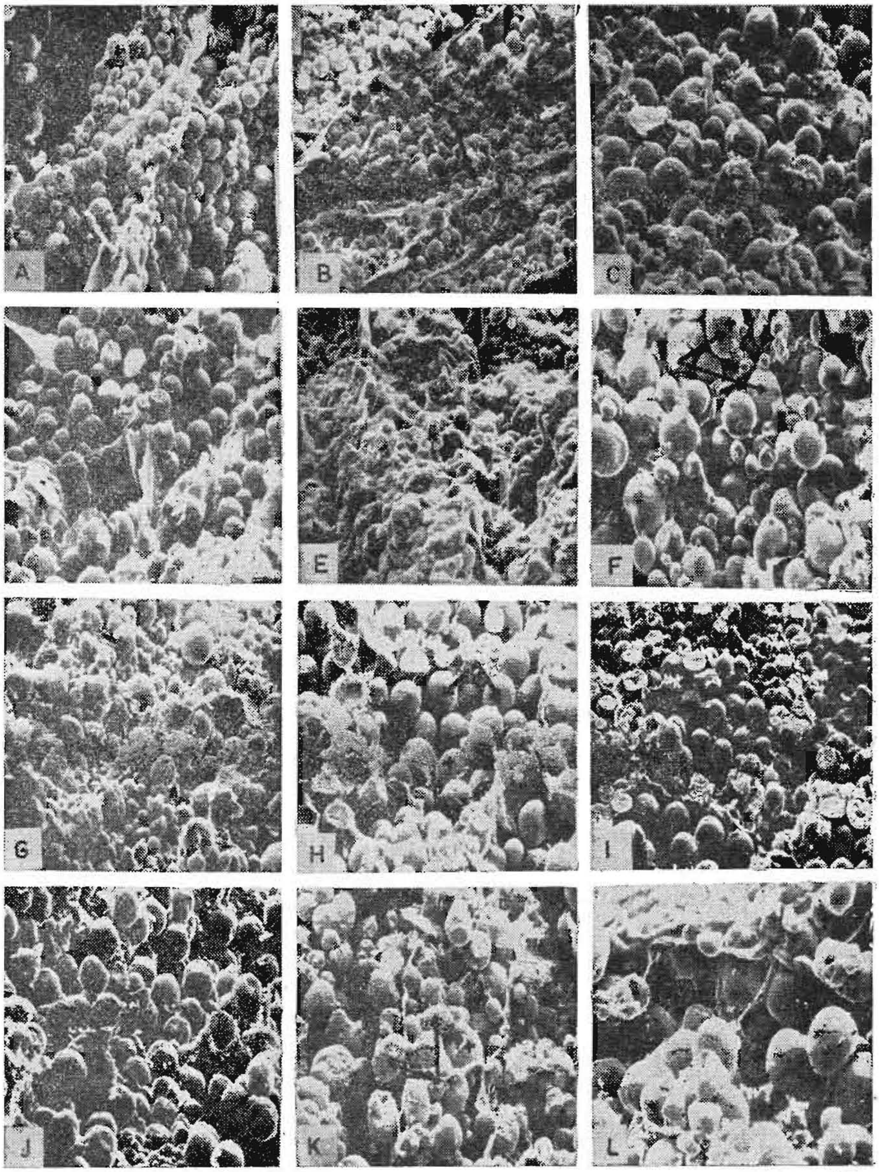

Fig. 1. Scanning electron micrograph showing central endosperm in high lysine sorghum parents and cross derivatives.
A. IS 11167 (×1200) B. IS 11758 (×1200) C. P 721 (× 1250)
D. N 49 (×1150) E. N 82 (×1200) F. N 93 (× 1200)
G. N 82 × P 721 F_1 (x 1300)
H. (P 721 × N 49) × P 721 BCF_1 (×1200)
I. (N 93 × P 721) × P 721 BCF_1 (×1200)
J. (P 721 × N 94) × P 721 BCF_1 (×1200)
K. (N 82 × P 721) × P 721 BCF_1 (×1250)
L. (N 82 × P 721) × P 721 BCF_2 (×1200)

94. However, it was not possible in case of N 82 to measure the size of the granules since it had more amorphous deposits (1-E). The surface granularity is very clearly seen in both the cases. The number of granules and their distribu.ion in N 93 and N 94 resembles the Ethiopian parents, IS 11167 and IS 11758. The granules were loosely packed with more number of intracellular gaps.

(b) *Cross derivatives* : Plate 1-G to L shows the internal endosperm structure of the cross derivatives. The starch granules in the cross N 82×P 721 with high protein and lysine showed resemblance to both the parents (1-G). The bigger starch granules resembled P 721 while smaller starch granules to IS 11758 which is one of the parent of N 82.. The starch granules were not tightly packed and intracellular gaps ware evident. The starch granules were sandwitched with amorphous material, a character derived from P 721. The starch granules of the backcross (P 721×N 49) × P 721 were oval and resembled its parent, P 721 (1-H). The amorphous material deposition also followed its parent P 721. Smaller size granules were not seen. Majority of the granules were of the size of 0.25 μ (Table 2).

The backcrosses (N 93×P 721) × P 721 and (P 721×N94) × P 721 showed oval shaped starch granules with some size variation in both i.e., 0.20 μ

TABLE 2

Size distribution of starch grains in high lysine sorghum grains

Parent Cross	Length		Breadth		Smaller Particles	Bigger particles	Distribution
	Minimum	Maximum	Minimum	Maximnm			
IS 11167	0.111	0.277	0.111	0 222	43	57	Uniform
IS 11758	0.111	0.222	0.083	0.166	33	67	Uniform
P 721	0.250	0.361	0.166	0.222	16	84	Uniform
N 49	0.174	0.284	0.116	0.261	13	87	Uniform
N 82	—	—	—	—	50	50	Uniform
N 93	0.222	0 416	0.138	0.305	45	55	SL
N 94	0.111	0.333	0.077	0.250	55	45	Uniform
N 82×P 721 F_1	0.111	0 277	0.077	0 205	48	52	Uniform
(P 721×N 49)×P 721 BCF_1	0.277	0.305	0.014	0.194	20	80	SL
(N 82×P 721)×N 82 BCF_1	0.083	0.264	0.042	0.166	35	65	SL
(N 82×P 721)×P 721 BCF_1	0.240	0.346	0.133	0.186	33	67	SL
(N 93×P 721)×P 721 BCF_1	0.277	0.500	0.166	0.277	20	80	Localized
(P 721×N 94)×P 721 BCF_1	0.287	0.459	0.229	0.345	35	65	Localized
(N 82×P 721)×P 721 BCF_2	0.305	0.472	0.222	0.306	26	74	Localized

SL=Slightly localized

to 0.45 μ. Majority of the starch grains were of bigger type (1-I and J). The endosperm showed large amount of amorphous protein between the starch grains. The surface of the starch granules was smooth in (P 721 × N 94) × P 721 while that of (N 93 × P 721) × P 721 was slightly granular, since starch grains could easily be cut into two halfs in the former. The (N 82 × P 721) × P 721 backcross had oval shaped starch granules with size from 0.19 μ to 0.27 μ. and the second backcross with N 82 shows oval shaped grains of smaller size (1-K). The surface of the bigger grains in both the cases were more or less smooth. Amorphous protein was less in the BCF_1 of (N 82 × P 721) × N 82 than its BCF_2 (1-L). This BCF_2 showed plump character whose starch grains were slightly bigger than its BCF_1 generation and were equal to the BCF_1's of other backcrosses. The starch grains were very smooth at their surfaces and the smaller grains were about 35% of the larger particles. The amorphous protein was high and was seen covering these starch grains.

Discussion

Cereal grain proteins have poor nutritional quality mainly on account of deficiency of lysine. In addition, in sorghum and maize the imbalance in leucine and isoleucine ratio had been shows to develop pellagra in populations subsisting on these diets (Gopalan, 1968, 1972: Gopalan and Srikantia, 1960; Gopalan, Belavady and Krishnamurty, 1969). In maize and barley, high lysine mutants were induced or identified (Mertz, Bates and Nelson, 1964; Nelson, Mertz and Bates, 1965; Munck, Karlsson, Hagberg and Eggum, 1970; Bansal, 1974). Similarly in sorghum also high lysine types, IS 11167, IS 11758 and P 721 were identified (Singh and Axtell, 1973; Mohan, 1975). The high lysine lines IS 11167 and IS 11758 are shrivelled types and have lower yield. The plump opaque mutant P 721 is also low yielding compared with commercial cultivars.

Scanning electron microscopy of high lysine barley mutant Notch-2 showed that yield reduction is mainly due to the reduction in starch granules coupled with intracellular spaces within the endosperm (Sood, 1982).

The starch grains in all high lysine strains are smaller than the size of the grains reported for normal sorghums and barley. However, the surface of the bigger starch granules of all high lysine parents specially in IS 11167 and IS 11758, N 93 and N 94 showed (+) rough granularity on the surface which was maximum in the Ethiopian parents but decreased in the derived parents. This feature has a direct positive correlation with the lysine content and seed type. All the plump seeded lines are having more or less smoother surfaces on the larger grains.

The P 721 plump opaque mutant is moderate in lysine content with inter mediate surface granularity structure on the surface of larger grains thus indicating that it may be related to lysine. In all such starch granules with surface granularity, protein was adhering to them. Such adhering character has been reported by Munck (1970) in high lysine barley. This indicates that there may be association of protein containing high lysine with starch.

In the crosses with P 721, plump seeded character was selected. In the F_1 of N 82×P 721 which is a high lysine cross the number of smaller granules are more resulting in seed shrivelledness. The surface of the bigger starch granules was intermediate in surface granularity. Both the backcrosses showed high lysine with a decrease in the number of smaller starch granules. However, the surface of the bigger starch granules remained intermediate in the granularity. The other backcrosses (P 721×N 94) × P 721, (N 93×P 721) × P 721 and (N 94×P 721) × P 721 showed more resemblances with P 721 and the plump character was retained with increased lysine content. Electron microscopy studies on parents and cross derivatives indicate that high lysine character is associated with the adherence of protein to the larger sized starch granules, the surface granularity of the starch granules and the percentage of smaller granules present.

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Breeding for Shoot Fly and Stem Borer Resistance in Sorghum

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Abstract

The information on stable resistance sources, mechanisms, genetics, character associations, and breeding for resistance is reviewed, and progress made in breeding for multiple resistance to shoot fly and stem borer is documented. Resistance to these pests is found in some traditional Indian varieties which are agronomically inferior. Nonpreference for oviposition is a major mechanism of resistance to shoot fly, but antibiosis seems also to be present. For stem-borer resistance, antibiotic characters are more important than ovipositional nonpreference.

Heritability of shoot-fly resistance is fairly high, but that of stem-borer resistance is low. In the absence of sources of immunity, selection at one standard deviation (SD) below the population mean for pest damage can help to increase the resistance level gradually. A moderate level of multiple resistance (shoot fly and stem borer) has been built into a high-yielding background.

Résumé

Sélection pour la résistance à la mouche des pousses et au borer des tiges chez le sorgho : *Les informations présentées concernent la résistance stable, plus précisément, les sources, les mécanismes, la génétique, les caractères associés et la sélection. Le progrès dans le domaine de la sélection pour la résistance multiple à la mouche des pousses et au borer des tiges est documenté. La résistance à ces deux insectes se trouve chez certaines variétés traditionnelles indiennes qui sont autrement peu intèressantes du point de vue agronomique. La résistance à la mouche des pousses est fondée avant tout sur la non préférence pour la ponte et, peut-être, l'antibiose. En ce qui concerne la résistance au borer des tiges, les caractères antibiotiques sont plus importants que la non préférence.*

L'héritabilité de la résistance à la mouche des pousses est assez élevée mais celle du borer est inférieure. Dans l'absence des sources d'immunité, la sélection à un écart-type au-dessous de la moyenne de la population pour les dégâts permettra d'augmenter progressivement la résistance. Un niveau modéré de la résistance multiple (mouche des pousses et borer des tiges) est déjà incorporé dans un matériel à haut rendement.

Plant resistance should play a particularly important role in pest management programs in dryland crops. Landraces of cultivated sorghums from the plateaus of southern India survived under insect pressure and developed a high degree of resistance to shoot fly (*Atherigona soccata* Rond.) and stem borer (*Chilo partellus* Swin.). They are, however, low in productivity and are vulnerable to climatic fluctuations.

A systematic program of transforming these tropical sorghums into higher yielding genotypes in India commenced in the 1960s, utilizing early and dwarf temperate germplasm (Rao 1982; Rao and Rana 1982). The temperate x tropical crosses of sorghums provided the basis for combining resistance with more productive backgrounds. This paper analyzes the information on sources, mechanisms, and stability of resistance; genetics; selec-

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tion criteria; and advances from selection in breeding for shoot fly and stem borer resistance in sorghum.

Shoot Fly

Sources and Stability of Resistance

The genetic differences of resistance to shoot fly were first established by Ponnaiya (1951). Most of the resistant lines were from peninsular India. Subsequently, however, more than 10000 varieties from the world collection were systematically screened at different locations (Singh et al. 1968). Deadheart in the main shoot was taken as the parameter for evaluating resistance. A number of varieties showed consistently little damage, but none of them was found immune to shoot fly attack. Young (1972) has listed the following cultivars as promising sources: IS nos. 1034, 1054, 1061, 1082, 2122, 2123, 2146, 2265, 2269, 3969, 4507, 4522, 4545, 4553, 4567, 4646, 4664, 4776, 5251, 5285, 5383, 5469, 5470, 5480, 5483, 5490, 5566, 5604, 5613, 5615, 5622, 5633, 5636, 5658, and 5801.

Subsequent screening in the All India Coordinated Sorghum Improvement Project (AICSIP) has identified the following resistant lines: IS nos. 2312, 5511, 5641, 8315, 15551, 18557, and 22133.

Identified resistant lines mostly come from the *maldandi* (semicompact head type) or *dagadi* (compact-head type) grown in the *rabi* (postrainy) season. Insect populations vary from location to location and season to season, causing varying degrees of damage. In the absence of high levels of resistance, persistence or stability of even a low level of resistance is of considerable value. Identification of varieties with such inherent genetic characteristics is useful for a resistance breeding program.

We modified the method of analysis for stability of performance developed by Eberhart and Russell (1966), and used a susceptibility index in place of their environmental index (Singh et al. 1978). The susceptibility index is defined as mean deviations from a known susceptible variety. A variety with low susceptibility and repeatable rate of change resistance performance over environments is considered to be stable. The absolutely stable variety is one with zero insect damage ($\bar{X} = 0$), zero rate of change (b=0), and lowest deviations (σ_d^2), whereas a susceptible variety shows a higher degree of damage and high regression coefficient and deviations. Using this modified analysis, Singh et al. (1978) established genotypic differences for stability of resistance over different environments. Such changes in resistance over environments were additive in effect and could be predicted. Based on means and regression coefficients, the varieties were classified into homogeneous groups. The varieties IS 1054, IS 5469, and IS 5490, constituted a single group and provided the most stable sources of resistance.

Recently 23 germplasm and 13 breeders' lines were tested for stability of resistance (AICSIP 1983). Among them IS 1082, IS 2146, IS 4664, IS 5470, IS 5566, and IS 22121, and a breeders line, SPV 491, showed mean deadheart percentages slightly less, though not significantly so, than that for IS 1054 (Table 1). Their regression coefficients and deviations were lower than those for IS 1054, indicating better stability of resistance.

Mechanisms of Resistance

There is consistently less oviposition on resistant varieties than on susceptible ones. Jotwani et al. (1971), Sharma et al. (1977), and Singh and Jotwani (1980a) demonstrated ovipositional nonpreference to be the major mechanism of resistance. Screening of 20 resistant and 2 susceptible varieties over 3 years under late planting revealed 0.38 to 0.71 eggs per plant on resistant varieties versus 1.37 to 1.70 eggs per plant on susceptible controls (Sharma and Rana 1983). Nonpreference appears to be a relative term, as there is no resistant variety showing zero oviposition. Relative nonpreference operates at all levels of infestation, over different environments. However, when a preferred host is absent and the shoot fly does not have a choice, the nonpreference mechanism is suppressed under heavy infestations.

Low larval survival on resistant varieties, however, showed the presence of antibiosis (Soto 1974). Retardation of growth and development, prolonged larval and pupal periods, and poor emergence of adults on resistant varieties also provided direct evidence of antibiosis (Singh and Jotwani 1980b).

Ovipositional nonpreference and deadheart formation are related phenomena in the sense that less egg laying results in less deadhearts (Sharma et al. 1977). This relationship holds good in parental varieties as well as in their F_1 and F_2 generations. Deadheart formation as a consequence of the

Table 1. Stability parameters of some promising shoot fly resistant sorghum germplasm and breeding lines, rainy season 1983 (No. of locations = 9).

	Shoot fly deadhearts (%)		
Entry	$\bar{X}$	b	$\overline{\delta ij^2}$
Germplasm line			
IS 1054	24.5	0.68**	144.8
IS 1082	22.8	0.51**	357.2
IS 2146	19.0	0.51**	242.6
IS 4663	25.1	0.76**	151.4
IS 4664	23.5	0.41**	259.5
IS 5470	20.6	0.43**	160.4
IS 5566	21.4	0.51**	276.7
IS 5585	25.1	0.51**	385.9*
IS 22121	24.2	0.54**	431.5*
Breeding line			
SPV 491	20.7	0.53**	172.9
R 1207	24.9	0.70**	231.9
Local (control)	36.9	0.78*	499.6*
SE	±2.73	±0.11	

Source: AICSIP (1983).
* Significant at 5%; ** significant at 1%.
i = variety; j = environment.

death of the main shoot and main shoot survival depend on the level of primary resistance (Sharma et al. 1977). Recovery resistance does not operate under Indian conditions.

Some morphological factors, such as toughness of leaf sheath (Singh and Jotwani 1980d), presence of trichomes (Gibson and Maiti 1983), glossiness of leaves, presence of irregularly shaped silica bodies in the fourth to seventh leaves (Ponnaiya 1951), and lignification and thickness of cell walls enclosing *the* vascular bundles (Blum 1967) also contribute to resistance.

Information on the chemical basis of resistance is limited. Low nitrogen content, reducing sugars, total sugars, moisture, and chlorophyll content of leaf, and, especially, low lysine content of the leaf sheath are related to resistance (Singh and Jotwani 1980c).

Seedling height and plant recovery are characters negatively correlated with oviposition and percent deadhearts (Sharma et al. 1977). These relationships indicate that tall seedlings and high plant recovery are characteristics of resistant varieties. Tiller development consequent to deadhead formation in the main shoot and subsequent survival and recovery of the plant depend on the level of primary resistance. Varieties with better recovery resistance appear to yield more under moderate shoot fly infestation (Fig. 1).

Genetics of Resistance

The Ft hybrid shows an increase over the midparent value under low shoot fly infestation, but this relationship is reversed under high infestation. Resistance exhibits partial dominance under low infestation but appears to be partially recessive under high infestation (Rana et al. 1981; Borikar and Chopde 1980). Heterosis in S x S and R x R F_1 s for percent deadhearts was 1.9% and 3.9% respectively and therefore negligible. Heterosis in S x R F_1s however, was 17.2% (Sharma and Rana 1983). Inbreeding depression in the latter crosses was 6.7% and relatively higher than S x S and R x R groups. Parent versus F_1 and F_1 versus F_2 differences were nonsignificant for oviposition, indicating absence of heterosis as well as the presence of inbreeding depression for oviposition.

Parental performance is a good indicator of hybrid behavior (Sharma et al. 1977; Rao et al. 1978). Regression of F2 on F_1 was also significant for eggs per plant (b = 0.321**) and deadheart percent (b = 0.563**). Thus the resistant F_1 is expected to produce a resistant F2 (Fig. 2).

Shoot fly resistance in terms of deadheart percentage is a quantitative character, which is predominantly governed by additive genes in the F1 and F2 generations (Rao et al. 1974; Balakotaiah et al. 1975). Under heavy infestation, Sharma et al. (1977) reported 49.7% and 82.1% heritability for percent deadhearts in the F_1 and F_2 generations, respectively.

Borikar and Chopde (1980) evaluated a diallel under three different dates of planting to ensure various levels of infestation. In general, the proportion of additive:dominance variance increased with the increase in shoot fly infestation. Heritability in their studies was 48 to 86% for percent deadhearts and 77 to 93% for eggs per plant. Under selection, heritability of deadhearts in the F3 was about 25% (Rana et al. 1975).

Single plants of 16 F_2 progenies from crosses between susceptible x resistant parents were eval-

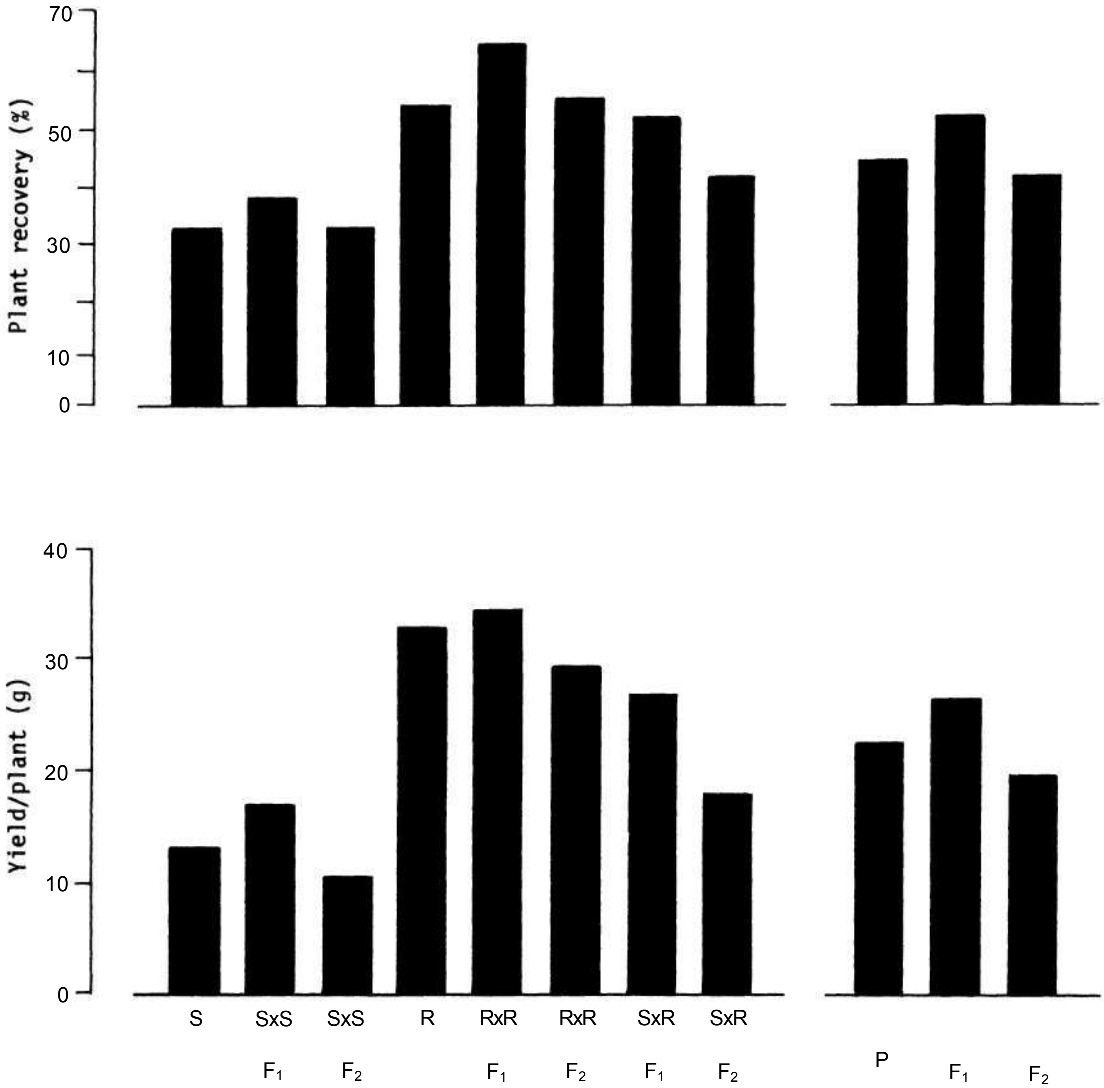
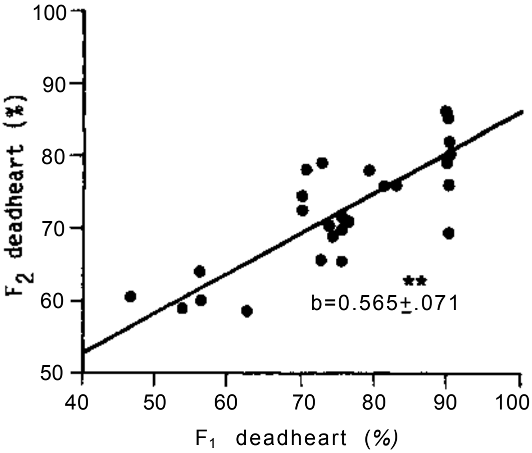


Figure 1. Recovery resistance to shoot fly and yield in different crosses between susceptible high-yielding (S) and resistant (R) sorghum varieties.



** Significant at 0.01% level of probability

Figure 2. Regression of F2 and F1 hybrids in sorghum for shoot fly deadhearts (%).

uated for oviposition and deadhead formation. F2 frequencies of resistant plants with and without eggs fit a 3:1, while deadhead resistant plants versus susceptibles fit a 15:1 Mendelian ratio (Table 2). These studies revealed that a single recessive gene governs nonpreference for oviposition and two duplicate recessive genes govern the resistance to deadhead formation (Rana and Sharma 1983). The double recessive genotype, npo npo is responsible for nonpreference for oviposition and the $dh_1\,dh_1\,dh_2\,dh_2$ double recessive genotype governs the resistance to deadhead formation.

The presence of trichomes on the abaxial surface of the leaf is controlled by a single recessive gene (Gibson and Maiti 1983) and appears to be a highly heritable ($h^2 = 0.9$) trait (Omari, unpublished). Glossy leaves, another character associated with resistance, are also governed by a single recessive gene (Tarumoto 1980).

Breeding for Resistance

Shoot fly resistance showed a systematic gradation in a series of crosses among susceptible (temperate), intermediate, and resistant varieties (Fig. 3). The F2 and F3 distributions conform to a normal distribution, immunity being absent (Balakotaiah et al. 1975). While F2 modalities enable identification of potential crosses, differences among resistant and susceptible progenies are established by the F3 generation. With such a situation, it is possible to select one standard deviation below the population mean in the F2 and F3 generations (Rana et al. 1975). The significant regression of the F1 on the parent (Rao et al. 1974) and the F3 on the F2 indicate that pedormance of selected progenies would be reflected in the next generation.

Although resistance in the F_1 and F_2 generations is highly additive, the heritability in F3 is reduced to 25%. Ten percent of the total F3 progenies tested for shoot fly resistance were selected under moderate fly pressure as less susceptible by considering only progenies with less than 20% deadhearts, which provides enough flexibility to operate selection within and between progenies. Selection in subsequent generations should be carried out under heavy shoot fly infestation. By adopting this selection procedure, it has been possible to develop agronomically desirable genotypes, such as CSV nos. 5,6, 7(R), and 8(R), and SPV nos. 102, 104, 107, 221, 292, 315, 491, 502, and 504, from temperate x tropical crosses with satisfactory levels of resistance.

Table 2. Genetics of shoot fly oviposition and deadheart formation in sorghum.

Class	F_2 frequency	Genetic ratio
(A) Oviposition		
No. of plants with egg laying	211	3
No. of plants without egg laying	87	1
$X^2 =$	2.79	(P 0.10-0.25)
(B) Deadheart formation		
Deadheart formation (Susceptible)	3076	15
No. deadheart formation (Resistant)	211	1
$X^2 =$	0.16	(P 0.50 -0.75)

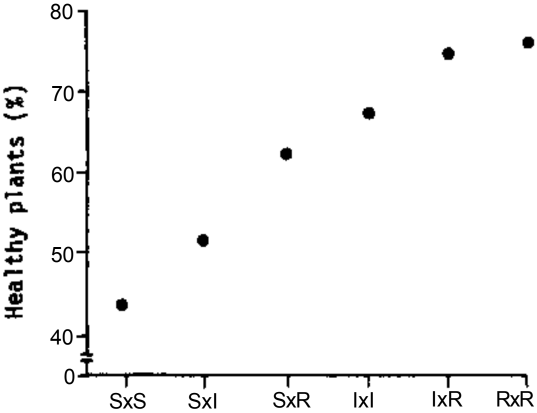


Figure 3. Shoot fly resistance (%) among resistant (R), intermediate (I), and susceptible (S) varietal crosses of sorghum.

Further selection in some high-yielding varieties was carried out under high infestation. Table 3 shows that the selected lines such as E 404, E 406, E 409, E 416, and E 426 possessed stable resistance to shoot fly (Prem Kishore and B.S. Rana 1984, Selection for shoot fly *[Atherigona soccata* Rond.] resistance in high-yielding varieties of sorghum, unpublished).

Selection for shoot fly resistance in segregating generations of temperate x tropical crosses has resulted in some highly resistant lines: E nos.103, 108, 109, 112, 115, 119, 124, 302, 303, and P 151. Some of the resistant breeding lines evolved at ICRISAT were also tested in AICSIP trials during the rainy season, 1982. Deadheads ranged from 23 to 39% against 58% in CSH 1. Five lines—PS nos. 14454, 18257, 18527-2, 18601-3, and 21113-showed less than 30% deadhearts. Agrawal and House (1982) reported 24 promising shoot fly resistant lines that showed only 27.7 to 60.0% deadheart formation at ICRISAT Center in Patancheru, against 100% deadheart formation in the susceptible control. The six most promising lines were: (IS 2816 C x 5D x Bulk)-2-2-1 - 1 , (UChV2 x IS 3962)-6-1-1-1, (ESGPC x IS 12573 Q-3-1-1-3, (ESGPC x IS 12573 C)-3-2-3-1, (IS 2816 C x 5D x Bulk)-2-1 - 1-1, and (SPV 29 x IS 3962)-1-2-1.

Stem Borer *(Chilo partellus* Swin.)

Sources and Stability of Resistance

The existence of resistance to stem borer in sorghum was reported by Trehan and Butani (1949) and Pant et al. (1961). Subsequently, Singh et al. (1968) screened 3953 germplasm lines from the world collection. Systematic screening was continued by Jotwani and his colleagues, who screened an additional 6243 germplasm lines. Twenty-four lines found consistently less damaged under repeated hatural and artificial infestation were: IS nos. 1044, 1056, 1155, 3096, 4424, 4552, 4651, 4689, 4707, 4764, 4776, 4782, 4827, 4841, 4875, 4934, 4994, 5030, 5031, 5470, 5837, 6041, 8314, and 9136. A further multilocation screening program enabled us to identify the following lines: IS nos. 2122, 2205, 4329, 4829, 4839, 4863, 4866, 5469, 5490, 6046, 6101, 6119, 10676, 10711, 10795, 12448, 17934, 18463, 18574, 18578, VZM 2B, BP 53, and DJ 6514.

Thirteen germplasm lines were tested over seven AICSIP locations during the rainy season, 1983; IS 5538, IS 18551, and IS 18584 were the most stable for resistance in terms of percent

Table 3. Shoot fly resistance in some sorghum selections over a 3-year period.

Selection No.	Origin	Deadheart (%) Year 1	Year 2	Year 3	Average
E 404	CSV 6	32.4	28.7	29.8	30.3
E 406	SPV 8	29.1	27.6	28.1	28.3
E 409	SPV 13	29.7	29.0	28.3	29.0
E416	SPV 29	31.1	28.5	29.4	29.7
E 426	SPV 70	32.5	32.8	30.7	32.0
Control	CSH 1	71.1	90.0	90.0	83.4
SE		±0.91	±0.89	±0.87	±2.97

Table 4. Stability parameters of some promising sorghum germplasm lines for stem borer resistance.

Entry	Deadheart (%)			Tunneling (%)		
	Mean	b	δij^2	Mean	b	δij^2
IS 5538	4.8	0.19**	6.44	6.4	-0.24*	0.68
IS 18551	4.1	0.17**	0.56	3.5	-0.11**	4.77
IS 18577	8.1	0.38**	18.90	4.0	-0.29*	6.78
IS 18578	5.9	0.26**	11.47	4.9	-0.50	4.65
IS 18584	3.7	0.13**	9.13	3.0	-0.07**	3.22
PB 8272	5.3	0.33**	1.01	2.7	0.37	2.81
PB 8313	4.3	0.15**	2.30	3.3	-0.01**	3.38
PS 21206	8.3	0.14**	11.48	2.3	-0.06**	3.62
Local	10.4	0.25**	36.75	4.0	0.17**	8.03
SE	±3.2	±0.12		±1.7	±0.33	

Source : AICSIP (1983), Unpublished data.
* Significant at 5%; ** significant at 1%.
i = variety ; j = environment.

deadhearts and percent stem tunneling (Table 4). IS 18577 and IS 18578 and some ICRISAT breeding lines, such as PB 8272, PB 8313, and PS 21206, were stable for resistance to stem tunneling (AICSIP 1983).

Resistance Parameters

Stem borer attacks both seedling and adult plants. Emerging larvae start feeding on leaf-whorls of seedlings and the leaf-feeding lesions appear after 20 days of crop growth. When stem borer infestation is heavy, feeding in the leaf-whorls results in deadheart formation. The second cycle of borers establishes on the adult plant by making holes in the stalk and peduncle. Thus, borer attack can be measured in terms of leaf-feeding injury; deadheart formation; and tunneling parameters such as number of holes, number of tunnels, and percent tunneling separately in stalk and peduncle.

Relationship among Resistance Parameters

Leaf-feeding injury rating, deadhearts, and tunneling percentages are not correlated and are inherited independently (Singh et al. 1983). However, tunneling parameters per plant are significantly correlated among themselves (Table 5). Number of

Table 5. Correlation between stalk and peduncle resistance parameters (DF= 151).

Parameter	Correlation coefficient					
	1	2	3	4	5	6
Stalk						
1. No. of holes	1.00	0.66**	0.64**	0.19	0.07	0.06
2. No. of tunnels		1.00	0.64**	-0.01	0.03	-0.13
3. Tunneling (%)			1.00	0.08	-0.05	-0.04
Peduncle						
4. No. of holes				1.00	0.29**	0.32**
5. No. of tunnels					1.00	0.55**
6. Tunneling (%)						1.00

** Significant at 1%

holes, tunnels, and percent tunneling per plant, therefore, depend on one another. When these parameters were measured in stalk and peduncle separately, they were positively and significantly correlated. Stalk parameters were not significantly correlated with peduncle parameters, indicating possible independence of stem borer resistance in stalk and peduncle.

Correlation among Growth Parameters of Borer

Oviposition, larval duration, larval mortality, and pupal weights were studied separately on leaf-whorls and stalks of 70 sorghum varieties (Singh and Rana 1984). Number of eggs per plant was negatively correlated with larval duration and mortality and positively with pupal weights on leaf-whorl tissue. Thus, preference for oviposition is related to shorter larval duration, low larval mortality, and increase in pupal weights. In other words, these relationships indicate that nonpreference and antibiosis in the leaf are related characters. Longer larval duration associated with high larval mortality and low pupal weight was observed when the larvae fed on either the leaf-whorl or the stem tissue. The growth parameters of the borer on the leaf-whorl were not significantly related to corresponding or other parameters on the stem. Hence, the factors affecting borer biology in the leaf-whorl are different from those in the stalk.

Correlation between Oviposition, Larval Development, and Field Resistance Parameters

Oviposition and larval development in relation to field resistance under artificial infestation were simultaneously studied on released hybrids and varieties, experimental varieties, and two resistant controls (Singh and Rana 1984). The leaf-feeding injury rating was not related to oviposition or larval development parameters either in the leaf-whorl or on the stalk. The varieties preferred for oviposition showed higher deadheart and tunneling percentages. Low deadheart formation was significantly related to prolonged larval duration, higher larval mortality, and lower pupal weights on the leaf-whorl but not when larvae were raised on the stalk (Table 6). Tunneling percentage per plant showed a similar relationship to larval development parameters when larvae were fed only on stalk tissue. Antibiosis present in leaves thus hinders deadheart formation, while in the stalk it affects the larval growth and reduces tunneling percentage.

Mechanisms of Resistance

An experiment with one susceptible (Swarna) and one resistant (P 37) variety was laid out to study the mechanisms of resistance (Table 7). On both sides of these test varieties, three rows of another susceptible (CS 3541) variety were planted in a first,

Table 6. Correlation between stem borer biology and field resistance parameters of 70 sorghum varieties.

Parameter	Leaf-feeding injury	Deadheart (%)	No. of holes	Tunneling (%)	Grain yield
No. of eggs/plant	0.10	0.92**	0.32**	0.24*	-0.21
Leaf-whorl					
Larval duration	-0.01	-0.81**	-0.21	-0.27*	0.11
Larval mortality	-0.12	-0.06	0.40**	-0.81**	0.01
Pupal weight	-0.05	-0.69**	-0.20	0.18	-0.08
Stem					
Larval duration	0.09	0.21	0.50**	-0.83**	0.02
Larval mortality	0.02	0.64**	0.11	0.12	0.05
Pupal weight	0.01	0.17	0.06	0.50**	-0.07

* Significant at 5%; ** significant at 1 %.

Table 7. Relative stem borer resistance in resistant (R) vs. susceptible (S) sorghum varieties, under artificial infestation (1).

Experimental design				Tunneling (%)		
Border variety	Test variety	Border variety	Pupae/ plant	Stalk	Peduncle	Grain yield (g/plant)
S	S	S	2.4	16.2	13.9	35
S	S_1	R	3.1	13.5	11.8	39
R	s_1	R	3.3	13.8	12.6	31
S	R	S	0.1	7.9	7.0	33
S	R	R	0.1	7.4	6.7	31
R	R	R	0.0	6.9	6.9	31
SE			±0.16	±0.73	±0.75	±2.3

and three rows of a resistant (E 302) variety in a second, set of plots. In a third set, one side of the three test rows was planted with a resistant variety and the other side with a susceptible variety. The test varieties were infested with freshly emerged larvae at the leaf-whorl and boot-leaf stages of plant growth. The susceptible test variety when compared with the resistant one, showed a clear trend in having more pupae per plant and a higher percentage of tunneling.

Field-resistant sorghum varieties, when tested in the laboratory, were nonpreferred by the stem borer for oviposition and also slowed down larval development compared with the susceptible varieties (Singh and Rana 1984). Hence, both nonpreference and antibiosis mechanisms act together to determine the degree of resistance. The varieties that induced the most larval mortality on both the leaf-whorl and the stem were: CSV 8(R) and SPV 35; on the leaf-whorl alone: E 302, CSV 3, CSV 6, and SPV nos. 101, 292, 305, and 311; on the stem alone: SPV 103, SPV 104, P 37, P 151, R 133, IS 2312, and Aispuri. Thus genotypes exist with leaf-feeding and stem-feeding resistance expressed independently but the coexistence of both resistance characters in one genotype is also possible.

Deadhead formation was possibly reduced in those varieties where larval duration and mortality on the leaf-whorl was high (Fig. 4). The number of holes, number of tunnels, and tunneling percentages were negatively and significantly correlated with larval duration and mortality on the stem (Fig. 5). Thus, factors present in the stem that influence larval development also affect the tunneling parameters. The varieties relatively more resistant in the field were found to adversely influence larval development on both the leaf-whorl and stem. The magnitude of correlations of larval duration and mortality with tunneling parameters was higher than that of number of eggs per plant; i.e., oviposition (Table 6). Thus, the influence of antibiosis on field resistance is much greater than that of ovipositional nonpreference.

Earlier, Kalode and Pant (1967) and Jotwani et al. (1978) had provided evidence of antibiosis. Girdharilal and Pant (1980) also observed low larval survival on resistant sorghum varieties and expected it to be due to the presence of antibiosis factors.

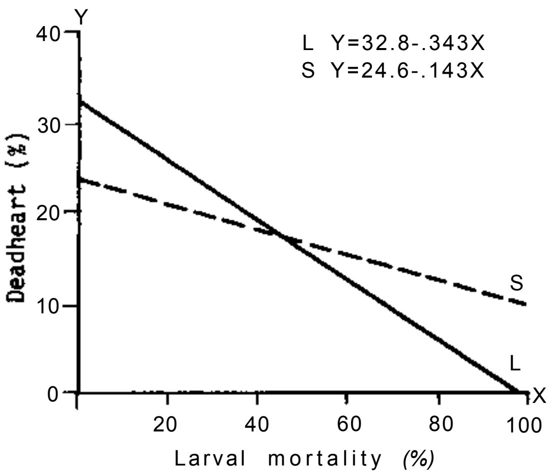


Figure 4. Relationship between deadhearts (%) and larval mortality of stem borer feeding in the leaf whorl (L) and on the stem (S) of sorghum.

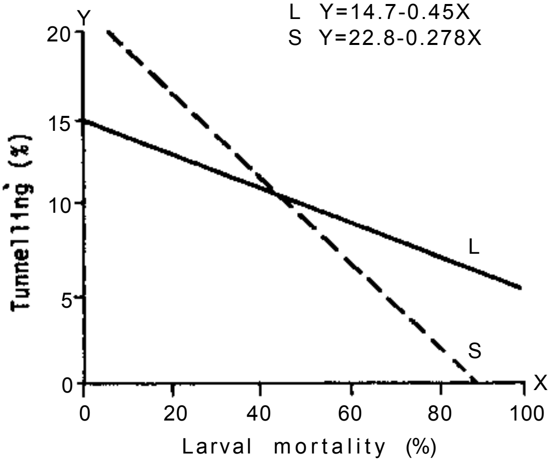


Figure 5. Relationship between stem tunneling (%) and larval mortality of stem borer feeding in the leaf whorl (L) and on the stem (S) of sorghum.

Genetics of Resistance

Rana and Murty (1971) had reported the quantitative nature of resistance. Male-sterile lines were not significantly different for secondary damage but male parents provided significant variability. These authors found that general combining ability was predominant for primary damage (leaf injury), while specific combining ability was 1.5 times more for secondary damage (percent tunneling).

Seventeen parental varieties and the 136 possible F_1 hybrids among them were evaluated under artificial infestation. Compared with midparental values, the F_1 hybrids were more susceptible for number of holes per stalk and tunneling percent per stalk and peduncle (Rana et al. 1984). Heterosis for these parameters was 94.5, 22.8, and 15.8%, respectively (Table 8). This reveals almost complete dominance of susceptibility for number of holes per stalk and partial dominance for the other characters.

Table 8. Heterosis for resistance parameters in 17 x 17 diallel crosses in sorghum

Parameter	Heterosis (%)
No. of holes/stalk	94.5
No. of holes/peduncle	6.3
No. of tunnels/stalk	16.4
Tunneling (%)/stalk	22.8
Tunneling (%)/peduncle	15.8

Combining ability analysis in a 17 x 17 diallel involving high yielding and resistant varieties was carried out by Rana et al. (1984). They reported σ^2 gca almost half σ^2 sca for number of holes per stalk and per peduncle and equal for number of tunnels per peduncle. Heritability was 44% for number of holes per peduncle and fairly low (10-15%) for tunneling parameters both in the stalk and peduncle.

Subsequent studies of a subset of this diallel (7 x 7) in the F_1, F_2, and F_3 generations indicated that heritability increased 14 to 34% for number of holes, and remained constant (20 to 21 %) for percent tunneling (Table 9). Heritability of resistance, especially in terms of percent tunneling per plant, was therefore fairly low.

Breeding for Resistance

Response to directional selection as well as correlated response in tolerant x resistant varietal crosses revealed that directional selection for

Table 9. Estimates of additive (σA^2) and nonadditive (σD^2) genetic variance for stem borer resistance in sorghum.

Estimate	No. of holes			Tunneling (%)		
	F_1	F_2	F_3	F_1	F_2	F_3
σA^2	0.38	1.3	5.2	5.3	0.32	9.9
σD^2	1.20	6.0	6.2	13.5	1.20	29.0
$\sqrt{\sigma A^2/\sigma D^2}$	1.78	2.2	1.1	1.6	1.94	1.7
Heritability (%)	14	17	34	21	21	20

number of holes was 0.369 and for percent tunneling in the stalk, 0.495 (Rana et al. 1984). Direct response for number of tunnels was very poor. Correlated response for percent tunneling due to number *oi* holes was very high. Thus, selection based on few holes would be helpful in selection for tunneling resistance in the stalk.

Selection based on low leaf-feeding injury rating and stem tunneling was practiced in the F_3 to F_6 generations of six crosses originally selected for agronomic traits and shoot fly resistance in the F2 generation (Kishore et al. 1984). A selected bulk of each cross was advanced. The progenies of CSV 5 x IS 4664, and R 147 x IS 4664 responded to selection (Fig. 6).

Singh et al. (1980) made selections in 17 advanced-generation derivatives of two temperate x tropical crosses, IS 2954 x BP 53 and IS 3922 x Aispuri. In spite of low heritability of resistance, it was possible to develop the resistant derivatives D 168, D 172, D 259, D 358, D 367, and D 369. By continuous selection in segregating generations of other temperate x tropical crosses, 12 varieties—SPV nos. 35, 103, 107, 110, 135, 140, 192, and 229, and E 302, E 304, P 37, and R 133—were developed, which were at par with resistant varieties for percent tunneling per plant (Singh et al. 1983).

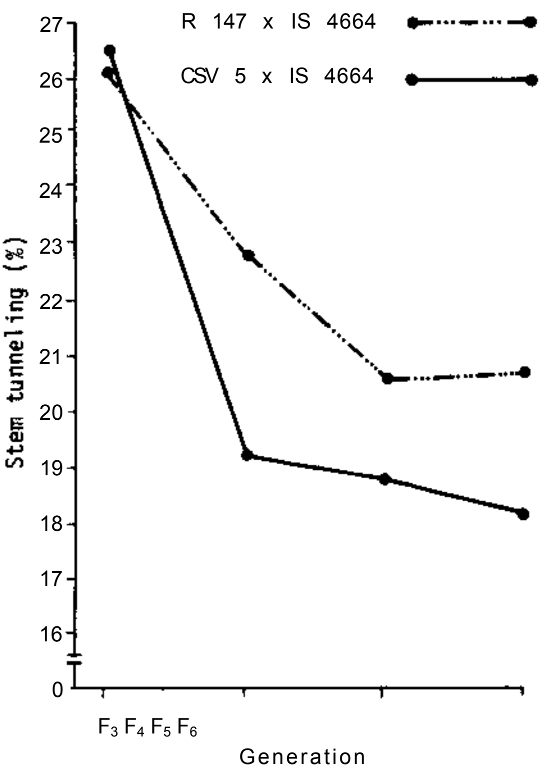


Figure 6. Effect of selection on stem tunneling (%) in two sorghum crosses.

Breeding for Multiple Resistance to Shoot Fly and Stem Borer

Resistance to more than one pest can gradually be built up in the high-yielding background by using suitable parents, mating system, screening technique, and selection procedure. Tropical germplasm, particularly from India, furnishes the source of resistance to sorghum shoot pests. Generally, local cultivars resistant to shoot fly also show some degree of tolerance to stem borer. Some of these stocks, such as IS nos. 5538, 5566, 19551, 18577, 18578, and 18584, have been reported (AICSIP 1983). These sources are in no way immune to either pest. Ovipositional nonpreference and antibiosis are common resistance mechanisms but the factors controlling resistance are different for shoot fly and stem borer.

Derivatives of temperate x tropical crosses which combine a high degree of tolerance to both the pests in a desirable agronomic background furnish good parents for crossing (Rana et al. 1981). A selective mating system involving derivatives, resistant germplasm, and other varieties for diversity of alleles has been shown to be useful (Seshagiri Rao 1979). Testing the F3 segregating material in locations where the pests are endemic and rotating the selected progenies in those locations can enable selection for multiple resistance.

In the absence of absolute resistance, an approach outlined by Rana et al. (1975) for breeding shoot fly resistance can be adopted for other pests also. When selection for yield and resistance is simultaneously done, the genetic advance for resistance is fairly slow (Rana et al. 1981). A moderate degree of resistance could be combined in improved varieties with satisfactory yield levels (Table 10). Due to the high heritability of shoot fly resistance, it is possible to recover a high degree of resistance under high selection pressure, but this is not necessarily possible for stem borer resistance. Thus combining multiple insect resistance in a good agronomic background appears to be a slow process and requires several cycles of crossing.

Table 10. Shoot fly and stem borer resistance of some recently bred high-yielding varieties of sorghum. (No. of locations = 9).

Variety	Yield (kg/ha)	Av.% shoot fly deadhearts		Stem borer damage	
		Normal sowing[1]	Late sowing[1]	Leaf injury rating[2]	Stem tunnelina (%)
SPV 96	2530	8.6	45.9	1.8	10.4
SPV 97	2610	6.9	45.1	2.5	13.1
SPV 102	3020	10.2	40.9	1.7	11.3
SPV 104	3390	7.5	40.8	1.4	9.4
SPV 105	2730	8.2	55.7	1.3	10.7
SPV 106	2780	12.8	48.7	1.8	12.8
SPV 107	2470	4.9	42.3	1.7	11.5
SPV 108	2890	8.1	46.5	1.2	9.7
SPV 221	2900	5.5	40.0	2.0	12.9
SPV 225	2750	10.4	50.2	2.7	11.6
SPV 247	2470	6.3	42.0	1.8	9.2
Resistant control					
IS 5-90	1200	2.8	28.7	1.7	18.1
E 302	2000	7.2	41.3	1.6	15.9
Susceptible control					
CSH 1	2730	33.8	67.3	3.3	25.6
SE	±1.37	±1.98	±2.36	±0.05	±1.17

1. Normal sowing is done at onset of monsoon; late sowing, 15 days later.
2. Rating : 1 = resistant; 5 = susceptible.

Future Research Needs

Additional information on the biology, bionomics, economic injury levels, and reliable screening techniques, particularly for stem borer, is essential to effective work on host-plant resistance. Some of the stable sources of resistance to shoot fly and borer have been identified but these are in no way immune to the pests. A search for durable multiple resistance donors in better agronomic and disease resistance backgrounds should be continued.

Major genes governing resistance should be identified to enable easy transference and accumulation of resistance to more than one pest. With the biotechnological knowledge now available, the feasibility of transferring resistance to insect pests from wild genera to cultivated forms has also increased. A moderate level of multiple resistance to shoot pests in high-yielding backgrounds has been achieved. Efforts to transfer a high degree of resistance against both shoot and earhead pests in a suitable agronomic background will continue.

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Sorghum Production in Relation to Cropping Systems

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Abstract

*Efforts to enhance agricultural production and productivity involve changes in the components of agricultural systems. Genotype and management changes leading towards higher levels of crop productivity and stability in turn enable design and development of stable and profitable cropping systems. During the period of transition, the genotype and system changes may present different insect and disease problems that need to be tackled by cultural methods and other means. Since the temperate * tropical crosses are being used both in the tropics and in temperate regions, resistance to a range of pests could be incorporated during the breeding process. The Indian experience in developing new hybrids and their influence on cropping systems is described. In the light of the West African experience, the scope for alteration of traditional African cultivars and cropping systems to enhance production and impart stability to African dryland agriculture in the different rainfall zones is presented.*

Resume

***La production de sorgho dans le cadre des systemes d'exploitation agricole**: L 'augmentation de la production et de la productivite en agriculture suppose un changement des differents composants des systemes agricoles. La modification des genotypes et de l'amenagement cultural augmente la productivite et la stabilite des recoltes, ce qui permet d'etudier et d'elaborer des systemes d'exploitation stables et rentables. Cependant, ces changements peuvent entrainer, pendant la periode de transition, des problemes de ravageurs et de maladies qu'il faudrait surmonter par les pratiques culturales ou par d'autres moyens. Etant donne que les croisements de types temperes x tropicaux sont mis en culture a la fois dans les zones tempere'es et tropicales, on peut envisager d'incorporer la resistance a de nombreux insectes nuisibles au cours de la selection. Cette communication presente l'experience faite en Inde dans la creation de nouveaux hybrides et leur influence sur les systemes d'exploitation. L'auteur decrit egalement les possibilities de modification des cultivars traditionnels africains et des systemes d'exploitation en vue d'une production superieure et stable dans le cadre de l'aridoculture des differentes zones pluviome'triques en Afrique de l'Ouest.*

Traditional tropical agricultural systems generally contain a large number of species planted in space and time. Such systems have a structure close to natural ecosystems. In our quest to enhance agricultural production and productivity to meet the demand of growing populations, we have brought about changes in the components of the agricultural systems leading towards changes in land-use patterns. Such changes, involving drastic alterations in genotypes and management practices led to the introduction of specialized farming systems with optimal resource use and productivity, which are evident in developed agriculture. The shift from natural to specialized agricultural systems does disturb the ecological balance and creates problems in regard to insect pests and diseases which need to be tackled, particularly, during the period of transition from subsistence to productive systems. I shall attempt to analyze some of these aspects in relation to sorghum-based cropping systems.

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The Indian Experience

The Indian experience of transforming traditional sorghums to more productive forms has been critically analyzed and documented (Rao 1982) and I do not propose to restate this. But I would like to state that the new hybrids, which are of much shorter duration than the traditional sorghums, have had a significant impact on the overall sorghum production in India. In spite of the fact that the hybrid coverage has been confined to the rainy season in some districts, primarily in the states of Maharashtra and Karnataka, even this limited spread had an overall impact on sorghum production as shown in Table 1. The impression that the "green revolution" is confined only to irrigated crops such as wheat and rice is erroneous, and sorghum is an example that shows it could encompass rainfed areas as well.

The change began with the introduction in 1965-66 of an early-maturing (95-100 days) hybrid CSH 1 in the black soil areas of the Deccan, where the traditional sorghums cultivated were of 5 to 5.5 months' duration. CSH 1 is known to be susceptible to shoot fly, stem borer, leaf spots, grain molds, and *Striga,* and is currently being used as a control in most insect- and disease-resistance studies. Although, superior hybrids such as CSH 5, CSH 6, and CSH 9, with slightly better resistance and better grain quality have been developed and propagated, CSH 1 is still being cultivated on a large scale and has stood the test of time. The significant point is that hybrids like CSH 1, CSH 5, CSH 6, and CSH 9 represent altered and optimal plant types whose critical growth phases coincide with periods of optimal soil moisture and yield well in years of normal, subnormal, excessive, and aberrant rainfall. This conferred considerable stability on rainfed sorghum production. By adopting suitable management practices like timely planting, the insect pest problems have been well contained. Using these altered genotypes as the basis, both hybrid and varietal improvement programs are presently oriented towards incorporation of greater levels of resistance against the prevalent insect pests and diseases to further enhance the level of stability.

Table 1. All-India compound growth rates (%) of area under cereal crops, agricultural production, and yield during 1967/68 to 1978/79.

	Compound growth rate, 1967/68-1978/79		
Crop	Total area	Total production	Yield (kg/ha)
Sorghum	1.49	2.07	3.62
Wheat	3.16	6.02	2.76
Rice	0.82	2.64	1.80
Pearl Millet	-1.26	0.28	1.53
Maize	0.05	-0.04	-0.07

Initially, high-yielding hybrids were grown as sole crops in place of traditional intercropping and an impression was created that they may not be suitable for intercropping (Jodha 1980). It was demonstrated (Rao and Rana 1980) that sole-crop production and stability are essential for developing suitable intercropping systems. Studies carried out by Rao et al. (1981) on inter- and intra-species competition, spatial arrangements, and interactions demonstrated the design and development of productive and stable intercropping systems that are different from the traditional subsistence intercropping systems.

A large number of intercropping experiments were conducted in India under the All India Coordinated Sorghum Improvement Project (AICSIP), the All India Coordinated Project for Research on Dryland Agriculture (AICPRDA), and ICRISAT, and a wealth of information is now available (Table 2). The significant point is that all these later studies were based on altered cultivars of sorghum. If the studies had been carried out with traditional cultivars, the results would have been different. Intercropping of sorghum with grain legumes and edible oilseeds is now an established practice, and the Government of Maharashtra consciously promotes intercropping of hybrid sorghums.

The short-season hybrids, besides increasing stability of production under low and erratic rainfall conditions, opened up opportunities for two crops per rainy season in better rainfall areas. Growing a following crop of safflower, chickpea, linseed, etc., under rainfed conditions is now feasible after *kharif* (rainy-season) grown hybrid sorghum. The sequence crop yields have been about 300 to 600 kg/ha.

In the *rabi* (postrainy-season) sorghum areas, the kharif fallows are now planted to short-season mung bean or urd bean, and soybean is a potential crop for this purpose. Where such a practice was followed in Marathwada, the grain legume production increased from 227 900 metric tons (tonnes) to 330600 tonnes. A portion of this increase is from

Table 2 . Yields in sorghum-based intercropping systems, averaged over several experiments.

	Average yield (kg/ha)			
Intercropping system	Sorghum as sole crop	Sorghum in inter-cropping system	Intercrop component as sole crop	Intercrop component in inter-cropping system
Sorghum/pigeonpea	3580 ± 190	3240 ± 140	1650 ± 90	940 ± 40
Sorghum/soybean	3300 ± 190	3220 ± 180	1390 ± 70	550 ± 40
Sorghum/groundnut	3360 ± 270	3310 ± 180	1040 ± 140	480 ± 50

the legume preceding rabi sorghum, where legume yields range from 400 to 600 kg/ha.

The potential for ratooning of sorghums and management of ratoons has been studied, and in Jalgaon district of Maharashtra, vast areas of hybrid sorghums are ratooned even under rainfed conditions. The potential is even greater under irrigation.

Under irrigation, both in the Deccan and Malwa plateaus, a rainfed hybrid sorghum followed by irrigated wheat is one of the most productive systems in terms of water-use efficiency and productivity (Table 3).

Cropping systems in sorghum are now taking a different direction. There is a limit to the consumption of coarse grains like sorghum. There are also limits to interstate grain movement, and Maharashtra now being self-sufficient in sorghum, the question of demand and supply and fall in prices tends to limit sorghum production. It is therefore necessary to explore alternative uses for sorghum and one of these would be to utilize sorghum land for grain legumes and edible oilseeds, which are in short supply in India. Consequently, the potential of sorghum-based cropping systems to meet the shortages of grain legumes and edible oilseeds has been examined and demonstrated (Rao and Rana 1980).

The intercropping studies in the sorghum project are now taking a different direction. Earlier we maintained the full population recommended for a sole crop of sorghum in the intercropping system to maintain sorghum yields at the sole-crop level, and the intercrop yield was a bonus. In view of the demand-supply position for sorghum and the need for pulses and oilseeds, we are now trying to reduce the sorghum component and increase the intercrop pulse or oilseed component to enhance the profitability of the system and to meet national needs. Sorghum is still the most productive crop during the rainy season in the black soil belt under rainfed conditions. It is therefore necessary to redesign cropping systems around sorghum.

The West African Situation

Most African farms are small and the prevalent mixed-cropping systems are essentially replacement systems in time and space and are aimed mainly at meeting the farmer's family needs. The

Table 3 . Comparative yields of some crop sequences under irrigation in national demonstrations in the Marathwada region, Maharashtra, India.

		Total yield (kg/ha)		
Crop sequence	No. of demonstrations	Mean	Highest	Lowest
Sorghum-wheat	95	7941	9543	5615
Rice-wheat	30	6952	8031	5971
Groundnut-wheat	12	5341	5252	4902

risk is distributed over time, space, and species. The agricultural systems have experienced little change—the traditional sorghum cultivars are low yieiders, tall, and late compared with the duration of the rainy season; plant populations are low; and fertilizer is hardly used. By developing alternative agricultural systems, the components of the cropping systems could be readjusted in such a way that the systems become more stable, productive, and profitable. I shall examine this in the light of my West African experience.

Environmental Resources—Rainfall and Crop-growing Season

The potential crop-growing season in various parts of West Africa varies from 70 to 260 days. The annual rainfall in the sorghum-growing regions ranges from 500 to over 1500 mm. Figure 1 shows the rainfall distribution in the 500 to 700 mm, 700 to 1000 mm, and 1000 to 1300 mm zones and the potential evapotranspiration. Except for the amount of precipitation, the pattern is unimodal and remarkably similar, with the exception of two peak situations in the Guinea savanna.

While crop productivity and stability of a simultaneously planted intercropping system should be the major objective in low-rainfall areas, the longer growing season in higher rainfall areas provides greater opportunities for sequence cropping. With appropriate genotypes and management, there is no reason why higher yields comparable to those obtained elsewhere in the world could not be obtained in West Africa.

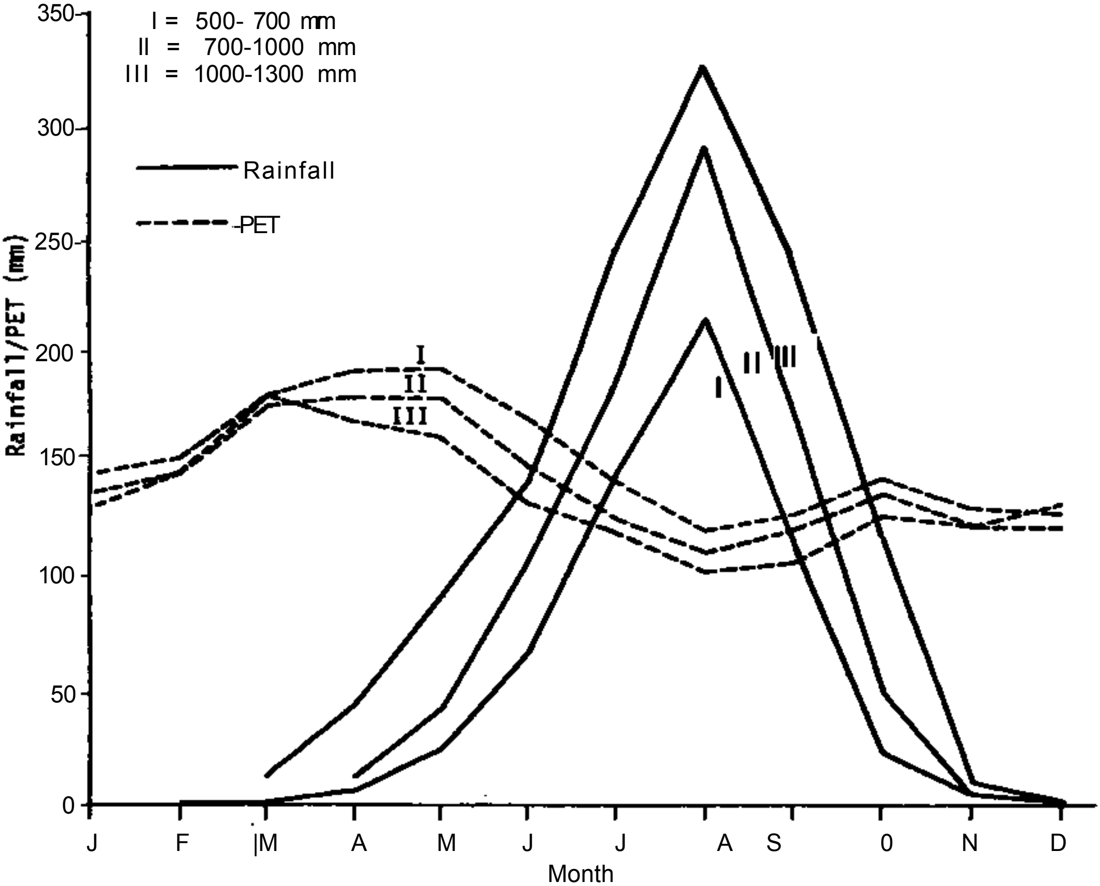

Figure 1. Rainfall distribution and potential evapotranspiration (PET) in three rainfall zones of West Africa.

Sole-crop Productivity and Stability

Breeding efforts in the region have attempted the introduction of short-duration types including hybrids with a duration of 3 to 4 months. In addition, selections were made from crosses between traditional and dwarf cultivars leading to photosensitive high-yielding dwarf varieties with durations similar to local varieties (Andrews 1975).

Some success with respect to yield levels was obtained with short-season varieties, but probably ecological limitations did not favor their spread. The situation on farmers' fields has not changed, and current efforts of most programs are aimed towards breeding improved varieties similar to locals in maturity in the respective agroclimatic zones.

Goldsworthy (1970a) had shown that dry-weight gain after heading in the tall late-maturing Nigerian Farafara took place in the stem. On the other hand, in an early-maturing hybrid, NK 300, over 70% of the dry matter formed after heading was stored in the grain. Comparative yield levels of early-planted Farafara and late-planted NK 300 were 2160 and 4690 kg/ha, respectively. A similar situation existed with Indian cultivars and hybrids (Rao 1982). Goldsworthy (1970b) further demonstrated that, unlike hybrids, the Nigerian locals do not respond to increasing population levels. The situation is similar with Indian local varieties. Yet, unlike the situation in India, the advantages of short-season hybrids have not been utilized in Africa until now.

Genotypic alterations of traditional tropical sorghums are a prerequisite for sole-crop performance as well as cropping system performance. Such modifications do furnish greater resilience to system alterations, and I studied this aspect in West Africa during 1981-83.

Cultivar Alteration for Changing Cropping Systems

Prevalent intercropping systems like the *gicci* system of Nigeria, based on traditional cultivars, are largely of the relay type. The number of components that enter into the system and their populations vary. There is continuous interplanting, sometimes starting early in May and continuing to August. The features and advantages of these systems have been listed by Okigbo (1978), and modifications for improvement have been suggested by Baker (1979).

What is particularly striking is that the prevailing soil and rainfall conditions do permit continuous relay planting. Modifications and readjustments of the components of the system could enable us to develop an alternative that makes the most efficient use of available environmental resources. I will attempt to elaborate on this, based on my brief experience in Nigeria under the ICRISAT-SAFGRAD project.

Alternative production systems for sole and mixed crops based on altered cultivars, if conceived and implemented properly, could result in much-needed improvements in productivity and stability. Suitable short-season cultivars with built-in resistances and flexibility for planting across a range of environments and planting dates could be useful in the drier areas of the north, the moderately heavy rainfall north Guinean zone, and as a late-sown crop in the long-season heavy-rainfall south Guinean zone.

Superior short-season cultivars are known for their better harvest index and better response to increased populations and fertility levels. They are also less competitive and more suitable for the development of stable and productive cropping systems in place of the traditional ones. Such cultivars could be of immediate use and also provide the basis for future improvement.

In other words, the need is for an alternative base with wide adaptation as has been developed with wheat and rice on a global basis and with sorghum on a limited scale. The use of short-season sorghums in place of 6- to 8-month cultivars could lead towards better resource utilization of time, space, and inputs.

To meet this goal, a large number of improved tropical sorghum genotypes (available from ICRISAT, AICSIP, Ethiopia, Sudan, Mali, Burkina Faso, etc.) were screened for insect and disease reactions and adaptation across West Africa. Although a number of breeding lines had to be eliminated, 1982 data from Maroua in Cameroon (dry zone), Samaru (moderately wet), and Mokwa (heavy rainfall, long season), supplemented by visual observations at Kano, Kadawa, and Yandev, lead to useful conclusions. The practice of testing across latitudes and planting dates without plant protection measures ensures, to a reasonable extent, the selection of high-yielding and resistant cultivars which can then be used in a breeding program. Some of the problems encountered during such a process are described.

Seedling Deadheads

Both stem borers and shoot flies cause seedling deadhearts. During normal season plantings, deadheads result primarily from stem borers *(Busseola fusca* mainly), with shoot flies occasionally attacking late plantings. In off-season plantings, *Sesamia* sp predominates and can cause heavy stand loss.

Studies during 1981 at Kano and Samaru revealed significant varietal differences related to seedling deadhearts, mainly from stem borers. Increasing applied nitrogen increased deadhead percentages, which were high under low populations at both Kano and Samaru. Both nitrogen x cultivar and population x cultivar studies indicated that borers prefer vigorous plants but shoot flies prefer weak ones. The interactions indicated scope for selecting vigorous seedlings that resist stem borer attack.

Forty days after planting sorghum in 1982, seedling deadhearts (primarily from stem borer) were studied at Samaru, Kadawa, Mokwa, and Yandev. At Samaru, deadhead percentages in a late-July planting under serious shoot fly attack were also recorded. All the trials were replicated. The varietal differences resulting from 48 entries were statistically significant. Entries that showed lowest deadheart percentages were S36, S40, and S2. We have analyzed shoot fly resistance from five environments. The most stable varieties were S 40, S 36, S35, and S2. The stability for seedling deadheads is reflected in Figure 2.

Stem Tunneling

During 1981, stem borer tunneling was heavier than in 1982. Our studies indicated that stem tunneling did not result in heavy yield loss but stem

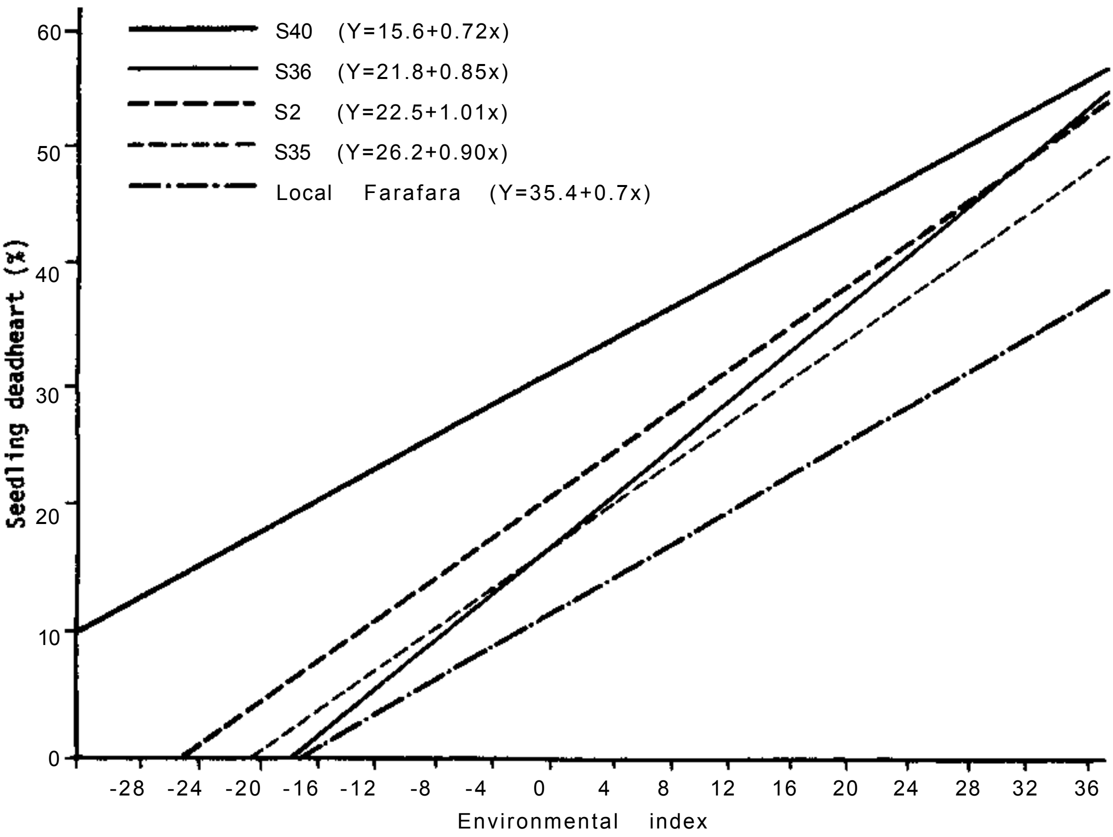

Figure 2. Stability of shoot-fly resistance in five sorghum entries as reflected by seedling dead head (%).

breakage due to heavy tunneling did. Therefore, we shook the plants vigorously at harvest time and estimated percentages of plants that did not break. We identified entries that did not break easily. Apparently, selected entries have reasonable tolerance. During the off-season plantings, screening for *Sesamia* species resistance was possible and a number of highly susceptible lines could be eliminated.

Disease Resistance

During 1981, lines highly tolerant to grey leaf spot *(Cercospora sorghi),* anthracnose *(Colletotrichum graminicola)* and sooty stripe *(Ramulispora sorghi)* were identified. Leaf disease incidence was lower in 1982 than 1981, but the resistance pattern remained the same as in 1981. Late October rains in 1982 caused molds; we used these for mold resistance screening. Eighteen entries with better agronomic traits and less mold incidence were selected.

By screening breeding material in dry and wet locations under various planting dates, it was possible to identify lines less affected by potential pests and diseases but the results have to be confirmed.

Selection of Tropical Cultivars

Fifty lines were selected during the 1981/82 rainy season and off-season and replanted for further yield evaluation in 1982 at Kano and Maroua in Cameroon (dry zones), Samaru (moderately wet north Guinean zone), and Mokwa and Yandev (long-season south Guinean zone).

The trials clearly separated high-yielding from low-yielding lines. We also recorded their reactions to insects and diseases under a range of planting dates. The plant density was kept at 50 000 to 55 000 plants/ha, the optimum recommended for local Farafara. Plant populations of short and early-maturing varieties could go up to 150 000/ha.

Lines S 40, S 35, S 36, S 19/20, and K 4 were promising under August plantings and a range of planting dates. They were less attacked by the prevalent insect pests and diseases, and showed less grain deterioration.

In spite of low rainfall, S 34 at Samaru in the Guinean zone and S 35 at Kano and Maroua in the Sudanian zone gave reasonable yields. During adaptational studies, lines like S 34, S 35, S 36 and K 4 were identified, which are high-yielding and could be used in cropping system studies over a range of West African latitudes.

S.V.R. Shetty used some of these selections together with locals in population and fertility interaction studies to develop more productive cropping systems. His first studies during 1983 were encouraging.

Insect Problems in Relation to Genotype and Cropping System Changes

I have stated before that for tropical agricultural systems to become more productive and stable, radical genotypic changes are a must (Rao 1982). For various reasons, both in temperate and tropical regions, the temperate x tropical crosses have been exploited through the conversion approach in the USA and more conventional approaches in India. Thus the breeding materials handled in both cases have been similar if not the same. The utility and consequences of temperate x tropical crosses have been critically analyzed (Rao and Rana 1982).

With particular reference to the major insect problems, shoot fly and stem borers may be more serious in the tropics and therefore temperate, less adapted sorghums may be more susceptible in this region of the world. Midge is common both in the tropics and in temperate regions.

The levels of resistance available for shoot fly and stem borers are not very high. Fortunately, the incidence of shoot fly and stem borer in the tropics can be managed to a considerable extent through cultural practices and this is a positive feature. The temperate x tropical crosses could be used for breeding optimum plant types, provided the high susceptibility of the temperate genetic backgrounds to shoot fly and stem borer is reduced. If this can be done, the resulting altered cultivars will have great potential as sole crops and in cropping systems. The Indian program is presently trying to follow this approach.

When changes in genotypes and cropping systems in a country occur, the pest complex and the relative importance of individual pests may also change. Even new pests not known so far and new biotypes may show up. A good example is the midge fly, which gained economic importance only after the introduction of new high-yielding hybrids. Late local cultivars suffered especially because of the early generation buildup of midge flies on short-duration hybrids not resistant to this pest.

Since the temperate x tropical crosses are presently being exploited in the USA and the tropics, it should be possible to evolve a mechanism through which resistances to both temperate and tropical insect and disease problems could be synthesized in common cultivars, which in the long run should lead towards the goal of multiple and durable resistance.

Analysis and Conclusions

If the productivity of traditional tropical sorghums is to be enhanced and stabilized, major genotypic alterations are necessary, and the major route is the exploitation of temperate x tropical crosses, irrespective of whether the end product is a hybrid or an improved variety. Agriculture based on such altered genotypes is not incompatible with lower levels of inputs. During the process of transition from traditional to more productive genotypes and agricultural systems, insect and disease problems will have to be encountered and managed until a productive equilibrium is re-established. To enhance this process, resistance breeding will be an important factor in genotype alterations.

In the Indian context, this has been proved beyond doubt in the rainy season, and the altered genotypes that represent intermediate optima furnished the basis for higher levels of productivity and stability in sole crops as well as cropping systems. No doubt further improvement will come over time. If in the near future, there is a shift towards tall sorghums, it will be for a different objective—biomass and energy.

The stagnant African situation needs analysis. In a recent analysis of the African drought, the *Christian Science Monitor* rightly stated, "It was in the African savanna that man evolved and learned to make fire, talk and shape tools of flint. Today, almost 40 000 years later, man has applied science and technology to set off a quiet agricultural revolution all over the planet—except in Africa. Africa, where man began, now needs his most advanced scientific techniques."

In the same article, some of the scientists working in Africa reflected their opinion, "We must respect what exists, otherwise we can destroy. Real progress comes hard and from slogging away. You have to advance step by step and carefully." "In places where draft animals and the plough were introduced not more than 20 years ago, there is already rapid degradation of soil." They tend to plead for existing cultivars, existing maturities, and preservation of existing systems with minor additions and changes. This is what has been done all these years, with no visible effect.

The report on African agricultural research assembled by the members of a committee of consultants for this purpose has been documented by the U.S. National Academy of Sciences (1974). The new role of agriculture in Africa according to them will require "an expanding and changing base of knowledge including the knowledge of the environment—the organisms that live in it, the systems in and by which these organisms can be changed—and the economic and social facts of life in the rapidly changing African societies."The committee emphasized "more, different and if possible better agricultural research. "Kowal and Kassam (1978) stated that blueprints of innovations and changes in the farming methods are not presently available for West Africa.

In the African context, we still seem to have a quarrel with our goals, some pleading largely for the preservation of the existing systems with minor changes and others for radical genotype and system changes. The choice, therefore, is between the evolutionary and revolutionary approaches.

To me there is no choice. Based on my long involvement in the Indian program and my brief West African experience, I feel that unless we bring about genotypic and cropping system changes of a far-reaching and revolutionary nature, we may not witness a rapid change in productivity of African agriculture.

I am of the opinion that the system has to change, but the values have to be preserved.

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GENETICS OF FERTILITY RESTORATION IN SORGHUM

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Abstract

The genetics of fertility restoration was studied in **A × B, A × R, B × B** and **B × R** crosses. Based on near complete agreement of segregation patterns in various crosses, a four gene model has been suggested. It may be necessary to account for a fifth gene for fertility restoration on VZM_2 and GI steriles. The genetics of fertility restoration may be complete only then and it is, therefore necessary to identify a genotype that could restore fertility on these two steriles.

Index words : *Sorghum bicolor*, sorghum, fertility restoration, genetics.

A comprehensive analysis of the cytoplasmic systems in sorghum was presented by us earlier (Rao, Tripathi and Rana, 1984). The present study, based on the diverse male steriles, their maintainers and restorers, presents the genetics of fertility restoration.

Materials and Methods

The materials and methods have been described earlier by Rao, Tripathi and Rana, (1984).

Results

(1) *A×B and A×R crosses* : Restoration were worked out in F_2 and BC generations using test of goodness of fit of Mendelion ratios (Table 1). The F_1, BC_1 and BC_2 of A×B crosses of CK60A and Nagpur-A among themselves were sterile and therefore, there was no difference of maintainer gene(s) between these two male steriles. This indicates that cytoplasms and maintainer system of CK60A and Nagpur-A were similar.

Rest of the B-lines and R-lines restored fertility on CK60A and Nagpur-A, while some F_1's were totally sterile or fertile, certain others exhibited 'segregation' for fertility in the F_1 generation itself (Table 1).

TABLE 1 : *Genetics of fertility restoration* (rabi *season*)

Female Male	Generation	Grouping	CR60B	NagB	M35-1B	M31-2B	V2M2B	G1B	Nandyal	GM1-5	K.local
CK60A	F_1		S	S	F	F	F	F/PF	F	F/PF	F/PF/S
	F_2	(i)	+	+	54 : 10	NA	54 : 10	54 : 10	54 : 10	3 : 1	45 : 19
		(ii)			3 : 1		3 : 1	3 : 1**	3 : 1	45 : 19	37 : 27
	BC_1 ($F_1 \times P_1$)	(i)	S	S	5 : 3	NA	1 : 1	3 : 1	1 : 1	3 : 1	39 : 25
		(ii)			3 : 1		1 : 1	3 : 1	1 : 1	45 : 19	39 : 25
	BC_2 ($F_1 \times P_2$)	(i)	S	S	F	NA	F	F	57 : 7	F	57 : 7
		(ii)							57 : 7		55 : 10
Nagpur-A	F_1		S	S	F/PF	F	F/PF/S	PF/S	F	F	PF/S
	F_2	(i)	+	*	3 : 1	NA	3 : 1	54 : 10	54 : 10	3 : 1	45 : 19
		(ii)			45 : 19		45 : 19	3 : 1	3 : 1@	45 : 19	39 : 25
	BC_1	(i)	S	S	1 : 1	NA	1 : 1	NA	1 : 1	NA	1 : 1
		(ii)			1 : 1		1 : 1		1 : 1		1 : 1
	BC_2	(i)	S	S	3 : 1	NA	F	F	F	F	3 : 1
		(ii)			3 : 1						39 : 25
M35-1A	F_1		S	S	S	S	S	S*	F/PF	F	F
	F_2	(i)	*	+	+	+	+	+	15 : 1	15 : 1	15 : 1
		(ii)							55 : 9		
	BC_1	(i)	S	S	S	NA	NA	NA	S	1 : 3	1 : 3
		(ii)									1 : 3
	BC_2		S	S	S	NA	NA	NA	S	F	F
M31-2A	F_1		S	S	S	S	S	F*	F	F	F
	F_2		+	+	+	+	+	15 : 1*	NA	63 : 1*	63 : 1*
	BC_1		NA	NA	NA	—	NA	NA	NA	NA	NA
	BC_2		NA	NA	NA	—	NA	NA	NA	F	NA
VZM2A	F_1		S	S	S	S	S	S	S	S	S
	F_2		+	+	+	+	+	+	+	+	+
	BC_1		S	S	NA	NA	S	NA	S	S	NA
	BC_2		S	S	NA	NA	S	NA	S	S	NA
G1A	F_1		S	S	S	S	S	S	S	S	S
	F_2		+	+	+	+	+	+	+	+	+
	BC_1		S	NA	NA	S	NA	NA	NA	NA	S
	BC_2		NA	S	NA	S	NA	NA	S	NA	NA

(i) Grouping I (Fertile + towards fertile + towards sterile *vs* sterile) @ F *vs* rest

(ii) Grouping II (Fertile + towards fertile *vs* sterile + towards sterile) * Summer data

NB : All genetic ratios presented in table show good fit to expected frequencies

S—Sterile; F—Fertile; PF—Partial Fertile; NA—Data not available.

F_2 generation segregated in fertile (F) sterile (s) and partial fertile plants which were classified as 'towards fertile' (> 70% seed set) or 'Towards sterile' (< 30% seed set). Since frequencies of sterile individuals (recessive) were fairly large as compared to partial fertiles and no genetic ratio with three or four phenotypic classes could be fitted, partial fertile classes were merged into fertile class for fitting of Mendelian ratios. First ratio in Table-1 was computed by merging all partial fertiles in fertile class (Grouping-I) and second ratio by merging partial fertile predominantly sterile in sterile class (Grouping-II). BC_1 was designated when F_1 was crossed to first parent (female) and BC_2 when F_1 was crossed to second parent (male).

Four F_2's *viz.*, CK60A×M35-1; CK60A×GIB, CK60A×VZM2B and CK60A×Nandyal segregated in 54F : 10S ratios while their back-crosses with B counterpart of *ms* lines (BC_1) segregated in 5F : 3S, 3F : 1S, 1F : 1S ratios, respectively. 54F : 10S trigenic ratio can be explained that combination of two or three dominant genes restored fertility but double or triple recessive combination could not. BC_1 in this case would show 1F : 1S ratio as observed in case of CK60A×VZM2B and CK60A×Nandyal crosses but BC_2 would be fertile as observed in above crosses. Deviation from normal BC_1 ratio such as 5F : 3S and 3F : 1S indicated major effect of one of the three genes, converting eight phenotypic classes of segregation into 5F : 3S. When two genes showed conspicuous effect, the ratio changed to 6F : 2S *ie.*, 3F : 1S.

When grouping-II was followed, F_2 ratios of above four crosses showed 3F : 1S ratio indicating that there was one gene difference between parents for restoration. The change from 54F : 10S trigenic ratios to monogenic 3F : 1S ratios by merging predominantly sterile (partial fertile) plants into sterile class indicates that while one gene primarily governs fertility, two other genes are responsible for partial fertility.

Two other CK60A crosses showed different ratios. According to grouping-1, CK60A×GM1-5 segregated in 3F : 1S ratio and CK60A×K. local in 45F : 19S ratio indicating that GM1-5 carried one major fertility restorer gene. K.local carried three genes while two genes restored fertility in presence of third gene but do not restore fertility while alone. In other words, two genes independently or in combination intensify the effect of major gene but do not restore fertility themselves.

According to grouping-II, 3F : 1S ratio of CK60A×GM1-5 changed to 45F : 19S trigenic ratio and CK60A×K.local F_2 45F : 19S ratio into 37F : 27S trigenic complementary ratio. BC_1 ratio of CK60A×GM1-5 cross also changed similar to its F_2. It indicates that GM1-5 possessed three modifiers apart from one major fertility restorer gene. Fertility restorer gene of GM1-5 appears to have much stronger effect on restoration and less influenced by modifiers in contrast of major gene system of B-lines restoring fertility on CK60A. Change of CK60A×K.local F_2 ratio revealed trigenic system where two-three genes interacted and modified fertility gene reaction.

Nagpur-A crosses with M35-1B, VZM2B and GM1-5 showed 3F : 1S F_2 ratio and 1F : 1S BC_1 ratio conforming to one major gene difference between parental lines when grouping-I was considered. These F_2 ratios showed shift to 45F : 19S ratio when grouping-II was followed. It confirmed the presence of one major plus two genes with minor effect in M35-1B, VZM2B and GM1-5 as observed earlier in CK60A crosses. However, their operation changed with the change in the cytoplasmic and genetic background of female parent.

Nagpur-A×G1B and Nagpur-A×Nandyal showed 54F : 10S ratio in F_2 as earlier observed in CK60A crosses. This shows three gene system operating to restore partial to full fertility. These ratios changed to 3F : 1S monogenic ratios when grouping-II was followed. It reveals that two out of three genes are minor.

A duplicate digenic ratio 15F : 1S was observed in M35-1A×Nandyal and M35-1×GM1-5 F_2s indicating that Nandyal and GM1-5 carried two major genes restoring partial to full fertility independently. The BC_1 ratio which should be 3F : 1S was not as expected. In M35-1A×Nandyal, all plants became sterile while in M35-1A×GM1-5, 1F : 3S ratio was observed. It indicates that one of the genes carried by M35-1B inhibits major gene effect of fertility restoration. When grouping-II was used for fitting the genetic ratios, digenic duplicate ratios changed to trigenic modified ratios. M35-1A×K.local F_2 ratio (57F : 7S) showed that while one major gene independently governs the fertility other two genes interact among themselves and segregate in digenic complementary ratio.

Three F_2's involving M31-2A were studied for segregation in summer season. M31-2A×G1B segregated in 15F : 1S ratio while M31-2A×GM1-5 and M31-2A×K.local segregated in 63F : 1S ratio. It indicates that two duplicate genes in M31-2A×G1B and three genes in M31-2A×GM1-5 and M31-2A×K.local crosses govern the fertility restoration system.

Seasonal interactions for seed set are presented in Table 2. CK60A×K.local interacted in summer season but F_2 and backcross ratios showed normal monogenic inheritance while in *rabi*, 45F : 19S/3F : 1S ratio was observed. Fertility restoration system of CK60A×K.local and Nagpur-A×G1B was fairly unstable over seasons and governed by one dominant gene in summer.

TABLE 2 : *Variation in cytoplasmic-genic interaction for seed set in different seasons*

Cross	Genetic ratio: F_2 Rabi F : S	F_2 Summer F : S	BC_1 Rabi F : S	BC_1 Summer F : S	BC_2 Summer	Seasonal interaction
CK60A × M35-1B	54 : 10	3 : 1	1 : 1	1 : 1	—	Interaction
CK60A × K.local	45 : 19	3 : 1	39 : 25	1 : 1	F	Interaction
Nag. A × G1B	3 : 1	3 : 1	NA	1 : 1	F	Interaction
M35-1A × G1B	S	57 : 7	NA	S	F	NA
M31-2A × CK60B	S	15 : 1	NA	S	1 : 1	Interaction due to nonshedding in *rabi*
M31-2A × G1B	S	15 : 1	NA	NA	NA	NA
M31-2A × GM1-5	F	63 : 1	NA	NA	F	NA
M31-2A × K.local	F	63 : 1	NA	NA	F	NA
VZM2A × G1B	S	57 : 7*	NA	NA	NA	Interaction

F=Fertile; S=Sterile; NA=Data not available; *=Partial; NB : All ratios fit well.

M35-1A×G1B F_1 was sterile in *rabi* but sterility broke in summer season. F_2 segregation studied in summer, showed that fertility was governed by three genes, two functioning as complementary factors (9:7) and one segregating normally giving 57F : 7S ratio.

Pollen shedding was absent in M31-2A×CK60B which showed seasonal interaction and shed fertile pollen in summer. Due to breaking of mechanical barrier of sterility, this cross segregated in 15F : 1S ratio in F_2 generation. Two genes were responsible for fertility restoration and acted as duplicate factors. However, BC ratios observed did not confirm it.

VZM2B×G1B F_1 shed sterile pollen in *rabi* but higher temperature induced pollen fertility in summer. The F_2 of this cross showed segregation for [illegible] : 7PF. No sterile plant was observed.

Major conclusions which arose from different segregating patterns and changes in genetic ratios by shifting the grouping pattern are :

(a) There are three fertility restorer genes; one of them shows major effect.

(b) Action of the genes changed with the cytoplasmic-genetic background of male sterile line eg., one major gene of GM1-5 was apparent when crossed to CK60A and Nagpur-A but the second gene effect was more pronounced when GM1-5 was crossed to M35-1A.

(c) G1B and Nandyal restoration system was consistent in CK60A and Nagpur-A cytoplasm. M35-1B and VZM2B fertility restoration system on CK60A and Nagpur-A also shows similarity.

(d) Karad local fertility restoration system appears to be different from other restorer parents since two out of three genes show complementary interaction in milo cytoplasm.

(e) Nandyal, GM1-5 and Karad Local's restoration system is different from M35-1B and VZM2B.

(f) VZM2B and G1B also differ in restoration system. G1B restoration system appears to be more stronger since it restores fertility on M35-1A and M31-2A in summer and VZM2B does not.

(g) All the F_1 and backcrosses of VZM2A and G1A were sterile. Even three Indian restorer lines which restored fertility on CK60A, Nagpur-A, M35-1A and M31-2A cytoplasms could not restore fertility in VZM2A and G1A cytoplasm. The restoration system of these two *ms* lines was, therefore, governed by some other genes not present in either of restorer lines used here.

(h) Sterility maintenance system of CK60A and Nagpur was similar in respect of each other.

(i) Seasonal interactions for fertility restoration were present. Major gene effect was more pronounced in summer.

(2) *B×B and B×R crosses* : All possible F_1's among six B-lines and three R-lines were tested for pollen sterility and seed set to judge their reproductive status in reciprocal crosses. All the F_1s were perfectly fertile. However, in F_2 generation, five crosses segregated in different ratios as given in Table 3.

Fertility status was classified as fertile (F), towards fertile (TF), towards sterile (TS) and Sterile (S). 'Towards fertile' meant that the individual was almost fertile with <30% sterile spikelets. Similarly 'TS' meant that individual was partially fertile (<30%). Since, no genetic ratio could be fitted to three classes or four classes segregation pattern, all the individuals showing partial fertility were clubbed alongwith fertiles. Two class ratios showed good fit (Table 3).

M35-1B×CK60B and M35-1B×Nagpur-B segregated in 54F : 10S ratio indicating three genes system where fertility was controlled by two or three genes interactions. Single dominant gene or triple recessive individuals were sterile. Sterility in these crosses arose due to segregation of genes and interaction with M35-1B cytoplasm. Trigenic additive ratio (27 : 27 : 9 : 1) could not fit and

TABLE 3 : *Genetics of fertility restoration in five B×B and B×R crosses*

Sl. No.	Cross	F_1	F_2 segregation				Genetic ratio	X^2	Probability
			F	TF	TS	S	(F+TF+TS) : S		
1.	M35-1B×CK60B	F	97	3	—	15	54 : 10	0.582	.30-.50
2.	M35-1B×Nagpur B	F	72	11	—	16	54 : 10	0.562	.30-.50
3.	VZM2B×Nagpur B	F	83	14	—	3	63 : 1	1.350	.20-.30
4.	G1B ×CK60B	F	77	8	28	3	63 : 1	0.795	.30-.50
5.	Nandyal×CK60B	F.	76	14	4	35	45 : 19	0.404	.50-.70
							3 : 1	0.313	.50-.70

F=Fertile; S=Sterile; TF=Towards Fertile (<30% sterile spikelets)
TS=Towards Sterile (<30% fertile spikelets)

hence, fertility reaction in these crosses was not governed by additive effect of genes.

The crosses VZM2B×Nagpur-B and G1B×CK60B segregated in 63F : 1S genetic ratios in F_2. Either of three dominant genes or in combination governed fertility. Individuals recessive at all the three loci in G1B or VZM2 cytoplasm were sterile. Since different classes of fertility (T, TF, TS) appeared in F_2, the effects of different dominant genes were unequal.

DISCUSSION

(1) ms CK60 and Nag A (milo source of cytoplasm) crossed with M35-1, G1B, VZM2B, Nandyal, GM1-5 and Karad Local

The F_2 and backcross ratios fit a 54 : 20 ratio which is a modified trigenic ratio. If 'towards fertile' category is merged with fertile and toward sterile with sterile class, then they all fit a monogenic 3 : 1 ratio. In case of GM1-5 and Karad Local crosses the ratios fit trigenic interaction with fertile class more predominent than 54 : 10. This means, there is a major gene (**msc_1**) whcih interacts with *milo* cytoplasm and two other genes which may be interacting genes. They may probably correspond to **pf_1, pf_2** genes described by Miller and Pickett (1964). Thus the observed genetic ratio for fertility restoration conforms to the previous findings.

(2) M35-1A and M31-2A crossed to Nandyal, GM1-5 and Karad Local

In all these cases, the F_2 and backcross segregation ratios conform to a trigenic or digenic ratios of 63:1 and 15:1. In case of M35-1A crosses, the ratio is 15:1 while in case of M31-2A crosses, it is 63:1 during summer. This clearly establishes a two to three genes effect for fertility restoration, but sterility will be expressed, only under double recessive or triple recessive condition. One of the genes interacts with temperature.

While M35-1B and M31-2B restore fertility on *milo* cytoplasm, they are maintainers on other cytoplasmic sources. Obviously the dominant gene **MSC_1** is unable to restore fertility. Therefore, there has to be an additional non-allelic gene (s) in the restorer lines like Nandyal, GM1-5 and Karad Local. Crosses of Maldandi steriles with such restorers segregate in 15:1 or 63:1 ratio. The 15:1 ratios are confined to crosses M35-1A×Nandyal, M35-1A×GM1-5, M35-1A× Karad Local and M31-2A×G1B indicating two dominant genes. The 15:1 ratio fits well but there are also some partial fertile cases. Since sterility is expressed under a double recessive condition and the existance of additional genes is demonstrated, it may be stated that the other two genes are possibly **MSC_2** and **MSC_3**. Since complete sterility is expressed only under double or triple recessive condition, the **MSC_2** is also a major gene and may act as a major or modifier gene in *Maldandi* type of cytoplasm.

In VZM-A and G1A none of the R lines restore fertility. This means **MSC_1**, **MSC_2** and **MSC_3** together could not restore fertility. As such the existence of an additional gene may have to be explored.

(3) **B×B and B×R crosses**

Some of the B×B and B×R crosses though fertile in F_1 segregated for fertility and sterility in F_2. Only seed set was studied and pollen fertility was not scored. All the R×R crosses were fertile in F_1 and did not segregate in F_2.

Amongst B×B and B×R crosses M35-1B×CK60B, M35-1B×Nag-B, VZM2B×Nag-B G1B×CK60B and Nandyal×CK60B segregated for fertility and sterility. Their reciprocals did not exhibit such segregation. Hence, the segregation is only for the interacting gene in non-milo cytoplasm.

The crosses M35-1B×CK60B and M35-1B×Nag-B segregated in F_2 in the ratio of 54:10 which is a modified trigenic ratio. The fertility restoration genes in M35-1 have to be **MSC_1 MSC_1**, **MSC_2 MSC_2**, **MSC_3 MSC_3**, Interactions amongst these three genes with three of Kafir could result in the modified 54:10 ratio. Thus, the restoration system in *Maldandis* is a three gene system.

The crosses G1B×CK60B segregate in 63:1 ratio confirming a three gene restoration system. Thus most of the segregating B×B or B×R crosses also conform to a three gene system.

(4) **Genetics**

Schertz and Stephens (1966) assigned the symbols $\mathbf{msc_1}$ and $\mathbf{msc_2}$ to the genes interacting with milo cytoplasm to result in male sterility. They did not take cognisence of $\mathbf{msc_3}$ gene reported by Erichsen and Ross (1963). There have been reports about the operation of a three gene system governing cytoplasmic genetic male sterility (Joglekar and Deshmukh, 1961; Cragmiles, 1962; Patil and Rane, 1968). Miller and Pickett (1964) reported the operation of pf_1 and pf_2 genes governing partial fertility. Thus, the reports on genetics of fertility, restoration in cytoplasmic genetic male steriles to date hypothesize the presence of a single dominant gene or 2-3 interacting genes.

The present studies clearly establish the presence of three interacting genes as far as restorating on *milo* (A_1) cytoplasm is concerned. But when the *maldandi* cytoplasm (A_2) is involved, unless a non-allelic gene is present in addition to the three genes, fertility restoration cannot be explained. But even then it is only three gene interactions which restores fertility.

The four gene system is still inadequate to bring about fertility restoration on VZM or G1 steriles. A genotype homozygous at all the four dominant MSC loci or an addtional MSC_3 locus may only restore fertility on G1 and VZM steriles. Till such a genotype is available, the full genetics of restoration has to wait.

In literature a total of six ($\mathbf{ms_1}$ to $\mathbf{ms_2}$) genes causing genetic male sterility have been reported. It is likely that it is these very genes which interact with appropriate cytoplasmic sources. This point needs to be confirmed.

Based on the genetics of A×B/R, B×B and B×R crosses, the following genetic constitution is assigned to various lines under study. They satisfy most of the observed ratios. The seasonal interactions and possible self-incompatibility might bring in some descrepancies only in few cases.

Kafir	:	$\mathbf{msc_1\ msc_1\ msc_2\ msc_2\ msc_3\ msc_3\ msc_4\ msc_4}$
M35-1 M31-2 VZM_2 G_1	:	$\mathbf{MSC_1\ MSC_1\ MSC_2\ MSC_2\ MSC_3\ MSC_3\ msc_4\ msc_4}$
Nandyal	:	$\mathbf{msc_1\ msc_1\ MSC_2\ MSC_2\ MSC_3\ MSC_3\ MSC_4\ MSC_4}$
GM1-5 K. Local		$\mathbf{MSC_1\ MSC_1\ MSC_2\ MSC_2\ msc_3\ msc_3\ MSC_4\ MSC_4}$

$\mathbf{MSC_1}$ and $\mathbf{MSC_4}$ are major genes. $\mathbf{MSC_1}$ and $\mathbf{MSC_2}$ interact with $\mathbf{MSC_1}$. $\mathbf{MSC_1}$ and $\mathbf{MSC_2}$ may be same as $\mathbf{pf_1}$ and $\mathbf{pf_2}$ genes. $\mathbf{MSC_3}$ may be sensitive to temperature and hence shows seasonal interaction. This MSC_3 or some other factor may be responsible for some incompatibility. A fifth major gene needs to be explored for fertility restoration on VZM and G_1 steriles.

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PROGRESS IN GENETIC IMPROVEMENT OF KHARIF SORGHUMS IN INDIA

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ABSTRACT

The paper attempts an analysis of the present status of improvement of varieties and hybrids of sorghum in India during the *kharif* season. Improved varieties like SPV-462 and SPV-475 are superior to the hybrid CSH-1 for yield as well as stability of performance and approach the commercial hybrid CSH-5. This is significant. The improved varieties are less sensitive to years and more sensitive to locations whereas the hybrids are less sensitive to both years and locations as revealed by the interactions. The commercial hybrids are yet to show significant advance over CSH-9 in yield. The trial differentiation index as developed by Fasoulas (1983) is a useful tool for evaluating test locations in coordinated crop improvement programmes. Based on the results, guidelines for future improvement of hybrids and varieties of sorghum during *kharif* in India have been furnished.

Index words : Sorghum, kharif, yield performance, stability, cultivar performance index, trial differentiation index.

Two-thirds of the area under sorghum in India is in the kharif season. Analysis of the performance of commercial hybrids and varieties of sorghum has generally proved that hybrids were superior to the varieties with respect to yield levels and stability of performance (Rao *et al.*, 1981). Varietal improvement has now made rapid strides and the present-day improved varieties are superior to the earlier hybrids in yield levels and they tend to approach current hybrids. Research efforts have been towards development of varieties that equal commercial hybrids with respect to yield levels and stability (Reddy and Rao, 1982). The present study analyses the relative performance of currently available hybrids and varieties of sorghum, using conventional statistical methods and a method developed by Fasoulas (1983).

MATERIALS AND METHODS

The experimental material for this study consisted of four experimental hybrids (SPH-196, SPH-221, SPH-225 and SPH-232) and three released hybrids (CSH-5, CSH-6 and CSH-9) as checks. Similarly, nine promising varieties (SPV-126, SPV-245, SPV-346, SPV-351, SPV-386,

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SPV-459, SPV-462, SPV-472 and SPV-475) with two hybrid checks (CSH-1 and CSH-5) and local were compared. Data on both trials were available over a two-year period, 1982 and 1983, over 25 common locations distributed over the sorghum growing tracts in India during the kharif season under rainfed conditions in different agroclimatic regions of the country. The net plot size was 13.5 m^2. Stability analysis was done separately for each entry following Eberhart and Russell (1966). Cultivar performance index and trial differentiation index were calculated according to Fasoulas (1983).

RESULTS

PERFORMANCE FOR YIELD AND OTHER ATTRIBUTES

The mean performance of the varieties and hybrids is presented in Table 1. The improved varieties, SPV-346, SPV-351, SPV-462, SPV-472 and SPV-475, are significantly superior to CSH-1. They tend to approach the yield levels of CSH-5. The varieties SPV-462 and SPV-475 are statistically on par with CSH-5 for grain yield. They are comparable to CSH-5 for plant height and maturity, indicating that varietal improvement for yield has made significant strides. Improvement in fodder yields is reflected in several varieties which is an advantage.

None of the experimental hybrids are superior to CSH-9, the most promising amongst released hybrids; SPH-196 followed by SPH-225, have advantage for fodder yield. For resistance to charcoal rot, SPH-196 is the best available hybrid.

COMBINED ANALYSIS OVER YEARS AND LOCATIONS AND STABILITY OF PERFORMANCE

The combined analysis of variance for varieties and hybrids is presented in Table 2. The variety × years interaction is not significant, indicating that improved varieties are relatively stable across the years. The variety × location interaction and the variety × location × years interaction is significant, indicating varietal sensitivity.

With regard to hybrids, not only *the* hybrid × years but also *the* hybrid × location interaction is not statistically significant. This indicates that hybrids are stable across the years and locations revealing their general superiority over varieties with respect to performance as well as stability of performance.

The estimates of components of variance (Table 3) reveal that while the magnitude of the error component is about the same, the magnitude of the genotypic and interaction components for varieties are larger than the hybrid values, further indicating greater stability of hybrids.

TABLE 1 : *Performance of sorghum varieties and hybrids tested over a two-year period (kharif 1982 and 1983)*

Entry		Grain yield (q/ha)	Fodder yield (q/ha)	Plant height (cm)	Days to flower
Varieties :					
SPV-126		31.69	155	207	71
SPV-245		35.22	122	175	72
SPV-346		37.86	147	206	71
SPV-351		37.12	126	181	69
SPV-386		36.38	139	229	70
SPV-459		36.42	147	216	70
SPV-462		39.08	131	225	69
SPV-472		36.85	159	229	70
SPV-475		39.47	125	181	72
CSH-1		34.46	91	148	60
CSH-5		41.18	117	187	69
Local		23.62	169	262	81
	Mean	35.78	136	204	70
	S. Em	0.85	3.61	—	—
	CD 5%	2.36	10.00	—	—
Hybrids :					
SPH-196		44.28	168	262	67
SPH-221		46.38	114	194	67
SPH-225		45.30	129	206	67
SPH-232		42.82	110	180	66
CSH-5		39.19	112	184	68
CSH-6		37.47	99	167	60
CSH-9		46.13	120	189	66
	Mean	43.08	122	197	66
	S. Em	0.79	2.82	—	—
	CD 5%	2.19	7.84	—	—

TABLE 2 : *Combined analysis of variance for grain and fodder yields of kharif sorghum varieties and hybrids*

Source of variation	Varieties				Hybrids			
	mean squares				mean squares			
	d. f.	grain yield	d. f.	fodder yield	d. f.	grain yield	d. f.	fodder yield
Years	1	9140.12**	1	10219.95**	1	8106.01**	1	16.14
Locations	24	2522.28**	23	69323.24**	24	1905.01**	23	40913.23**
Years × locations	24	1637.68**	23	21380.17**	24	1241.60**	23	126525.24**
Replications × years × locations	100	18.53	96	233.29	100	17.95	96	146.63
Varieties/hybrids	11	1037.54**	11	21856.39**	6	610.30**	6	24249.02**
Varieties/hybrids × years	11	15.08	11	1094.80	6	40.88	6	256.15
Varieties/hybrids × locations	264	56.84**	253	1109.59**	144	39.36	138	503.72
Varieties/hybrids × locations × years	264	35.93**	253	624.16*	144	30.87**	138	383.77**
Pooled error	1100	8.36	1056	120.24	600	9.56	576	128.74

* and ** significant at 5% and 1% levels, respectively.

TABLE 3 : *Estimates of components of variance for grain and fodder yield of kharif sorghum varieties and hybrids*

	Grain yield		Fodder yield	
	varieties	hybrids	varieties	hybrids
$\hat{\sigma}^2g$	20.03	11.22	422.42	487.35
$\hat{\sigma}^2gl$	10.45	4.25	242.71	59.97
$\hat{\sigma}^2gy$	—0.83	0.40	19.61	—5.32
$\hat{\sigma}^2gly$	27.57	21.30	503.02	255.03
$\hat{\sigma}^2e$	8.36	9.57	120.24	128.74

Studies on stability of performance based on Eberhart and Russell (1966) are presented in Fig. 1 and 2. CSH-9 and SPH-221 are the most stable hybrids.

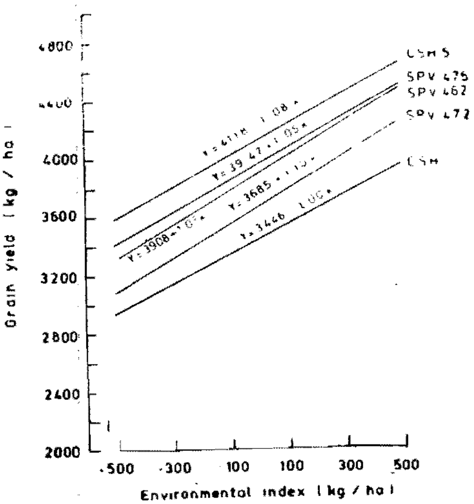

Fig 1 : Stabilty of performance of kharif hybrids.

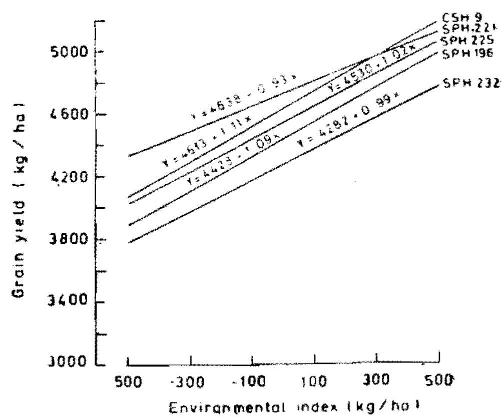

Fig 2 : Stability of perfomance of kharif varieties.

The improved varieties SPV-462 and SPV-475 are inferior to CSH-9, but superior to CSH-1 in yield as well as stability. The deviation mean squares were, however, significant in all cases.

CULTIVAR PERFORMANCE INDEX

The cultivar performance index based on the methodology of Fasoulas (1983) is presented in Table 4 with respect to grain and fodder yields. The improved varieties SPV-462 and SPV-475 approach the commercial hybrid CSH-5, confirming the results obtained from combined analysis of variance. Local is best for fodder yield, but improved varieties like SPV-346, SPV-386, SPV-462 and SPV-472 combine high grain yields with reasonably high fodder yield.

Similarly, the cultivar performance index for hybrids reveals SPH-221, CSH-9 and SPH-196 to be superior.

TRIAL DIFFERENTIATION INDEX

The trial differentiation index values according to Fasoulas (1983) range from 0 to 100 for the respective locations, the locations with higher scores reflecting the efficiency of the trial. The data are presented in Table 5.

Amaravati in Maharashtra is found to be the most efficient location with respect to hybrids as well as variety testing. It is further seen that the locations Amaravati, Dhule, Parbhani, Karad and Jalgaon, all in Maharashtra, were more effective locations. Palem (A.P.), Chindwara (Madhya Pradesh), Bailhongal (Karnataka) etc. are consistently poor.

DISCUSSION

The superiority of commercial sorghum hybrids over varieties with respect to yield and stability was brought over in several studies (Rao and Harinarayana, 1968; Singhania and Rao, 1976 and Rao *et al.*, 1981). Reddy and Rao (1981) pointed out that improvement in biomass without disturbing the harvest index could result in cultivars of higher yields and also indicated possibilities of developing varieties approaching commercial hybrids for yield and stability.

Varietal improvement since then has made rapid strides. The present study reveals that varieties like SPV-462 and SPV-475 are superior to the hybrid CSH-1 with respect to both aspects, namely, grain yield and stability and approach the

TABLE 4 : *Rating of kharif sorghum varieties and hybrids for grain and fodder according to cultivar performance index*

Entry	Grain		Fodder	
	over years and sites (pys)	rank	over years and sites (pys)	rank
Varieties :				
SPV-126	10.00	11	48.11	3
SPV-245	15.80	10	16.67	8
SPV-346	22.50	5	35.61	5
SPV-351	22.20	6	15.91	10
SPV-386	22.70	4	26.89	6
SPV-459	16.70	9	36.17	4
SPV-462	30.00	1	21.40	7
SPV-472	20.00	7	48.86	2
SPV-475	28.50	3	16.10	9
CSH-1	18.00	8	2.46	12
CSH-5	29.50	2	12.31	11
Local	5.50	12	59.85	1
Hybrids :				
SPH-196	24.33	3	84.72	1
SPH-221	27.33	1	15.28	5
SPH-225	23.33	4	37.85	2
SPH-232	17.67	5	13.19	6
CSH-5	8.33	6	15.63	4
CSH-6	6.67	7	5.21	7
CSH-9	26.33	2	24.31	3

TABLE 5 : *Trial differentiation index (D) for kharif sorghum varietal and hybrid trials for grain and fodder over years and locations*

Location	Varieties				Hybrids			
	grain		fodder		grain		fodder	
	mean	rank	mean	rank	mean	rank	mean	rank
Amaravati	84	1	42	19	86	1	69	6
Dhule	69	3	70	7	79	2	62	9
Jalgaon	65	4	78	3	57	5	57	11
Karad	55	6	46	16	60	4	79	3
Yavatmal	79	2	68	9	48	7	71	5
Parbhani	51	9	80	2	69	3	60	10
Somnathpur	44	16	59	11	50	6	50	13
Buldana	40	13	44	18	26	19	36	15
Rahuri	35	14	63	10	14	23	40	14
Nanded	40	17	58	12	17	22	64	8
Akola	29	18	72	5	31	13	55	12
Nagpur	28	18	69	8	31	12	69	6
Digraj	19	22	77	4	38	11	67	7
Surat	53	8	36	20	40	10	81	2
Deesa	58	5	44	18	0	25	57	11
Pantnagar	54	7	47	15	43	15	74	4
Dharwad	50	10	71	6	43	9	55	12
Bailhongal	16	24	85	1	29	18	90	1
Coimbatore	41	12	33	21	38	16	2	18
Bhavanisagar	44	11	45	17	31	17	29	17
Udaipur	30	15	42	19	19	20	55	12
Indore	23	20	56	13	31	14	31	16
Chindwara	18	23	NA	NA	17	21	NA	NA
ICRISAT	22	21	52	14	48	8	62	9
Palem	10	25	19	22	14	24	31	16

NA : Data not available.

commercial hybrid CSH-5 in both respects. This is a very significant aspect in varietal improvement.

Multilocation analysis over years revealed that improved varieties are more sensitive to locations and less sensitive to years as revealed by the interactions. On the other hand, the hybrid interactions with years and locations are not significant, indicating their greater stability of performance. The magnitude of the estimate of components of variance for hybrids is also smaller compared to the varieties. Thus, the hybrid superiority is still clearly felt. Further studies are needed to understand the causes of hybrid stability so as to manipulate the varieties in a suitable manner. The studies reveal that after the release of CSH-9 during 1981, yield levels of experimental hybrids have not advanced to any significant extent and future programmes should address to this problem.

The cultivar performance index, as developed by Fasoulas (1983), confirms the results obtained by the traditional methods of analysis. The advantage of Fasoulas (1983) methodology is the trial differentiation index which attempts to measure the efficiency of test locations. This is certainly a useful tool for crop coordinated programmes in evaluating the performance of test locations over years.

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PROGRESS IN GENETIC IMPROVEMENT OF RABI SORGHUMS IN INDIA

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ABSTRACT

Genetic improvement of rabi sorghums has not kept pace with kharif sorghums. The variety—hybrid differences are not conspicuous. Improvements obtained through the development of CSH-8R (hybrid) and CSV-8R (variety) are not reflected on a field scale. Subsequent progress to-date is also marginal. There are indications that hybrids could be more stable than varieties during rabi. Yield superiority needs to be built into them. Present female parents with kharif parentage seems to impart temperature sensitivity to hybrids. Efforts are outlined to develop superior rabi hybrids that combine yield advantage and stability of performance.

Key words: Sorghum, rabi, yield performance, stability, cultivar performance index, trial differentiation index.

Approximately one-third of the sorghum area in India is during the post rainy (rabi) season in the black soil belt of the Deccan plateau. Rabi sorghum improvement has not kept pace with progress achieved during the kharif. Rabi sorghums depend largely on the stored moisture in the black soil profiles since very little rain is received during crop growth. The problem of improving rabi sorghums poses greater challenge. The present paper analyses the state of arts and attempts to provide guidelines for improvement.

MATERIALS AND METHODS

Two sets of materials comprising six promising hybrids (SPH-200, SPH-201, SPH-203, SPH-204, SPH-218 and SPH-248) and eight promising varieties (SPV-422, SPV-440, SPV-489, SPV-491, SPV-504, SPV-511, SPV-513 and SPV-518) with CSH-8R and CSV-8R (SPV-86)—the released hybrid and variety—along with local, as checks were taken for comparison in two trials. Data on

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both trials were available over a two-year period, 1982-1983 and 1983-1984, over eleven common locations representing the typical rabi sorghum tract. Replicated trials were grown with the recommended cultural practices for rabi under rainfed conditions. The net plot size was 13.5m^2. Stability analysis was done following [1]. The cultivar performance index and trial differentiation index were obtained according to [2].

RESULTS

Data for yield and other attributes are presented in Table 1. The released hybrid CSH-8R and the released variety CSV-8R are on par for grain yield.

Table 1. Performance of sorghum varieties and hybrids tested over a two-year period (rabi 1982-83 and 1983-84)

	Grain yield (q/ha)	Fodder yield (q/ha)	Plant height (cm)	Days to flower
Varieties:				
SPV-422	23.21	53	182	74
SPV-440	22.72	63	209	71
SPV-489	26.80	56	193	71
SPV-491	25.50	57	206	73
SPV-504	27.78	57	192	74
SPV-511	26.19	53	165	74
SPV-513	24.99	44	157	73
SPV-518	25.11	45	159	69
CSV-8R	27.82	49	175	73
CSH-8R	28.54	39	142	69
Local	23.87	64	189	72
Mean	25.68	53	179	72
SE	0.69	1.47	—	—
CD, 5%	1.92	4.09	—	—
Hybrids:				
SPH-200	26.63	45	168	68
SPH-201	25.28	38	145	65
SPH-203	26.60	38	156	63
SPH-204	24.88	40	149	62
SPH-218	25.24	64	224	69
SPH-248	25.84	46	169	63
CSV-8R	23.51	51	176	73
CSH-8R	25.45	37	140	69
Local	21.50	63	186	71
Mean	24.99	47	168	67
SE	0.50	1.03	—	—
CD, 5%	1.40	2.87	—	—

None of the experimental varieties exhibit any superiority for grain yield. There is some improvement for fodder yield over CSV-8R. Similarly, none of the experimental hybrids reflect superiority over CSH-8R for grain yield. The hybrid SPH-218 is superior for fodder yield.

Table 2 contains data on combined analysis of variance. Varietal differences for grain yield are significant only at 5% level, whereas they are highly significant for hybrids. The variety × year and variety × location interactions are generally nonsignificant for both hybrids and varieties for grain as well as fodder yields.

Table 2. Combined analysis of variance for grain and fodder yields of rabi sorghum varieties

	Varieties				Hybrids			
	mean squares				mean squares			
	d.f.	grain yield	d.f.	fodder yield	d.f.	grain yield	d.f.	fodder yield
	1	112.55	1	15040.00**	1	0.02	1	3274.15**
Locations	10	2232.60**	9	5783.33**	10	403.89*	9	3252.00**
Years × locations	10	768.07**	9	4912.22**	10	467.30*	9	3244.55**
Replications × years × locations	44	47.83	40	75.79	44	24.69	40	47.27
Varieties/hybrids	10	82.80*	10	1216.40**	8	57.02**	8	2241.87**
Varieties/hybrids × years	10	32.56	10	66.70	8	6.15	8	158.75**
Varieties/hybrids × locations	100	25.34	90	119.39	80	12.17	72	105.47
Varieties/hybrids × locations × years	100	23.55**	90	92.32**	80	12.08**	72	76.18**
Pooled error	440	10.46	400	43.12	352	5.57	320	21.20

* and ** significant at 5% and 1%, respectively.

The estimates of components of variance for grain and fodder yields are presented in Table 3. As far as grain yield is concerned, the magnitude of genotypic interactions and error components are larger for varieties compared to hybrids. The same is not true for fodder yields, the hybrids being more sensitive.

Table 3. Estimates of components of variance for grain yield and fodder yield of sorghum varieties and hybrids

	Grain yield		Fodder yield	
	varieties	hybrids	varieties	hybrids
$\hat{\sigma}^2 g$	2.64	2.05	55.62	107.37
$\hat{\sigma}^2 gl$	0.90	0.10	13.53	14.65
$\hat{\sigma}^2 gy$	0.82	-0.54	-2.56	8.26
$\hat{\sigma}^2 gly$	13.09	6.51	49.30	54.98
$\hat{\sigma}^2 e$	10.46	5.57	43.12	21.20

Data on stability of performance are presented in Fig. 1 and 2. None of the experimental varieties are superior to CSV-8R (SPV-86). The hybrid SPH-200 is somewhat superior to CSH-8R.

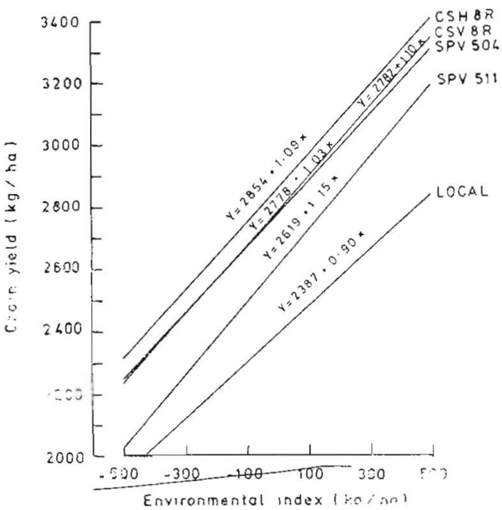

Fig. 1. Stability of performance of Rabi varieties.

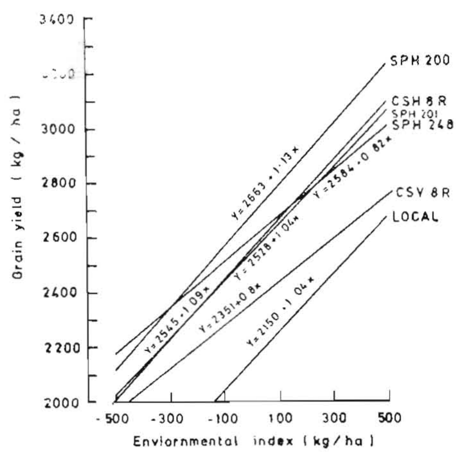

Fig. 2. Stability of performance of Rabi hybrids.

The cultivar performance index (Table 4) indicates SPV-504, CSV-8R and CSH-8R to be superior. Amongst hybrids SPH-200, SPH-201 and SPH-203 are somewhat superior for grain yield. For fodder yield, SPH-218 is comparable to local followed by CSV-8R.

Table 4. Rating of rabi sorghum varieties and hybrids for grain and fodder according to cultivar performance index

Entry	Grain		Fodder	
	over years and sites (pys)	rank	over years and sites (pys)	rank
Varieties:				
SPV-422	13.33	9	16.25	6
SPV-440	11.67	11	33.75	2
SPV-489	17.78	4	26.88	5
SPV-491	16.67	5	31.88	3
SPV-504	26.11	1	30.00	4
SPV-511	16.11	6	12.50	8
SPV-513	13.90	7	4.38	9
SPV-518	13.89	8	1.88	11
CSV-8R	23.33	2	15.63	7
CSH-8R	22.78	3	2.50	10
Local	12.78	10	41.88	1
Hybrids:				
SPH-200	19.44	1	15.87	5
SPH-201	16.67	3	7.14	7
SPH-203	18,06	2	7.94	6
SPH-204	15 .97	4	5.56	8
SPH-218	11.81	6	52.78	2
SPH-248	10.42	7	18.25	4
CSV-8R	9.72	8	43.65	3
CSH-8R	13.89	5	0.79	9
Local	2.78	9	64.29	1

Regarding locations (Table 5) with the exception of Mohol and Parbhani in Maharashtra, the test locations were neither effective not consistent. Data from Bijapur (Karnataka State) was consistently poor.

Table 5. Trial differentiation index (D) for rabi sorghum varietal and hybrid trials for grain and fodder over years and locations

Location	Varieties				Hybrids			
	grain		fodder		grain		fodder	
	mean	rank	mean	rank	mean	rank	mean	rank
Mohol	63	1	60	1	58	2	62	2
Parbhani	55	2	58	2	76	1	64	1
Rahuri	25	7	19	10	13	8	29	9
Sholapur	15	10	44	5	7	9	44	6
Ekarjuna	37	4	28	8	21	6	43	7
Nandyal	38	3	57	3	33	4	44	5
ICRISAT	25	8	NA	NA	7	10	NA	NA
Tancha	34	6	23	9	39	3	32	10
Dharwad	35	5	30	6	32	5	54	3
Annigiri	20	9	50	4	17	7	35	8
Bijapur	15	11	29	7	4	11	50	4

NA : Data not available.

DISCUSSION

The spread of commercial sorghum hybrids during kharif had a perceptible production impact. This is not so with rabi season where M. 35-1 is the predominant improved local variety under cultivation. A rabi hybrid, CSH-8R was released in 1977 and an improved variety CSV-8R (SPV-86) in 1979. These two cultivars do reflect some improvement over M.35-1 and other locals, but their production impact is yet to be felt on a field scale. Obviously, there are limitations to CSH-8R as well as CSV-8R. Subsequent improvement work has not also reflected any significant advance for grain yield even at the experimental level which is certainly not encouraging. What are the reasons for this and how could we get over the stagnating tendency during rabi?

The yield differences between hybrids and varieties as seen during kharif are not perceptible during rabi. Both CSH-8R and CSV-8R exhibit similar experimental yield levels. The recently released variety SPV-504 and hybrids SPH-201 and SPH 218 are only marginally superior for grain yield under rainfed conditions. So, the problem of yield plateaus persists even at the experimental level.

Combined analysis of variance indicates that while the yield levels are not superior, the magnitude of the components of variance in hybrids is somewhat smaller for grain yield but not for fodder yield. At least there is some indication that if superior yielding hybrids are developed, they might perhaps be expected to reflect greater stability for performance compared to the varieties.

How do we then develop such superior hybrids? An analysis of this was attempted by Rao [3]. The presently developed rabi hybrids have female parents of kharif type which exhibit greater temperature sensitivity. If this is eliminated, greater success may be anticipated, and efforts are in progress in this direction and should be pursued. Even on the male parent side, temperature insensitive rabi material should receive greater attention. From the behaviour of kharif× rabi crosses, temperature sensitivity seems to dominate. Hence both parents should be relatively insensitive and diverse. This is a difficult task but needs to be attempted. Efforts may also be made to capitalize on interacting genes as in case of Kafir × Hegari combinations, but within a rabi background.

The rabi environment is harsh on moisture. Hence manipulation of the soil physical environment to promote moisture conservation and fertilizer use are a necessary adjuant for the genetic efforts and then only results could become perceptible as in kharif. Rabi jowar improvement for the rainfed lands is the challenge.

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DWARFING GENES OF SORGHUM IN RETROSPECT

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The era of high yielding varieties in India, the sixties and seventies in particular, is the era of manipulation of plant height and maturity genes in the development of new cultivars and modified production technologies. In cases like sorghum, this approach was coupled with exploitation of heterosis. These manipulations had brought about changes in harvest indices, extended the range of adaptation, conferred resistance to lodging and superior fertilizer response and enabled higher plant populations per hectare. The physiological responses of the sorghum populations were thus modified. Based on our studies with sorghum in India, I shall attempt to summarise the results reflecting the role of dwarfing genes, the interrelationships between height, maturity, yield and related characters and how the altered plant types could contribute to productivity advances, particularly in rainfed kharif sorghums.

THE HEIGHT AND MATURITY GENES

Traditional tropical sorghums are of African origin. They are generally tall and late and are characterised by higher biological and low economic yields. The mutations for height and maturity seem to have occurred in Africa itself. After introduction into the long-day conditions of the United States of America, selection was directed towards early maturing forms and dwarfer mutants to suit mechanical cultivation. Commercial exploitation of heterosis using cytoplasmic-genetic male steriles gave a further boost to sorghum production. Thus, the mutations for maturity and height enhanced the range of adaptation of sorghums into the temperate regions and exploitation of heterosis rendered them more productive.

Brachytic dwarfs of sorghum arose from the tall forms as mutations. Internodal elongation is controlled by genes at four loci with allelic series at each locus. These genes have been designated as the height genes. Quinby and Karper (1954) identified four independently inherited height genes and a modifying complex that influenced elongation of internodes. These genes were designated Dw_1, Dw_2, Dw_3 and Dw_4. Genotypes recessive for one, two, three and four genes were termed 1-dwarf, 2-dwarf, 3-dwarf, and 4-dwarf, respectively. One of the four genes (Dw_3) is unstable and reverts to tallness frequently.

Studies based on isogenic lines and tall mutations on the effect of height genes on yield and other quantitative characters in both homozygous and heterozygous backgrounds revealed that the talls were generally superior and that the *Dw* and *dw* genes themselves accounted for a major portion of the observed differences in yield (Cassady, 1965; Hadley et al., 1965).

For maturity, four loci have been identified, Ma_1, Ma_2, Ma_3 and Ma_4, with several alleles at each locus. The process of temperate adaptation in sorghum essentially involved the mutation of dominant Ma_1 gene to its recessive ma_1. The maturity gene ma_1 and the height gene dw_2 are closely linked (Quinby, 1974). The maturity period in sorghum is determined by the interaction between genotype, photoperiod and temperature.

Based on induced mutation studies in Indian tall sorghums with partly exposed internodes, Rao et al. (1970) felt that the allelism of height and maturity genes between forms with exposed and enclosed internodes needed further analysis. A rare mutational event in talls with exposed internodes probably altered them to forms with enclosed internodes which concurrently brought about changes in a range of characters including height, panicle morphology, insect reaction etc., and the height genes designated by Quinby operate after such an *a priori* change. Segregation patterns in crosses between Indian talls and temperate dwarfs do not seem to fit into the expected patterns and hence the question about allelism may need further analysis. Till then the above observation should be treated as speculative.

The Analysis of Growth

In some of the tall Indian sorghums, the total dry matter produced under normal growing conditions could be as high as 450 g per plant of which 30-35% gets accumulated in the earhead. Some of the dwarf hybrids and high yielding varieties are of much less dry weight, 200-300 g/plant, of which 45-55% accumulates in the earhead.

The tall sorghums were characterised by a single peak for the rate of growth coinciding with flowering, whereas in the productive dwarfs there were two peaks for growth rate, one coinciding with flowering and the other with grain filling (Rao and Venkateswarlu, 1971; Anantaraman et al., 1978).

The pattern of internodal elongation reflects the pattern of growth. When the patterns of internodal elongotion were characterised in different groups of sorghums (Balarami Reddy et al., 1981), several of the dwarf varieties and hybrids generally exhibited a linear pattern of elongation, whereas a third degree polynomial curve was required for some of the tall and late Indian sorghums.

In traditional rainfed agriculture, the flowering period of the talls usually coincided with cessation of rains and if rains stopped earlier, which was not uncommon, crop failures resulted. In the modified dwarfer and earlier maturing cultivars, the flowering time coincided with the periods of high soil moisture and even when conditions turned out to be subnormal, satisfactory grain yields could be obtained. This has enabled planting of higher population levels, 180,000 plants/ha as against the traditional population levels of less than 100,000 plants/ha (Rao, 1981, 1982).

Nutritional Responses

Compared to the brachytic dwarfs, the tissue concentration of nitrogen in leaves is lower in the traditional Indian talls (Rao and Venkateswarlu, 1971). The response to nitrogen fertilization of the derived dwarf hybrids and varieties was three times greater than with the traditional talls. In the range of 0-40 kg N/ha, the response was 21 kg grain/kg N in the modified cultivars compared to only about 7-8 kg in the traditional types (Rao, 1972).

Insect and Disease Reaction

The introduced dwarfs were more susceptible to sorghum shootfly and stem borers, whereas the traditional talls were more tolerant. This could be attributed partly to growth habits and partly to inherent differences (Balakotaiah et al., 1975; Singh et al., 1983). It, therefore, became necessary to pay greater attention to insect management primarily through optimal planting times and through incorporation of resistance to these two pests.

While the earliness together with growth patterns did confer greater stability to production, late rains, if occuring at harvest, affected grain quality. Manipulation of plant pigments by developing tan plant types and incorporation of resistance to grain deteriotation due to grain moulds and other factors became necessary to maintain grain quality and this has been accomplished to a considerable extent (Rana et al., 1978).

HETEROSIS

In dwarf × tall Indian crosses, the accumulation of dry matter was mostly in the stem and, consequently, the hybrid advantage for grain yield could not be realised. On the other hand, in some of the dwarf × dwarf combinations, there was considerable heterosis for grain yield (Rao, 1970a; Rao and Venkateswarlu, 1971). Combinations involving different height groups revealed that 3-dwarf × 3-dwarf hybrids were superior to 3d × 4d or 4d × 4d hybrids (Maunder and Weddige, 1966).

CHARACTER ASSOCIATIONS, RECOMBINATION BREEDING AND THE "INTERMEDIATE OPTIMUM PLANT TYPE"

The agricultural consequences of such genetical-physiological character associations are that the tropical talls were characterised by restricted adaptation, climatic vulnerability and greater risk, lack of adequate response to increased populations and fertilizer levels and low economic yields. The dwarfer forms, on the other hand, had greater susceptibility to certain tropical pests and diseases and carefully planned breeding programmes could achieve the required recombination (Rao, 1982).

The distribution of dominant and recessive alleles for grain yield, plant height and flowering was asymmetrical and in opposite directions in the two groups, namely, dwarf early and tall lates (Rao, 1970b).

The estimates of general combining ability from crosses involving the two groups of sorghums (Table 1) reveal distinct differences between dwarf and tall parents and were also in opposite directions (Rao, 1972).

Character associations tend to restrict progress from selection for yield and related attributes. Positive relationships between height, maturity and yield were reported by several workers (Dalton, 1967; Subba Reddy and Rao, 1971). Our studies (Rao et al., 1973) on such character associations based on different height and maturity groups of sorghums in both homozygous and heterozygous backgrounds revealed interesting findings. While the correlations were positive and significant in the dwarf early group, they tended to be negative in the tall late group (Table 2).

The dynamics of association between grain yield, maturity and plant height in crosses involving the two groups reveal that productive intermediate populations could be established (Rao et al., 1973).

TABLE 1

Estimates of general combining ability (Rao, 1972)

Parents	Grain yield	Days to 50% bloom	Plant height	Nitrogen uptake
Dwarf Exotic				
Kafir B	—33.18**	—7.63**	—51.14**	—0.47**
IS 3691	—1.77	—5.53**	—55.42**	—0.18
Swarna	—4.16*	—2.83**	—17.02**	—0.24
Tall Indian				
R. 173	+12.46**	+5.78**	+46.03**	+0.30
R. 170	+9.46**	+5.84**	+41.22**	+0.43*
R. 160	+2.52	+3.50**	+29.90**	+0.14
R. 168	+14.57**	+2.77**	+47.36**	+0.36
S.E. (gi)	±2.27	±0.25	±0.85	±0.23

*Significant at 5% (*) and 1% (**) levels.

We (Rana et al., 1984) attempted to arrive at an optimum plant type using plant height, maturity, number of leaves, panicle branches, yield, 100-seed weight, and fodder yield, adopting a multiple regression model containing all the interaction terms. The studies revealed that the relationships between plant height, flowering, and grain yield were nonlinear. The optimum plant type was quantified to be combining 68 days to flower and 175 cm plant height (Fig. 1).

TABLE 2

Phenotypic correlation coefficients between flowering (x), height (z) and yield (y) (Rao et al., 1973)

Group	r_{xy}	r_{zy}	r_{xz}
DE	0.91*	0.90**	0.76
DE × DE	0.82**	0.70*	0.81**
TL	—0.41	0.28	—0.89
TL × TL	—0.53	0.22	—0.67
DE × TL	0.23	—0.17	—0.42

DE = dwarf early, TL = tall late

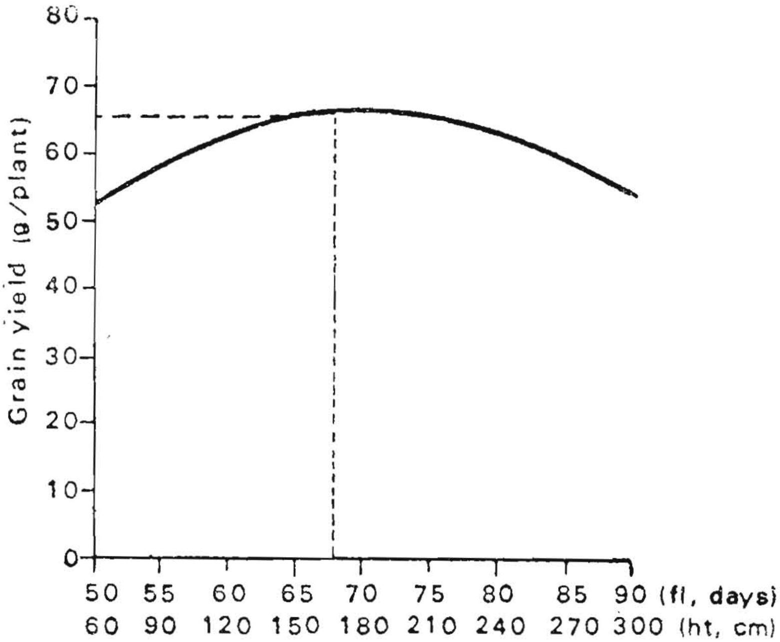

Fig. 1. Optimum phenotype as related to plant height and flowering time.

Excessive vegetative growth in terms of leafiness and fodder yield was disadvantageous for grain yield. The optimum plant type is an 'intermediate optimum' and generally meets the needs of food, fodder and security from generally prevailing southwest monsoon climate in the country with its fluctuations.

TABLE 3

Compound growth rates of sorghum compared to other cereals on all India basis (1968-69 to 1980-81)

Crop	Area, %	Production, %	Yield, %
Rice	0.73	2.20	1.45
Wheat	2.92	5.65	2.64
Sorghum	−1.18	2.06	3.28
Pearl Millet	−1.16	−0.34	0.79
Maize	Negligible	−0.05	0.03
Cereals	0·36	2.69	1.80
Food Grains	0.35	2.39	1.56

It has also been possible to recombine the required insect and disease resistance in such plant types at homozygous and heterozygous (hybrid) levels. However, the required levels of shootfly resistance could not be transferred so far although partial success was achieved (Rao and Rana, 1982).

The total sorghum production in the country, which was around 8 million tonnes in the mid-sixties, has now reached 11-12 million tonnes together with a reduction in area of about 2 million ha. The comparative growth rates of sorghum compared to other cereals after the advent of dwarf and medium statured and relatively early maturing hybrids are presented in Table 3.

Rainfed sorghum yields are, no doubt, low, but the growth rate is comparable to those of highly irrigated wheat and rice crops.

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AN ERA OF SELF-SUFFICIENCY IN FOOD PRODUCTION

ICAR

AN ERA OF SELF-SUFFICIENCY IN FOOD PRODUCTION

A TRIBUTE TO INDIRA GANDHI

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7

Dryland Sorghum

N. G. P. Rao*

SORGHUM *(jowar)* is the major food and forage crop of dryland areas. Its grain has potential utility in cattle and poultry feed rations, promoting agro-industries and in biomass production to supplement energy requirements.

The low-rainfall years like 1965–66, 1971–72 and 1972–73 affected agricultural production, and the dryland areas faced near-famine conditions. The drought-prone areas of Maharashtra, Karnataka, Andhra Pradesh, Madhya Pradesh, Rajasthan, Gujarat and Tamil Nadu, where sorghum is the staple food, became famine-prone and necessitated PL-480 imports of *milo*. In view of this, our late Prime Minister Indira Gandhi took personal interest in dryland food crops. The Government of Maharashtra and Karnataka took keen interest in promoting hybrid sorghum on a large scale to fight the drought. The early-maturing hybrids developed in India performed well in normal as well as sub-normal years. The hybrid sorghum also furnished a basis for the practice of productive intercropping and multiple cropping systems with pulses and edible oilseeds. Hybrid sorghum thus initiated an era of green revolution in dryland agriculture.

PRODUCTION TRENDS AND GROWTH RATES

The area under *jowar* which was over 18 million ha in 1966 decreased by nearly 2 million ha in 1984. The production of 8 million tonnes during 1965 reached a level of 11–12 million tonnes in 1984 during the normal and subnormal years. The compound growth rates of sorghum and other cereals after the advent of hybrids is presented in Table 1.

The compound growth rates for productivity in the post high-yielding variety era for the dryland sorghums are comparable to those for irrigated wheat and rice. This proves that green revolution is a fact as far as dryland sorghums are concerned.

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Table 1. Compound growth rates of different crops (all-India average data of 1968–69 to 1978–79)

Crop	Area	Productivity	Production
Rice	0.777	1.790	2.584*
Wheat	2.853	2.355*	5.281**
Maize	0.132	0.504	0.637
Sorghum	−1.458*	4.491**	2.958*
Pearlmillet	−1.291	1.670	0.353
Pulses	0.991	−0.053	0.939
Total foodgrains	0.481	2.259*	2.750**

*Significant at 5% level; **significant at 1% level

ADVENT OF EARLY HYBRIDS

Traditional varieties of sorghum all over the country were of longer duration compared with those grown during the rainy season. If the monsoon rains ceased

'CSH 5', a hybrid sorghum with quality grain, is suitable for the rainy season, yielding 4,514 kg/ha under high management and 3,185 kg/ha under low management

prematurely, which was not uncommon, crop failure was the result. Traditional sorghums accumulated only about 30% of their total dry weight in the grain and in dry years grain formation did not take place. However, a good portion of the *jowar* area had been in the drought-prone and famine-prone areas

The hybrid *jowar* project was initiated during 1962, and the first hybrid 'CSH 1' became available during 1965–66. Unlike locals, 'CSH 1' was earlier in maturity (100 days) and accumulated 50% of the total dry matter in the ear. Its critical growth periods coincide with periods of satisfactory profile moisture even in subnormal years. Consequently, even in the dry year like 1972–73, its yields were satisfactory.

The yield of 'CSH 1' was good, but its grain quality was questionable. Consequently newer hybrids like 'CSH 5', 'CSH 6' and 'CSH 9' for the rainy (*kharif*) season and 'CSH 8R' for winter season (*rabi*) were developed. These hybrids are superior to 'CSH 1' in grain yield and possess better grain quality. The grain does not deteriorate even if some rain is received at harvest. These new hybrids are responsible for increase and stabilization of yield level of dryland sorghums.

PRODUCTION TECHNOLOGY

The hybrids which had a different plant type brought in a new production technology. Planting with the onset of the monsoon became a regular practice, as this period was pest-free and farmers realized that delayed plantings reduce yield. Plant population levels were nearly doubled to 180,000 plants/ha. The response of the hybrids per kilogram of nitrogen applied was three times compared with that of the locals. It was also demonstrated that hybrids yielded well under both low and high management (Table 2).

Table 2. Mean yields and ranks of some hybrids and varieties under high and low levels of management during *kharif* 1974, 1975 and 1977

	High management		Low management	
	Yield (kg/ha)	Rank	Yield (kg/ha)	Rank
Hybrid				
'CSH 1'	3,569	4	2,468	4
'CSH 5'	4,514	1	3,185	2
'CSH 6'	4,125	3	3,346	1
Variety				
'CSV 3'	3,200	5	1,970	5
'CSV 5'	2,622	6	1,701	6

The investment being only on seed and fertilizer, the technology was within the reach of the small and marginal farmers. The efficacy of the technology was demonstrated through national and various other types of demonstrations and pilot project studies (Table 3). Consequently the spread of the high-yielding varieties has been on the increase.

Table 3. Grain yields from pilot project blocks on hybrid sorghum in Maharashtra (rainy season)

Year	Coverage (ha)	No. of experiments	Average yield (q/ha)
1976–77	75,063	5,579	27.40
1977–78	73,386	3,333	27.30
1978–79	35,539	959	22.80
1979–80	20,832	805	22.70

SORGHUM-BASED CROPPING SYSTEMS

The compatibility of pulses and edible oilseeds with hybrid sorghum in intercropping systems was studied all over the country. Productive and profitable intercropping systems with marginal reduction in sorghum yield were developed. Sorghum-pigeonpea, sorghum-soybean, sorghum-groundnut and various intercropping systems were standardized. Intercropping with pulses is also becoming a necessary and compulsory element in states like Maharashtra.

Yield stability of sorghum and millet across climates

N. G. P. Rao, G. R. K. Rao, and H. S. Acharya

Seventy percent of the world's area under sorghum and millet, about 70 million ha concentrated in the less developed economies of Asia and sub-Saharan Africa, is climate dependent. In India, technological innovations involving genetical alterations coupled with input management practices and a better understanding of the process of adaptation have resulted in moderate advances in the productivity and stability of sorghum and pearl millet cultivated during the rainy season. Such a change has yet to be accomplished in sub-Saharan Africa or in postrainy season sorghum in India. This paper uses the rainy season sorghum of India as a case study to analyze the climatic limits and limitations to production and demonstrates how manipulations of genotype and environment have resulted in accelerated growth rates and stability in production despite rainfall fluctuations. A similar analysis of the sub-Saharan situation analyzes the technological potential for a change in productivity and stability there. An analysis of the stagnant postrainy sorghum situation in India is attempted. Brief reference is made to such factors as resource limitations, demand and supply, pricing, and alternative uses for sorghum and millet, which have a bearing on promoting production.

Treatises on the green revolution seldom make a positive reference to dryland agriculture. The lack of progress in dryland production has been analyzed in terms of the nature and significance of risk imposed by environmental factors, the design of appropriate technologies, socioeconomic constraints, and policy implications. When references are made to small and marginal farms and resource-poor farmers, sometimes the so-called livelihood technologies also are mentioned. It appears we are still largely at an analytical and experimental stage in this sector of agriculture.

Stagnation or slow growth in the production of coarse cereals, pulses, and oilseeds in predominantly rainfed agriculture has become a serious concern for planners and policymakers. The poor performance of these commodities has been attributed to their low value, adaptation to poor habitats, and production and consumption by the poorer sections of the society (Jodha and Singh 1982). Are these factors responsible for low production, despite the availability of technology, political will, and effort? Is viable technology available to accomplish better growth rates in the same habitats? Is the market demand and price situation for coarse grains a constraint? Currently, there is talk of spreading the green revolution to rainfed agriculture in India and of an Indian-type revolution in Africa's mostly rainfed agriculture.

A significant and sustained productivity change has taken place in a portion of the rainy season (kharif) sorghum belt in India. This transformation of rainfed kharif sorghum is relevant to the climate-dependent agriculture of semiarid regions.

As much as 70% of the world's sorghum and millet area, about 70 million ha, is situated in the less developed economies of the semiarid tropics of Asia and sub-Saharan Africa. The coarse grains are cultivated primarily as rainfed crops. Grain yields are low and climatically vulnerable. Sub-Saharan Africa, West, Asia, and the millet and postrainy season sorghum areas of India are the probable regions of future coarse grain deficits (Ryan and Von Oppen 1984). Can yield levels of sorghum and millet in those areas be statbilized despite climatic anomalies? The following analysis is based on results achieved in India and on some limited experience in Africa.

The India case study

State and country level

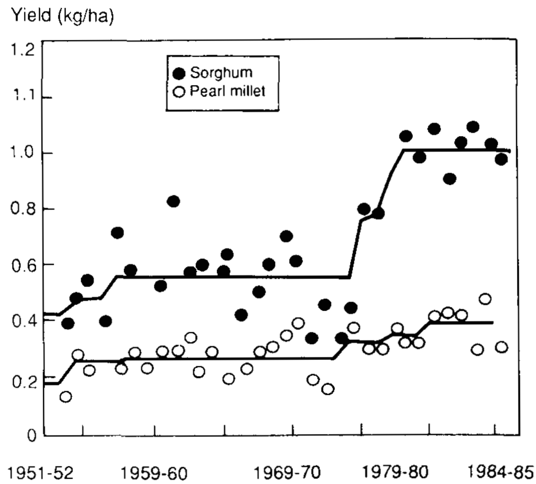
Of the more than 16 million ha currently under sorghum in India, 60% is grown during the rainy season and the rest during the postrainy season (rabi). Black soil dominates the sorghum belt, with a limited extent of Alfisols. The black soils may be shallow, medium, or deep; medium deep soils form the largest segment. A large portion of the sorghum belt is situated between 700 and 1,000 mm isohyets.

Maharashtra is the most important sorghum state, with 6.3 million ha; about 3 million ha are planted to sorghum during the monsoon and the rest during the postrainy season. Sorghum hybrids became available after 1965-66 and their adoption was spreading at a slow pace until their performance during the 1972-73 drought gave impetus to hybrid sorghum cultivation during kharif, and brought about a productivity change.

Using the method of monotonic approximations (Acharya and Kulkarni 1986), trends in productivity of rainy season sorghum have been analyzed (Fig. 1). After 1973-74, a quantum jump in productivity continued to 1978-79, then leveled off. While the trends for sorghum and pearl millet are similar, the productivity increases in sorghum are more marked. The mean yields and coefficients of variation for the two periods are presented in Table 1. After 1973-74, sorghum yields almost doubled and variability was reduced. The trend was similar for pearl millet, but the magnitude of change was lower.

A comparative analysis of the growth and stability of kharif and rabi sorghums in Maharashtra for the periods 1961-62 to 1972-73 and 1973-74 to 1983-84 shows advances in productivity during the rainy season but nearly stagnant production in the postrainy season. The advances during the rainy season were the result of hybrid cultivation.

The overall impact of the sorghum hybrids, whose coverage in India varies from 25 to 38% of the area in different states, compared with the progress made with other cereals like irrigated wheat and rice (Narain et a1 1984), is presented in Table 2. The growth rates of sorghum production after the development of high-yielding dryland varieties are comparable to those of irrigated wheat and rice, although the yield levels are still low.



1. Trends in productivity of rainy season sorghum and pearl millet in Maharashtra.

Table 1. Area, production, and productivity of kharif sorghum and pearl millet in Maharashtra during the periods 1956–73 and 1974–84.

	1956–73		1974–84	
	Mean	CV (%)	Mean	CV (%)
		Sorghum		
Area (thousand ha)	2531	3.86	2958	3.33
Production (thousand t)	1496	24.17	3048	11.50
Productivity (kg/ha)	589	23.50	1029	9.64
		Pearl millet		
Area (thousand ha)	1823	11.41	1663	8.98
Production (thousand t)	501	30.61	644	21.09
Productivity (kg/ha)	268	23.17	386	16.89

Table 2. Compound growth rates of different crops – All India (1968–69 to 1978–79).

Crop	Area	Productivity	Production
Sorghum	–1.458*	4.491**	2.958*
Pearl millet	–1.291	1.670	0.353
Maize	0.132	0.504	0.637
Rice	0.777	1.790	2.584*
Wheat	2.853	2.355*	5.281**
Pulses	0.991	–0.053	0.939
Total food grains	0.481	2.259*	2.750**

*Significant at 5% level, **significant at 2% level.

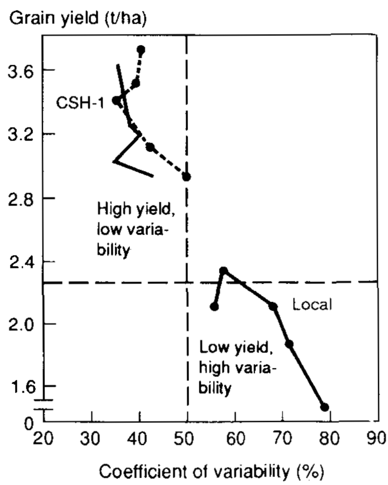
After the advent of hybrids, an increase in productivity together with some stability (reflected by reduced coefficients of variation) has been accomplished on an area basis. During these years, both normal and aberrant years of rainfall occurred.

Experimental level

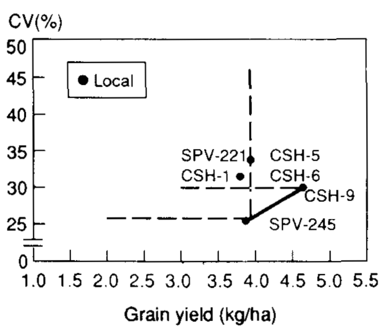
Since 1963, experimental hybrids and varieties have been tested in annual replicated field trials in 35-50 sites spread all over the kharif area. All India average yields of released hybrids CSH-1, CSH-5, CSH-6, and CSH-9 varied between 2.5 and 4.0 t/ ha; higher order yields ranged between 5.0 and 6.0 t/ ha.

Several analyses (Rao 1970; Rao and Harinariyana 1968; Rao et al 1982, 1986) clearly showed the yield superiority and stable performance of hybrids over local varieties. Hybrids also were superior to improved varieties, particularly under drought stress. The performance of CSH-1 compared to traditional local varieties across about 300 experiments over several years is presented in Figure 2.

Because risk aversion is an important criterion in rainfed agriculture, farmers' risk aversion (which considers both yield and stability) was used as a criterion to



2. Stability of sorghum hybrids and traditional local varieties.



3. Adaptability efficiency of some selected hybrids and local varieties.

rank genotypes (Fig. 3). Preference-based rankings did not differ markedly from yield-based rankings (Barah et al 1981). Further, there was no rank reversal of top yielders grown under low and high management conditions (Vidyasagar Rao et al 1981). The transformation from risk-prone traditional sorghums to high-yielding stable performers has been analyzed in detail by Rao (1982).

The yield gap

Average yields of kharif sorghum in Maharashtra State are still less than 1.0 t/ha, while experimental averages in all years are more than 2.5 t/ha and higher order yields more than 5.0 t/ha. Similar results have been obtained in several other states. This gap is certainly not a technological gap. At the same site and under similar climatic conditions, one farmer may harvest 2.5-4.0 t/ha, while his neighbor obtains only marginal yields. The factors responsible are such things as lack of resources, timing, prevailing prices, near absence of interstate or external marketing, and negligence.

Immediate efforts to enhance production will have to be in bridging the farmer-to-farmer gap in a given region, rather than in reducing the gap between experimental yields and farmer yields. Further technological research in areas where constraints have been identified is needed.

However, if the production and productivity of sorghum in India are to go up, demand will have to increase. At present, we seem to be self-sufficient as far as the food requirement is concerned. Exploitation of alternative uses of sorghum for animal feed, starch, malting, and energy might generate additional demand.

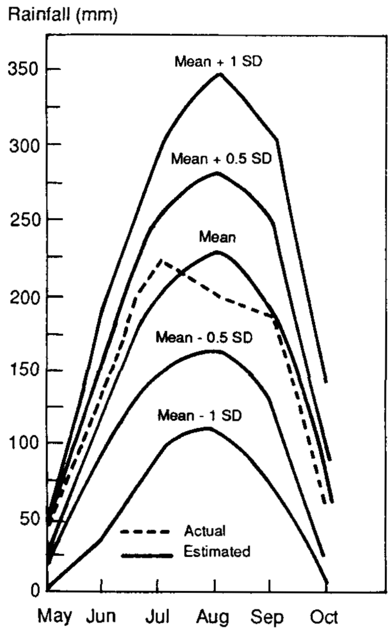
Climatic limitations and opportunities

Of the climatic elements, rainfall is the most potent influence on crop growth in the semiarid tropics. High temperatures at sowing in the Sahel of West Africa and low temperatures in the rabi sorghum belt of India are also significant, together with soil type, crop duration in relation to rainy season duration, and management practices. Rainfall aberrations include 1) delayed onset of monsoon, 2) premature cessation of rains, 3) alternate dry and wet spells during crop growth, and 4) years of lower or higher precipitation than normal.

A single location example

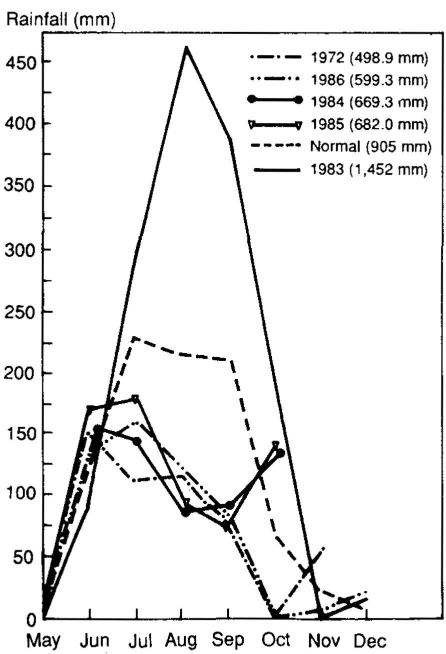
Parbhani in Maharashtra receives an average seasonal rainfall of 824 mm between 15 Jun and 15 Oct. Soils are deep to medium Vertisols. The area is considered to be in the assured rainfall zone. Sorghum is grown during both the rainy season and the postrainy season. A polynomial curve of the normal rainfall, with deviations on both sides, for the years 1944-86 is depicted in Figure 4.

Distribution of rainfall during some aberrant years is depicted in Figure 5. The years 1975 and 1983 were high rainfall years and 1972,1984,1985, and 1986 were low rainfall years at Parbhani and in the country as a whole (Kulkarni 1986). The range of rainfall was from 443 mm to 1,436 mm. Spread over time, this pattern could represent the rainfall situations likely to be encountered in sorghum-growing areas.



$$\text{Mean} = -233 + 136.2t - 1.59t^3 - 6.53 \times 10^{-3}t^5 \qquad (R^2 = 0.970)$$

4. Monthly rainfall distribution with deviations (Parbhani, Maharashtra, 1944-86).



5. Monthly rainfall distribution during some aberrant years (Parbhani, Maharashtra).

Table 3. Water budgeting (mm) through field measurements during rainy season, meteorological weeks 22-44 at Parbhani.

Parameter	1972	1983	1985	1986
Rainfall	442.7	1399.0	508.3	578.4
Potential evapo-transpiration	852.9	697.6	788.0	738.2
Evapotranspiration	398.7	545.0	465.6	454.2
Runoff	0	295.0	10.3	26.0
Percolation beyond root zone	0	300.0	0	2.0
Soil water storage at end of period	44.0	259.0	32.4	96.2
Soil water recharge	255.0	577.6	210.6	295.9

Table 4, Rainfall limits in sorghum- and pearl millet-growing regions of India.

Crop	Rainfall (mm)			Potential evapotranspiration (mm)		
	Mean	Range	0.5 SD	Mean	Range	0.5 SD
Kharif sorghum	915	805-1024	109.6	1682	1500-1864	182.0
Rabi sorghum	764	674-855	90.8	1771	1582-1880	108.7
Pearl millet	521	433-610	88.6	1687	1402-1892	204.9

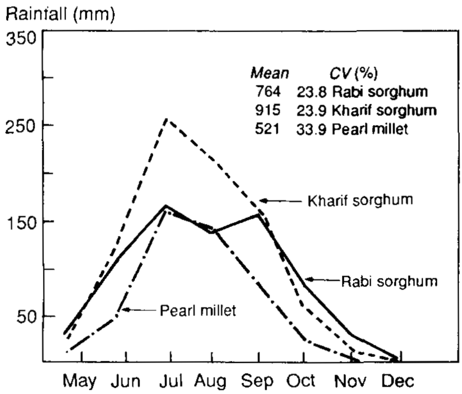
Data on weekly water budgeting during the growing season of kharif sorghum for the years 1983 (high rainfall), 1986 (moderate drought), and 1972 and 1985 (severe drought) were obtained from studies in runoff plots, percolation tanks, and lysimeters (Table 3). Water consumption for 110-d sorghum in the rainy season is 386 mm and in the postrainy season, 295 mm (G.R.K. Rao 1981). During the rainy season, this requirement is met even during years of severe stress when 150-d traditional local varieties would fail.

Multisite testing in India

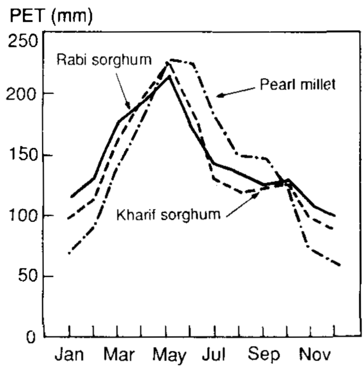
A similar analysis was carried out for 34 sites in the kharif sorghum area, 16 in the rabi area, and 19 in the pearl millet-growing area (Table 4).

Rainfall over the kharif area (Fig. 6) more or less resembles the single-location analysis. Rainfall deviations are within 0.5 SD. This means the area as a whole is reasonably safe for cultivars of 100- to 110-d duration. Rainfall during the postrainy season is less, but has two peaks during July and September, and relatively more rainfall is recorded during October. Rainfall in the pearl millet belt is less than in the rabi sorghum belt, with a single peak during July.

The potential evapotranspiration (PET) of rabi and pearl millet areas is higher than kharif sorghum (Fig. 7). Both pearl millet and rabi sorghum are cultivated in



6. Rainfall distribution in rabi sorghum, kharif sorghum, and pearl millet areas in India.

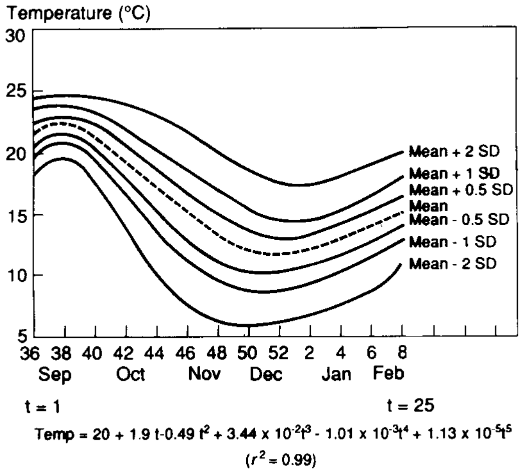


7. Potential evapotranspiration (PET) in rabi sorghum, kharif sorghum, and pearl millet areas in India.

the shallow black soils of Maharashtra, and both tend to become risky, with rabi sorghum more vulnerable. Short-season hybrids of pearl millet tend to be reasonably safe over most of the area.

The distribution zones of sorghum and pearl millet are reasonably distinct. Kharif sorghum is confined to better rainfall black soil areas, rabi sorghum to low rainfall medium and deep black soils, and pearl millet to low rainfall light soils.

During the postrainy season, minimum temperatures drop rapidly after 1 Nov (Fig. 8); this is not conducive to crop growth. Between 15 Nov and 21 Dec, the lowest minimum temperature ranges from 5 to 8 °C. Unless the crop is sown by mid-September in single-crop rabi areas and by 10 Oct in deep Vertisols where both kharif and rabi cropping are practiced, there will not be adequate time for initial rapid growth. Delayed plantings also will result in delayed maturity and greater drought stress. Depending on the progress of monsoon rains, the soil moisture profile, and soil workability, sowing dates need to be advanced.



8. Weekly minimum temperature distribution with deviations (Parbhani, Maharashtra).

West African multisite analysis

Rainfall distribution at 75 West African sites representing rainfall regimes ranging from 300 to 1,800 mm is shown in Figure 9. The curves conform to the single and multisite analyses of India except for the spread of the rainy season. West Africa has a single peak in August. PET rates are higher than in India (Fig. 10). Another difference is that West African soils are lighter and are described as tropical ferruginous. Sudanese soils are similar to the black soils of Deccan. There is a typical south-north orientation of rainfall, with a time lag between the start of rains in the south and the north of as much as 3 mo. The end of the rainy season is sharp, and occurs approximately 1.5 mo earlier in the north than in the south.

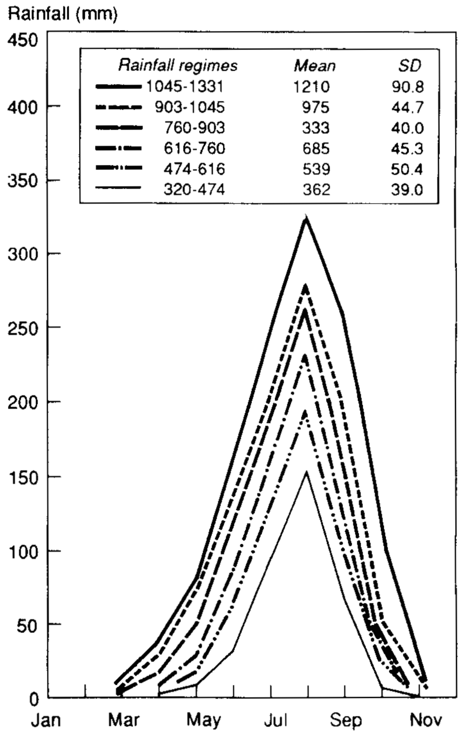
Millet is concentrated in the 400-700 mm rainfall zone, with sorghum where rainfall is 700-1,300 mm and higher (up to 1,600 mm). Both sorghum and millet also coexist in a relay intercropping system. By and large, the duration of the sorghum crop is 30-40 d longer than the duration of the rainy season. If the rains cease prematurely, yields in all zones are affected.

The climatic trends for tropical Africa have been analyzed by Farmer and Wigley (1985). They believe that for West Africa, Sudan, and Ethiopia, continuation of the low levels of rainfall of the 1970s and 1980s is more likely than a return to earlier wet spells. Because most rainfall in tropical Africa comes from convective clouds, rainfall tends to be highly variable in both time and space.

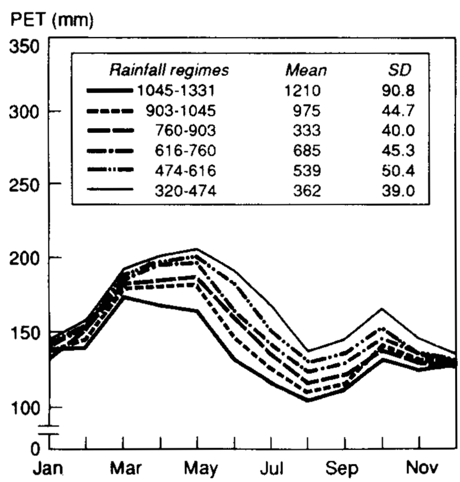
Relationship of rain to crop performance

Start of rains and sowing time

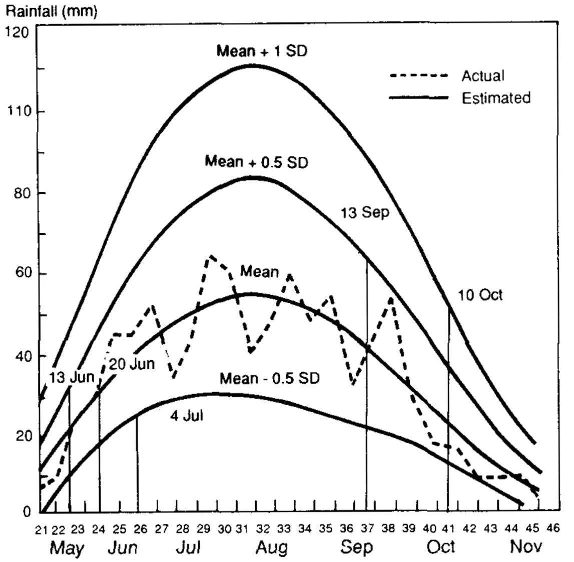
In India, after the onset of the southwest monsoon, the date by which an accumulated rainfall of 75 mm is received is considered the date of sowing. At Parbhani, this amount is normally received by 20 Jun, the earliest by 13 Jun, and the latest by 4 Jul (Fig. 11).



9. Rainfall distribution for different regions of West Africa.

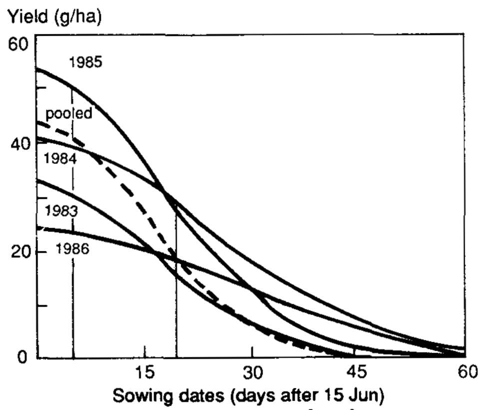


10. Potential evapotranspiration distribution for different regions of West Africa.



Mean = $4.34 + 6.37t - 1.79 \times 10^{-2}t^3 + 1.24 \times 10^{-5}t^5$ $R^2 = 0.812$

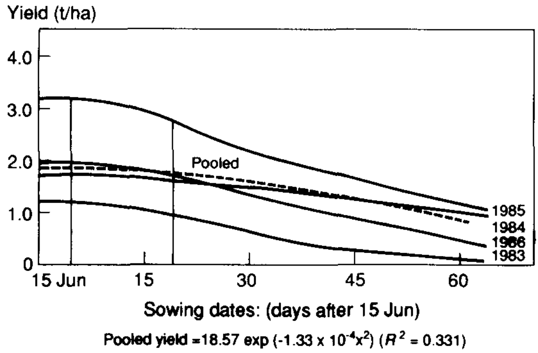
11. Weekly rainfall distribution with deviations in commencement, and cessation (Parbhani, Maharashtra).



Pooled yield = $44.6 \exp(-0.0021 x^2)$ ($R^2 = 0.644$)

12. Relationship between sowing time and yield of kharif sorghum.

If sowing rains are received but sowing is delayed, there is a progressive yield decline (Fig. 12). The reasons are both genotypic and due to the buildup of shootfly (*Atherigona soccuta* Rond), a serious seedling pest of sorghum. In a given area, if some farmers plant on time and others late, the latecomers have to face an aggravated pest situation. In high-rainfall years, incidence is high and the rate of



13. Relationship between sowing time and yield of pearl millet.

buildup fast. If the start of the rain is delayed, the pest buildup is also delayed. Depending on the arrival of rains, sorghum can be sown up to 7 Jul. Beyond that, it is not advisable and, if done, should be under plant protection. Genetic resistance to shootfly would help in all situations, but currently is available only at moderate levels. Indian farmers largely avoid shootfly by early sowing.

In pearl millet, yields also decline with progressive delays in sowing, but the rate of decline is slower than in sorghum (Fig. 13). Unlike sorghum, seedling pest problems are not serious, and pearl millet can stand relatively later sowings. If sorghum sowings are delayed, pearl millet would be a good alternate crop.

Premature cessation of rains

At Parbhani, the rains normally cease by the end of September, although small amounts of rain may fall during the first half of October. In aberrant years, the rains may be over by mid-September (Fig. 11).

When rains stop early, longduration sorghum fails to make grain, but 90- to 110-d sorghum will yield satisfactorily. For rabi crops, it has been estimated that 150 mm of rainfall received after sowing and stored moisture will return satisfactory yields. Depending on progress of the rainy season, the optimal time of sowing for rabi sorghums is from mid-September to 10 Oct. In the single-cropped rabi sorghum belt with medium black soils, mid-September sowings are preferable because pest problems are not serious. In deep Vertisols and where kharif and rabi sorghums are grown in the same region, a certain delay is needed to permit soil cultivation and to avoid heavy shootfly periods. Under all circumstances, delay beyond 10 Oct results in reduced yields.

Continuous dry and wet spells during crop growth

At Parbhani, hybrid sorghums normally are grown from 11 Jun to 21 Oct. During drought years, continuous rainless periods ranging from 12 to 32 d have been encountered during different growth stages (Table 5).

Despite several weeks of drought stress during the severe dry years, 90- to 110-d hybrids did not fail. However, crops of local cultivars of 150-d duration and longer failed. Alfisols are relatively more vulnerable, but in general, total crop failures have been avoided. The situation may vary in African climates.

Table 5. Severe dry spells at Parbhani, India.

Year	Date	Duration (d)
1972	17 Jul-4 Aug	19
	25 Aug-4 Sep	12
	16 Sep-15 Oct	31
1984	17-29 Jun	13
	10 Aug-10 Sep	32
	27 Sep-8 Oct	13
	16 Aug-11 Sep	27
1986	26 Jun-13 Jul	19
	16-31 Aug	16
	29 Sep-16 Oct	18

Tabla 6. Rainfall regimen at Parbhani, 1944-86. (Normal rainfall between June and October: 824 mm)

		Below normal	Above normal
Normal mean ± 0.5 SD	Range	686-824 mm	824-963 mm
	Years	1947,1950,1952,1960, 1962,1964,1965,1976, 1981	1944,1948,1953,1956, 1958, 1959, 1969
Moderately low/high mean ± (0.5-1 SD)	Range	547 mm - 686 mm	963 - 1,102 mm
	Years	1945, 1952, 1954, 1966, 1967, 1968, 1971, 1974, 1977, 1978, 1982, 1984, 1985	1949, 1957, 1970, 1973, 1979, 1980
Severe - low/high mean ±f >1 SD	Range	<547 mm	>1,102 mm
	Years	1946,1972,1986	1955,1961,1963,1975, 1983

Heavy and continuous rains in Vertisol areas have done more damage to sorghum than dry spells. Yield levels during 1975 and 1983, which were heavy-rainfall years, were lower than during 1984 and 1985, which were characterized by moderate drought. This is due to impeded drainage, leading to nutrient loss and associated factors.

Low- and high-rainfall years

In Parbhani, rainfall during crop growth may be classified as normal (Mean ± 1/2 SD), moderately low or moderately high (mean ± SD), and very low or very high (when rainfall is below or above 1 SD) (Table 6). All such years have occurred during the 1980s. Classification of years by rainfall indices in India (Kulkarni 1986) is close to this.

Apart from the effects of drought or impeded drainage, dry and wet years are generally characterized by the occurrence or absence of certain insect pests and diseases, although the trends can vary. Shootfly incidence and buildup are generally higher in high-rainfall years. The peak period of shootfly infestation in all years is

August-September. Earhead pests tend to be aggravated during wet years. Midge incidence was high during high-rainfall years 1975 and 1983. Because the occurrence of midge is usually severe after 15 Sep, late-flowering genotypes are affected. When the flowering in an area is prolonged because of early hybrids and late locals planted side by side, the problem is aggravated. Midge has been avoided by planting hybrids on an area-wide basis, rather than by mixing them in with local late-maturing cultivars.

Charcoal rot disease has appeared in both dry and wet years, more severely during dry years. Charcoal rot aggravates lodging. Good resistance to charcoal rot is available in varieties such as E 36-1 and SPV 511. Reasonable levels of resistance are being incorporated into commercial hybrids and varieties.

Grain molds and grain deterioration also are important problems in wet years. These conditions become acute with cloudy and wet spells during harvest. While CSH-1 is highly susceptible to grain molds, hybrids like CSH-5 and CSH-9 have good tolerance. If harvests are not delayed, the mold problem can be contained. Good levels of resistance to downy mildew and leaf spots have now been incorporated into cultivars. In normal years, wet years, or years of late rainfall, a second crop of safflower or chickpea is possible after sorghum in Vertisols.

In pearl millet, downy mildew in particular and ergot became setbacks in India and early advances in productivity were slowed. Currently available pearl millet hybrids have good resistance to downy mildew.

Net effects of climate-imposed limitations

Grain yield data for Parbhani and Maharashtra during 1951-85 were related to six rainfall regimes. Using the method of monotonic trends (Acharya and Kulkarni 1986), time series data were split into a technological trend and deviation from the trend, largely attributable to climatic factors.

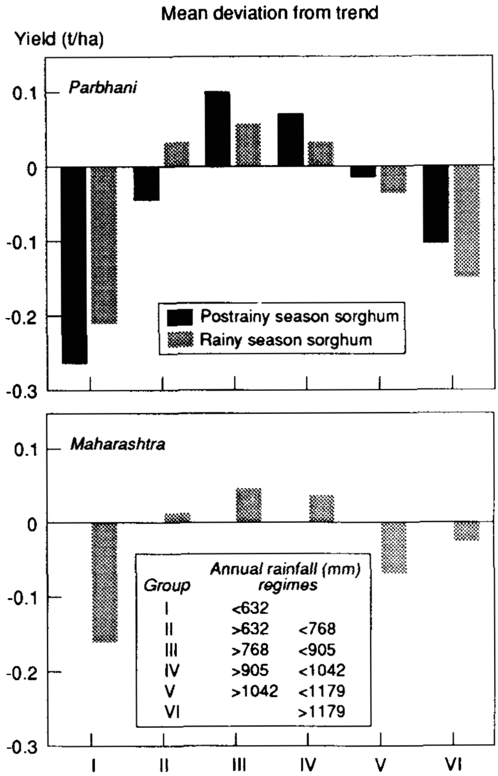
In the deviations from the trend, mean squares between groups were significantly larger than mean squares within groups. The means are diagrammatically presented in Figure 14. The deviations are large in both very low- and very high-rainfall years. There is indication that the advent of hybrids is helping bridge this gap.

Genotype-environment-input manipulations

For practical purposes, climate and weather are uncontrollable while the soil and the plant can be manipulated. Our understanding of climatic fluctuations, extreme weather events, and possible climate change is increasing. By manipulating and modifying the genotype-environment-input relations and interactions, we can minimize crop vulnerability across a range of climatic events.

Genotype alteration

Genotype alteration as the basis of agricultural transformation in tropical drylands has been analyzed in detail by N.G.P. Rao (1981). The attributes of traditional tropical cultivars have been tallness, long duration, photoperiod sensitivity, low harvest indices, and poor community performance. The timing of the main stages in

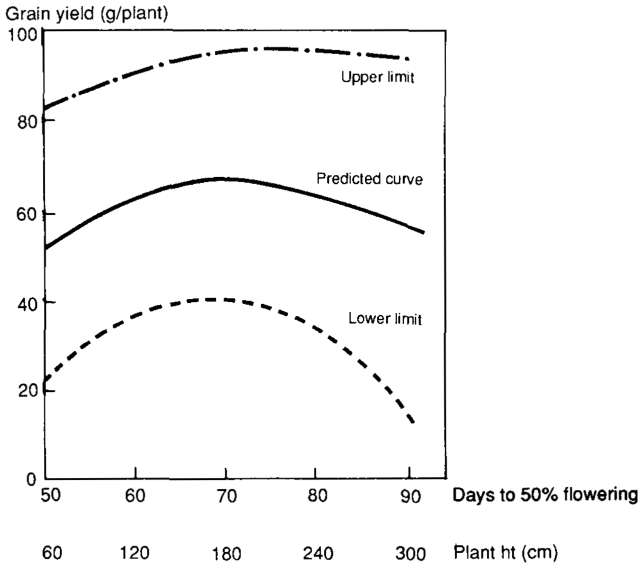


14. Deviations from the trend in sorghum yield in years of different rainfall patterns.

the growth cycles is optimized in relation to seasonal conditions through control mechanisms that are extremely sensitive to daylength and temperature. The design and development of productive and stable agriculture require changing the cycles of growth and reproduction in such a way that the emphasis is on the economic product rather than on total dry matter, with the more critical phases of growth coinciding with favorable periods of climate.

Duration, dry matter production, and distribution. Most traditional kharif sorghum of the Deccan and central Indian plateaus matures in 140 d or longer. Duration of a normal rainy season is from mid-June to late September, with July the peak rainfall month. Sorghum is usually in the vegetative stage until the 1st or 2d week of October. If the rains cease early, yield losses are heavy. Total dry matter produced may be as high as 450 g/plant, nearly 70% of it accumulated in the stalk before flowering. The new hybrids and high-yielding varieties produce less dry matter per plant with greater accumulation in the earhead, resulting in better harvest indices, as high as a ratio of 50:50.

Superior sorghum hybrids and varieties (CSH-1, CSH-5, CSH-6, and CSH-9) with shorter growth durations (100-110 d) consistently yield well. Average yields



15. Optimum phenotype, related to plant height and days to flowering.

under rainfed conditions ranged from 2 to 4 t/h, with more than 6 t/ha under favorable rainfall. The critical growth stages—seedling, flower primordia, and grain filling—coincide with periods of assured rainfall or satisfactory soil profile moisture. In breeding for efficient water use in grain production, corrections for duration, dry matter production, and differentiation at optimal times of the season should constitute the first steps in modifying traditional tropical sorghums (N.G.P. Rao 1981; Rao 1972, 1982; and Rana 1982).

Optimum plant type. On the basis of studies of a wide range of variation for plant height, maturity, and yield, Rana et al (1984) established that an optimum plant type for high yields was one with 68 d to flowering and 175 cm plant height (Fig. 15). The current high-yielding and widely adapted rainy season hybrids in India are intermediate in height (170-200 mm) and days to flowering (67-75 d) and are described as intermediate optima. The cultivars found promising in other parts of the world also vary around this optimum. Tall, late types have no yield advantage.

In the postrainy season, modified cultivars with resistance to shootfly that can tolerate low temperatures under delayed planting are yet to become available. Currently available hybrids such as CSH-8R exhibit superiority under controlled early planting but lose their advantage if planting is delayed. Rabi planting cannot take place before mid-September. Hybrids and varieties that exhibit general superiority over the prevalent cultivar M35-1 have not yet been developed.

Hybrid homeostasis and adaptability. Our studies also have established that hybrids have homeostatic advantages over improved varieties, particularly under moisture stress. The hybrids CSH-9, CSH-6, CSH-5, and CSH-1 yielded the highest in kharif areas of India and were the most widely adapted. Improved varieties were superior to local varieties in yield and adaptability but were not comparable to hybrids. Local varieties were characterized by low yields and high coefficients of variability.

Yield- and risk-preference-based rankings of the hybrids are closely related. Adaptability and stability also are correlated, lending support to breeding toward genotype alteration and multisite testing in pursuit of low risk and high yields (Barah et al 1981; Rao et al 1975, 1982, 1986).

Genotype-input management relations

Nutritional adaptation is widespread in nature, with distinct genotypic differences in responses to nutritional elements as well as to toxicities. The response of altered genotypes to fertilizer and population levels is spectacular and, coupled with their lower susceptibility to climatic variables, notably rainfall (Rao et al 1975), their adoption is on the increase, although fertilizer use on commercial sorghum fields is still low.

Considering all agronomic inputs, including use of fertilizer and pesticides, the performance of high-yielding hybrids and varieties remains satisfactory only under optimal inputs (including irrigation water) and management. Consequently, "high yield agriculture" is associated with "high input agriculture." Whether this technology is applicable to the small farmers in developing countries has been questioned. Vidyasagar Rao et al (1981) examined this aspect in multisite experiments over several years. The top ranking hybrids and varieties maintained their relative ranks under both high and low levels of inputs and management. Other studies indicate that agriculture based on altered genotypes is not incompatible with lower inputs. The use and level of inputs are related more to availability, supply, and credit than to limitations imposed by technology.

Sorghum-based cropping systems

The component cultivars of traditional intercropping systems are themselves products of climate-vulnerable subsistence agriculture. Except for the spread of risk over species, they are essentially replacement systems characterized by low yields. Unless the components themselves undergo radical alteration, the system will not change.

Rao and Rana (1980) demonstrated that single crop stability and productivity are prerequisites for productive intercropping systems. Several All India intercropping trials with pigeonpea, soybean, and peanut as intercrops showed that sorghum was the primary crop; it yielded 90-95% of its single crop yield. New and more profitable crops like onion and garlic are now being tested. Traditional intercropping systems which had been replaced by single crops of hybrid sorghum are now being oriented toward more profitable intercropping.

While such intercropping systems are advantageous in areas of relatively low rainfall, multiple cropping is more profitable in high-rainfall areas with moisture retentive soils. A vast portion of the black soil belt of the Deccan and central Indian plateaus where 800 mm annual rainfall sustained 5- to 6-mo crops of traditional sorghum can now produce an assured crop of a short-season hybrid in all years and a following crop of safflower or chickpea in normal and above-normal rainfall years. Kharif sorghum followed by safflower and mungbean followed by rabi sorghum have proven to be the most feasible and profitable cropping sequence in Vertisols.

Rao (1985) and Rao and Rana (1980) demonstrated that present shortages of grain legumes and edible oilseeds could be met by sorghum-based intercropping and sequence cropping in existing sorghum areas. That productivity will probably be achieved by maximizing the number of crops rather than by increasing the yield of each crop in areas in India and Africa where long season sorghums have traditionally been cultivated. Emphasis on manipulating the cropping system with modified cultivars will be more fruitful, as was demonstrated in India, than attempts to breed improved cultivars comparable to long-duration local cultivars.

Soil and water conservation measures

Resource conservation and effective utilization of all components of production are now being emphasized in watershed-based dryland farming in both black and red soils. These measures will provide a long-term base for reaping sustained benefits from modified cultivars, cropping systems, and production practices.

Analysis and conclusions

Vulnerability has been defined as the capacity to suffer from harm or to react to adversity (Timmerman 1981). In considering the vulnerability of crops to climatic elements, surface hydrology, soil processes, and systems of exchange between the atmosphere and biota also need to be considered. An approach that will obtain reasonably good yields under adversity and optimum yields if favorable conditions prevail is probably best. A production system using modified cultivars, cropping systems, and management practices has conferred considerable stability to the productivity of kharif sorghums across a range of geographic areas and climatic regimes in India.

Relevance of the case study to semiarid tropics

Components responsible for a change in the productivity of kharif sorghum in India include

- Development of hybrids with wide adaptation and stability, reflecting a quantum jump in yield level across a range of geographical areas and climatic regimes. Plants with intermediate height and growth duration met the demand for food and fodder and performed well in good and bad years.
- Production technology with emphasis on time of planting to avoid shootfly damage, moderate use of fertilizer, enhanced plant populations, and a block approach to hybrid coverage to avoid earhead pests like midge and head bugs.
- Improvements in grain quality, fodder yield, and tolerance for pests and diseases.
- Development of hybrid sorghum-based intercropping and sequence cropping systems that incorporate grain legumes and edible oilseeds.

The question has been raised, whether such a program is relevant and feasible in the rest of the semiarid tropics. One argument from West Africa has been that most technologies have been oriented toward improving single crops rather than complete farming systems, and that single crop technologies have not been compatible with the socioeconomic rationale of practices developed by the farmers (Abalu and D'Silva 1980).

Common features of several African agricultural systems are planting in wide rows; using long-duration, tall cultivars; cultivating low plant populations, not using fertilizer, cultivating predominantly with hand tools, and mixing several crops in space and time. The traditional component crops and practices themselves have been vulnerable to climatic fluctuations and have not provided the necessary yield increase or risk avoidance. Crop components must be altered in such a way that they have the capacity to yield well across varying conditions. Once single crop performance and stability are accomplished, the new components can be integrated into the cropping systems. Cultivar alteration must occur before farming system alteration (Rao 1980).

Another argument is that sorghum work in India may not have relevance to Africa. Rao (1977) studied the sorghum situation in Sudan, Somalia, and South and North Yemen. The Sudan situation is similar to the Deccan Vertisol conditions of India. He found no serious barriers to adaptation per se. Hybrid materials developed at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) were found promising, and a hybrid sorghum was released. Yield performance of a number of introduced varieties did not indicate any special barriers. In Somalia and the Yemen, introduced materials did well, although no serious efforts were made for large-scale adaptation.

A large number of advanced breeding material developed in India, at ICRISAT and various programs, were screened in West Africa for yield, pest complex, and grain quality over 3 yr. Selections S-34 and S-35 were released for general cultivation in Cameroon. S-35 performed well in Nigeria, Niger, and other countries. The trials also demonstrated that the long growing seasons of the Sudan and the northern and southern Guinean zones are amenable to more efficient cropping sequences over a single 6- to 7-mo sorghum crop.

In the southern African countries Zimbabwe and Zambia, breeding material developed at ICRISAT in Hyderabad, India, show promise and could be made available to farmers after production technology is developed. In East African countries with long and short rains, short-duration sorghum could be adapted to fit into the cropping systems.

In the dryland cereal areas of Africa, maize has made inroads into sorghum areas. It is vulnerable to climatic fluctuations. To stabilize cereal production, marginal areas of maize should be returned to sorghum or millet.

It is necessary to aim at quantum increases in yield levels rather than at marginal increases. Components of the cropping system need to be altered, then fitted into properly designed inter- and multiple-cropping systems with moderate fertilizer use. Only revolutionary changes, rather than evolutionary changes, can bring about the needed productivity and stability.

The resource-poor farmer

By and large, farmers who grow coarse grains, pulses, and oilseeds in mixed or sole cropping systems are in general resource poor. The coarse grains often are referred to as “poor man’s cereals.” Holdings of these farmers are marginal (less than 1 ha). In India, the net cultivated area of an average holding was 1.8 ha in 1976-77. Marginal holdings account for 55% of all holdings. Food crops predominate, with 80-90% coarse grains and mixed cropping in smaller holdings (Sarao 1983). In West Africa, most farms are small. In Mali, the number of hectares cultivated per resident ranges from 0.5 to 1.l; in Niger, it is 0.6 to 1.7. In Sudan, there are some large mechanized farms. In some southern African countries, both commercial large-size farms and small communal farms exist. Argentina has some large farms.

Analysis of technology option patterns in irrigated and rainfed areas of India shows that the operators of small- and medium-size farms have led in adopting new technology. Studies of kharif sorghum and dryland crops at Indore (Chaudhari 1980) and other areas showed that labor-intensive technology favored small farmers than large farmers.

The demand-price situation

Food crops, which occupy 80-90% of the small and marginal farms, are first for home consumption, then for the market. Prices of coarse grains in general are lower than those of grain legumes, edible oilseeds, or other commercial crops. The analysis of Binswanger et al (1980) indicated that variability in production is the major source of income risk, rather than price variability. The first priority has to be improved and stabilized production. While prices of legumes and oilseeds increased several fold, food grain prices, particularly those of coarse grains, were almost constant. Hence, there is a tendency to shift to other crops. In India, when sorghum production dropped below 8 million tons, imports were needed. But now, production of 11-12 million tons of sorghum per year meets the national demand. If that yield is exceeded, prices fall and farmers have no motivation to increase production.

Our approach in India has been to manipulate both intercropping and sequence cropping in such a way that net returns are maximized while meeting the need for coarse grains and fodder. We are trying to introduce high-value crops into the system. We also are attempting to diversify the use of sorghum into animal feeds and other areas, such as malt, starch, and energy production, to move in the direction of whole plant utilization. Our experience with the low-value crops has been that first, production has to increase and stabilize to meet national requirements. Then attention can be paid to income enhancement through manipulation of cropping systems and diversification of commodity uses.

Per capita consumption of coarse grain in general has decreased. In West Africa, there is evidence that pricing policies have contributed to shifts in consumption, from domestically produced coarse grains to imported staples.

A generalized approach

The vulnerability of most tropical sorghums stems from their growth duration relative to the rainy season, their pattern of dry matter production and distribution, and their highly localized adaptation. To develop better approaches to crop improvement, several agroclimatic regions have been defined and the duration of crop growing seasons computed. According to Krishnan (1974), the crop growing season in the sorghum belt of India varies between 130 and 206 d. In similar estimates in Africa, a season of up to 240-260 d has been computed.

One question is, when 90- to 110-d sorghum can yield better than traditional sorghum of 150-210 d, why should we grow excessively long-duration sorghum. Today, the adaptability barriers have been broken. In India, in place of a multitude of agroclimatic regions for the kharif season, we treat it as 1 zone and grow 90- to 110-d duration sorghum. Modified sorghum cultivars developed in India and screened for adaptation to the soil and climatic conditions of Africa have proved promising. The heterozygote advantage established with hybrids is being gradually built into inbred varieties. Coordinated international/national programs for screening, selection, and testing can identify cultivars that are more stable and resistant to prevalent and potential insect pests and diseases, with adaptability for a range of situations.

Despite experience with sorghum, wheat, and rice, some still tend to discourage a generalized approach and to create restrictions. The concept of site-specific research is being extended too far. In Africa, we still seem to quarrel with our goals, some pleading largely for preservation of existing systems, with only minor changes, and others for radical genotype and system changes (Rao 1985). Our choice is for the latter.

To us, the rainy season sorghum belt of the tropics is a coherent region. When 90-to 110-d sorghum yields as much as sorghum with double that duration, it is wasting the energies of the plant and ourselves to breed sorghum comparable in maturity to the traditional cultivars of different regions. The climatic resources in long-season areas could be better exploited by developing more efficient cropping sequences based on modified cultivars. Globally coordinated programs in cooperation with regional and national networks could bring about near elimination of the climatic vulnerability of sorghum.

The same approach may hold for millet. Breeding broad-based cultivars could provide the basis for refinements, with agronomic adjustment at the regional level.

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ADVANCING DRYLAND AGRICULTURE: PLANT BREEDING ACCOMPLISHMENTS AND PERSPECTIVE*

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INTRODUCTION

At the very outset, let us pay our homage to the memory of the founder of our Society, Dr. Benjamin Peary Pal, who left us for the heavenly abode on September 14, 1989. Genetics is a creative science and plant breeding creates superior forms. Be it wheat breeding, enhancing the beauty of the roses, nurturing agricultural and environmental sciences, refreshing the human environment with his ever fresh sense of dignified humour, combining science and statesmanship—creativity had been the hallmark of Dr. Pal. Let us pay our reverence to his foresight and extraordinary creative abilities. Wheat and Pal are synonyms in India.

While wheat furnished the leadership for irrigated agriculture, rainfed agriculture lagged behind. Let us, on this occasion, address ourselves to this risky endeavour of rainfed agriculture covering nearly 70% of the Indian agricultural canvas.

Agricultural systems represent induced changes in the natural balance. That such induced changes have not made a significant impact in improving the productivity and sustainability in dryland agriculture of the arid and semiarid tropical environments; that India's Green Revolution largely bypassed nearly 70% of its rainfed lands where productivity is low and risk-prone; that it continues to be near static and needs a change for promoting overall agricultural growth and equity; that without investments matching those in irrigated sector to modify its resource base, dryland agriculture would not advance are some of the statements frequently made by scientists and science administrators.

We continue to look at dryland agriculture as prone to yield risks, price risks, and resource risks. The weak resources of the farmer, the low value crops predominating dryland systems, the lack of multiple productivity options and institutional support have been frequently cited as constraints in the way of progress. Technological changes and their interactions with ecological situations, economic and social factors largely determine the magnitude of change in the dryland agricultural production systems. Plant manipulations

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*Second B. P. Pal Memorial lecture delivered at New Delhi on February 12, 1991.

are more potential and permanent compared to environmental modifications and together they could lead towards stability. It shall be my endeavour to analyse the present status of dryland agriculture and develop a perspective for its future in India.

AGRICULTURAL RESEARCH IN DRYLANDS: BRIEF HISTORY AND ANALYSIS

India's cultivated land varies between 141–143 million ha, of which 68% (95-96 million ha) is under rainfed agriculture. Compared to the significant changes in production and productivity of irrigated wheat and rice during the Green Revolution era, productivity changes in the vast rainfed belt are of a lesser magnitude. Nevertheless, the changes witnessed have been in the positive direction. The pace of agricultural advancement of this region needs acceleration and is vital to the overall agricultural growth and development. The history of dryfarming research may be considered in four phases, the salient features of which are briefly summarized:

(1) *Bombay dryfarming research (1930)*: Soil erosion control and moisture conservation through contour bunding and crop cover supplemented by agronomic practices (periodical deep ploughing, shallow preparatory tillage, interculturing, low seed rates, wide spacing etc).

(2) *Soil conservation research (1954)*: Understanding runoff patterns; matching crop varieties with farmers' resources etc; establishing soil conservation research centres.

(3) *High yielding varieties programme (1964)*: Growth rates of rainfed kharif sorghum matched those of irrigated wheat and rice due to development and spread of hybrids; advances and subsequent setback in the spread of pearl millet; limited success with pulses and oilseeds.

(4) *Establishment of All-India Coordinated Research Project on Dryland Agriculture (AICRPDA) (1970) and ICRISAT (1972)*: Their studies emphasize greater integration of resource and crop based technologies.

The watershed approach is being projected as the main plank for overall improvement of dryland agriculture in India in the years to come; the observations of Walker and Ryan [1] on watershed studies are briefly summarised below:

(1) The cost benefit ratios of water harvesting and supplemental irrigation were not attractive.

(2) The benefit of groundwater recharge are difficult to quantify.

(3) Frequently, water present in the pond when not needed, and absent when needed.

(4) Irrigating low value crops during the season had no justification.

(5) Available sealants were not cost effective in controlling seepages.

(6) The more beneficial watersheds were in the assured rainfall vertisol regions where once in three years, following soybean, water was available for wetting seed bed of wheat crop.

(7) Of the components of the watershed technology package, e.g. broad based furrows, field and main drainage channels, improved varieties and cropping systems, modest doses of fertilizers, dry seeding before onset of monsoon, placement of seeds and fertilizers and plant protection, only selective components such as plant protection in case of some crops, adoption of hybrids of sorghum and new crops like soybean have only been accepted.

Walker and Ryan [1] remarked, "it is hard to see how the marriage of technically optimal land and water management to biological technology is going to alter these perceptions."

Amongst these four stages, the high yielding varieties programme (HYV) had selective impact on productivity of drylands, especially with kharif sorghum, pearl millet, and spread of some superior varieties of pulses and oilseeds.

The observations of Walker and Ryan [1] on technology design for drylands may be summarized as follows:

(1) Land improvements, central to watershed approach, have several limitations and do not compare favourably with investment in well irrigation.

(2) Technology targetting towards vulnerable groups is ubiquitous; gradient approach to identify and promote practices compatible with local circumstances are more meaningful.

(3) Direct employment consequences of technology change in drylands are nearly absent.

(4) Productivity gains and increasing commodity supply will have a better impact on nutritional status than genetic improvements in nutritional quality.

(5) Reduction of variance for a given level of yield would not reduce fluctuating household incomes.

(6) Mean yield and profitability should remain front and centre on the agenda of the objectives.

THE APPROACH

It is against this background that future dryland research needs to be designed. Alternative research tools and models are being developed keeping in view the concept of sustainability together with productivity. Sustainability is a somewhat elusive concept, and different definitions are available. The FAO and University of Nebraska definitions are reproduced:

> "Sustainable agriculture should involve the successful management of resources for agriculture to satisfy changing needs while maintaining or enhancing the quality of the environment and conserving natural resources" (FAO/TAC).

> "A management strategy which helps the producer to select hybrids and varieties, cultural practices, soil fertility progress and pest management approaches which reduce costs of purchased inputs, minimize the impact of the system on the immediate and off-farm environment, and provide a sustained level of production and profit from farming" (University of Nebraska).

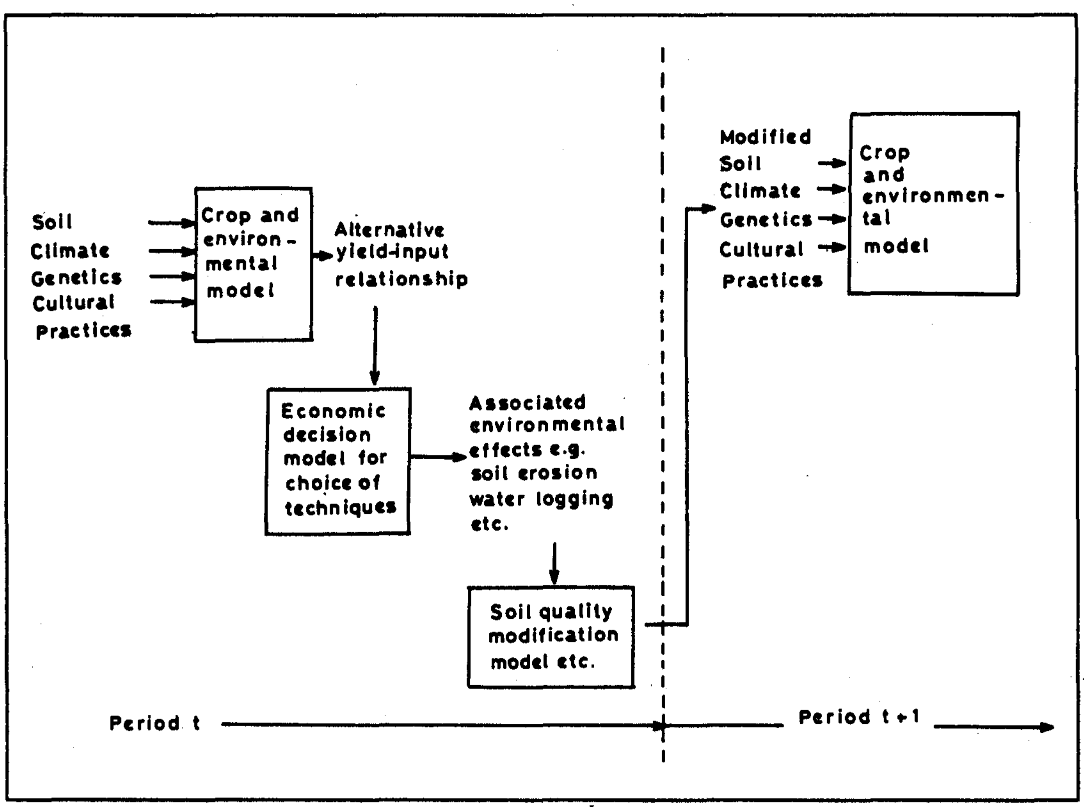

Fig. 1. **Schematic diagram of analytical elements in the methodological approach of Ereshko et al. Source: Parikh, 1988, p. 41 (reproduced from IIASA publication).**

With the Nebraska definition in view, one of the models developed by the International Institute of Applied Systems Analysis is reproduced in Fig. 1. Considering 1990 as the end of the period t, and with a critical analysis and understanding of the effect of our interventions in dry land agriculture on the resources and the output, which to a large extent has been elegantly analysed by Walker and Ryan [1], we could use this crop and environment model for the period t+1, may be about 10 years hence, to pursue the goal that "mean yield and profitability should remain front and centre on the agenda". It is with this objective and the current status of dryland agriculture in its totality that I approach the problem of advancing dryland agricultural production and productivity.

THE RAINFED BELT AND ITS SOILS

The distribution of the vast rainfed belt across the various states of the Indian Union is presented in Table 1.

Table 1. Major rainfed areas of India in 1984–85, million ha

	States	Net area sown	Net irrigated area	Rainfed area	Irrigated area (%)
(i)	Madhya Pradesh	19.205	3.010	16.195	13.9
	Maharashtra	18.047	1.964	16.083	13.1
	Karnataka	10.549	1.693	8.856	18.0
	Andhra Pradesh	10.486	3.522	6.964	36.6
	Rajasthan	15.215	3.204	12.011	22.2
	Gujarat	9.583	2.240	7.343	25.5
	Total	83.085	15.633	67.452	
(ii)	Uttar Pradesh	17.248	9.879	7.369	48.4
	Bihar	7.643	2.795	4.848	36.7
	Orissa	6.288	1.466	4.822	23.1
	West Bengal	5.341	1.980	3.361	26.1
	Assam	2.696	0.572	2.124	15.4
	Total	39.216	16.692	22.524	
(iii)	Tamilnadu	5.788	2.640	3.148	49.5
	Kerala	2.184	0.271	1.913	14.7
	Total	7.972	2.911	5.061	
(iv)	Punjab	4.189	3.621	0.568	90.5
	Haryana	3.616	2.189	1.427	63.6
	Himachal Pradesh	0.580	0.095	0.485	17.1
	Jammu & Kashmir	0.735	0.309	0.426	40.5
	Total	9.120	6.214	2.906	
(v)	N-E States	1.03	0.240	0.783	23.4
	Others	0.299	0.089	0.210	
	Total for India	140.715	41.779	98.936	30.7

States in category (i) represent the largest dryland belt of India's arid and semiarid tropics. The Northwestern arid zone with aridisols and low rainfall is a more fluctuating and risk prone environment for arable crops. The vertisol rabi sorghum belt of Deccan is also vulnerable. The vast vertisol belt of these states together with the Bundelkhand region of Uttar Pradesh receiving moderate to heavy rainfall and predominant kharif cropping (cotton-kharif sorghum) is the most potential belt for advancing crop production. The distribution of the assured and vulnerable portions of the vertisol belt of India under different rainfall regions is presented in Table 2.

The eastern and northeastern states in category (ii) have mostTof the lowland rice for which special rice production programmes have been developed. Under irrigation, sugarcane, wheat and rice–wheat systems are practiced. The productivity of rainfed kharif areas and kharif fallows of irrigated wheat belt has not witnessed any major change.

Table 2. Distribution of vertisol in different rainfall zones (area in million ha)

State	Area in different rainfall zones			
	500–750 mm	750–1150 mm	1150 mm	total
Maharashtra	10.00	11.22	3.35	24.57
Madhya Pradesh	0.16	8.51	7.85	16.52
Gujarat	2.40	1.81	2.28	6.49
Andhra Pradesh	1.96	2.66	2.35	6.97
Karnataka	5.97	0.76	0.11	6.84
Total	20.49	24.96	15.94	61.39

Under category (iii), dryland areas of Tamil Nadu served by the northeastern monsoon, are vulnerable.

States in category (iv) are largely irrigated. Himachal Pradesh, and Jammu and Kashmir are somewhat temperate. Category (v) represents the high rainfall regions of Northeastern India with specialized hill agriculture.

An analysis of the growth rates of these states for food production (Table 3) reveals that Maharashtra, in spite of being predominantly rainfed, has made good progress and serves as an example that rainfed nature by itself need not be a deterrent to agricultural progress. The black soil rainfed areas of Madhya Pradesh, Karnataka, Gujarat and Andhra Pradesh are showing signs of progress.

THE CLIMATIC DIMENSION

The major concern of the rainfed belt is its low productivity and sensitivity to climatic fluctuations, aberrations, catastrophies and possible climatic changes. India is divided into 34 meteorological subdivisions, 10 of which cover the black soil belt.

Rainfall is the most important parameter influencing crop yields. A deficiency of 26–50%

Table 3. Classification of Indian states by weather-adjusted rates of growth in foodgrains production and growth in total population: 1970–71 to 1984–85

Positive growth in production > population growth	Positive growth in production < population growth	Negative growth in production; population growth positive
Maharashtra (6.23, 2.22)	Jammu & Kashmir (2.31, 2.54)	Kerala (–0.38, 1.80)
Punjab (5.92, 2.15)	Gujarat (2.07, 2.37)	Tamil Nadu (–0.64, 1.65)
Uttar Pradesh (4.32, 2.26)	Madhya Pradesh (1.95, 2.27)	
Haryana (3.90, 2.65)	Assam (1.90, 2.76)	
Andhra Pradesh (3.16, 2.06)	Orissa (1.59, 2.18)	
All India (2.70, 2.24)	Bihar (1.25, 2.18)	
	Rajasthan (1.07, 2.87)	
	Karnataka (1.03, 2.35)	
	Himachal Pradesh (0.80, 2.10)	
	West Bengal (0.54, 2.09)	

Note. The figures in parentheses refer to growth rates (in %) of food grain production and population growth, respectively. Population (rural and urban) growth is estimated from the 1971 census and Registrar General's estimates for 1985.

from the mean precipitation of a subdivision is considered a moderate drought and that over 50% as severe drought. Similarly, an excess precipitation of 26–50% over the mean is flood and more than 50% severe flood. The probability of the frequency of occurrence of droughts and floods in the vertisol semiarid regions (Table 4) was nearly equal during the

Table 4. Droughts and floods (1871–1984) in the meteorological subdivisions of the predominantly vertisol belt

Subdivision/region with No.	Area (km^2)	Droughts			Floods		
		No. of drought years	probability of drought	No. of years of severe drought	No. of flood years	probability	No. of years of severe flood
18. East Rajasthan	147, 128	19	0.167	6	18	0.158	2
19. West Madhya Pradesh	232, 315	11	0.097	—	10	0.088	—
21. Gujarat	86, 034	23	0.202	9	24	0.210	3
22. Saurashtra & Kutch	109, 950	34	0.298	11	30	0.263	14
24. Madhya-Maharashtra	115,309	13	0.114	2	11	0.097	1
25. Marathwada	64.525	20	0.175	5	23	0.202	4
26. Vidarbha	97, 537	12	0.105	1	12	0.105	1
28. Telegana	114,726	17	0.149	—	18	0.158	3
29. Rayalseema	69, 043	22	0.193	4	20	0.175	6
32. North Karnataka	79,895	12	0.105	—	13	0.114	1

Source. Parthasarathy et al. [2].

period of study 1871–1984 [2]. While the damage resulting from droughts received considerable attention, damage due to excess rains, more particularly late (October) rains, did not attract similar scientific or political attention. In the black soil belt excess rains could be more damaging than moderate drought.

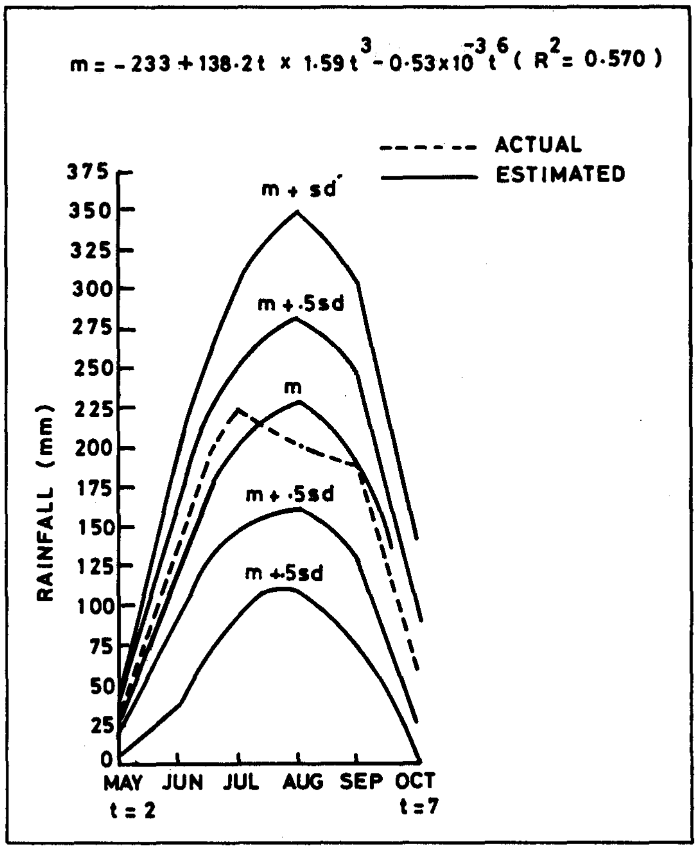

Fig. 2. Monthly rainfall distribution with deviations (Parbhani, Maharashtra, 1944-1986).

Rainfall fluctuations within 0.5 SD on either side of the mean are manageable without yield losses; fluctuations over this, particularly on the heavy rainfall side have been more damaging to cotton and sorghum and need further technological attention (Fig. 2). In case of cotton, square, bud flower, and boll shedding during rains and increased boll worm attack, and with sorghum, grain moulds and deterioration resulting in low quality grain are the consequences. These problems need further research attention.

Figures 3 and 4 reveal the greater vulnerability of the rabi sorghum and bajra belts. The bajra belt is characterized by low rainfall and high evapotranspiration. The vulnerability of the rabi sorghum belt at Bellary and to a lesser extent at Sholapur is reflected in the water balance studies (Fig. 5). Fig. 6 shows the aberrations of rainfall, the commencement of cessation of monsoon. Continuous rainless days up to 31 days have been encountered during the monsoon season. These have been taken into consideration in developing the breeding philosophies for the hybrids and improved varieties of sorghum which have not failed under the worst droughts encountered. They were at a disadvantage if late and continuous rains were received in October.

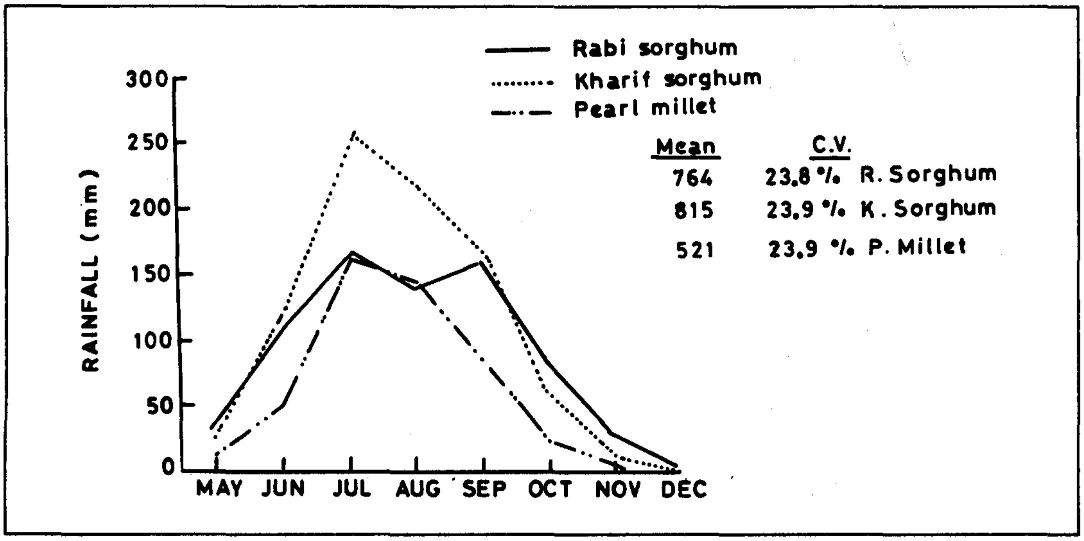

Fig. 3. Rainfall distribution in rabi sorghum, kharf sorghum and pearl millet tracts in India.

The effects of delayed monsoon and late sowings on yield of sorghum and pearl millet are depicted in Figs. 7 and 8. Sorghum is more vulnerable to delayed sowing and incorporation of shoot fly resistance will mitigate this to some extent. Consequent to the

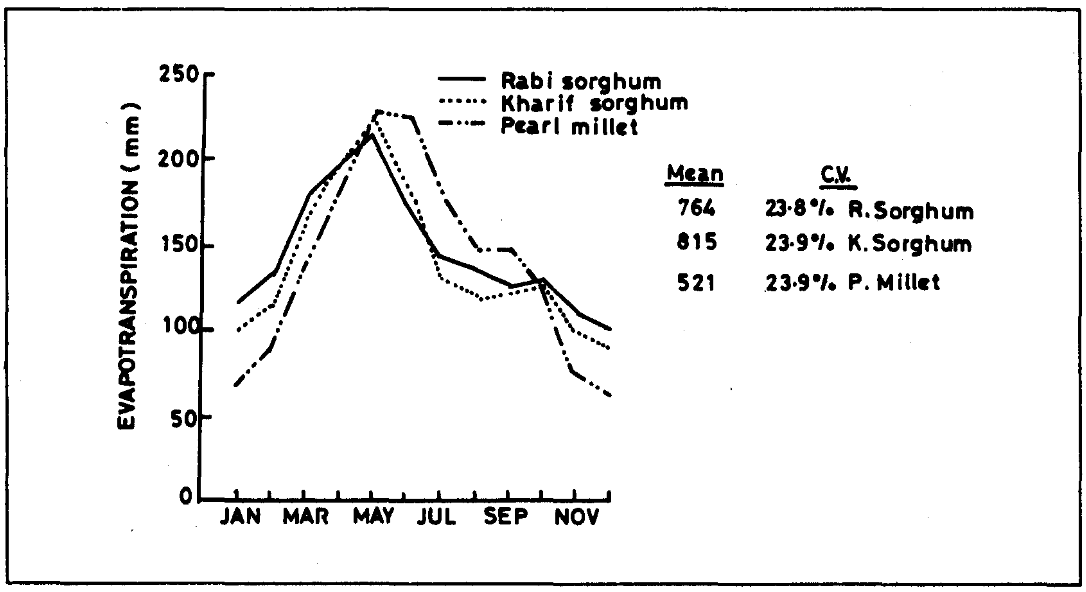

Fig. 4. Potential evapotranspiration in rabi sorghum, kharif sorghum and pearl millet tracts in India.

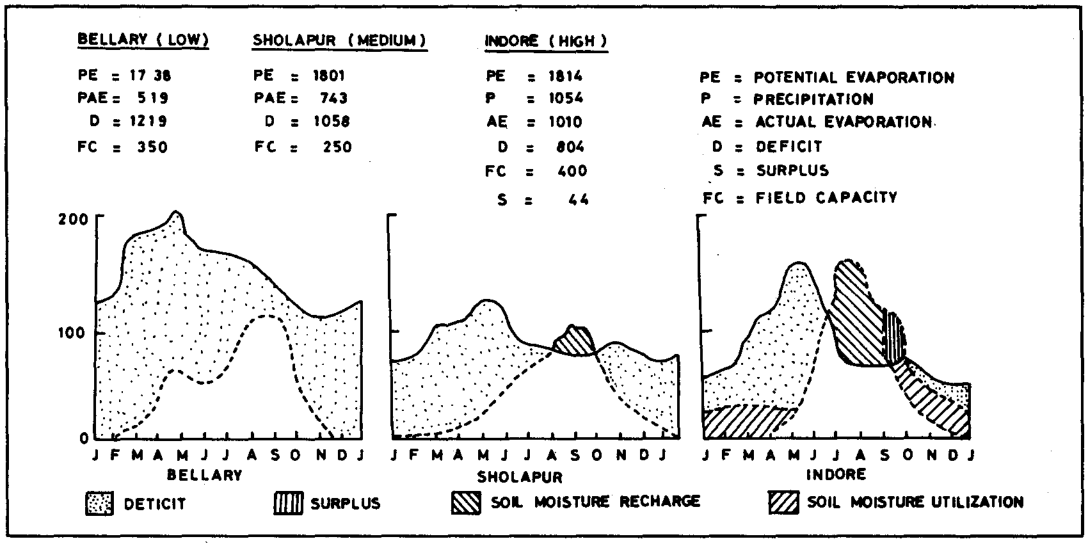

Fig. 5. Climatic water balance for low, medium and high rainfall zones in black soils (based on long-term meteorological monthly means, all measurements in mm).

crop modifications and improved practices with the HYVs, the effects of drought have been considerably mitigated and the Indian agriculture acquired resillience to subnormal monsoons (Table 5).

Decadal variability of rainfall in this century (Fig. 9) indicated that since 1940 there has

Table 5. Change in rainfall and foodgrain output

Year	Change in CRI from normal (%)	Fall in CRI with previous year as base, (%)	Fall in output over the previous year, %			Total Foodgrain output (million tons)
			kharif	rabi	total	
1964–65	+ 6.0	—	—	—	—	89.0
1965–66	–18.7	–23.3	–18.7	–17.7	–18.4	72.3
1978–79	+10.0	—	—	—	—	131.9
1979–80	–20.0	–27.3	–19.0	–13.7	–17.0	109.7
1981–82	+0.2	—	—	—	—	133.3
1982–83	–13.2	–13.4	–12.5	+9.2	–2.9	129.5
1985–86	–4.0	—	—	—	—	150.5
1986–87	–13.8	–10.2	4.3	–4.0	–4.3	144.0
1987–88	–27.5	–13.7	–8.8	+0.0	–4.9	138.4

Source. NCAER.

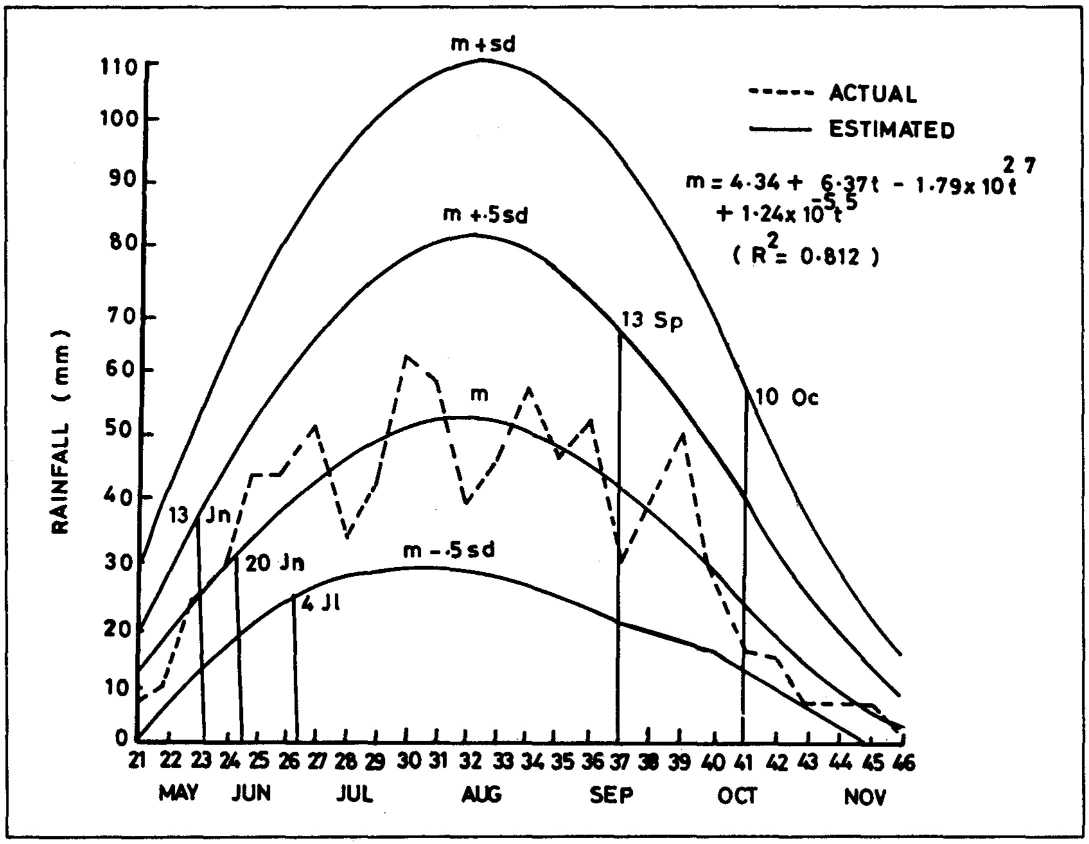

Fig. 6. Weekly rain fall distribution with deviations, com mencement and cessation (Parbhani, Maharashtra).

Table 6. Progress of production of some agricultural commodities in India (million tons)

Crop/commodity	1950–51	60–61	70–71	80–81	88–89
Foodgrains	50.82	82.02	108.42	129.59	170.25
Rice	20.58	34.58	42.22	53.63	70.67
Wheat	6.46	11.00	23.83	36.31	53.99
Coarse cereals	15.38	23.74	30.55	29.02	31.89
Grain legumes	8.41	12.70	11.82	10.93	13.70
Oilseeds	5.16	6.98	9.63	9.37	17.89
Cotton (m. bales)	3.04	5.60	4.76	7.01	8.69
Jute (m. bales)	3.31	5.26	6.19	8.16	7.70
Sugarcane	57.05	110.00	126.37	154.25	204.63
Potato	1.66	2.72	4.81	9.67	14.89
Tobacco	0.26	0.31	0.36	0.48	0.49
Coconut (m. nuts)	35.82	46.39	60.75	57.20	81.61

been a declining tendency together with an increase in the coefficients of variation [3]. The drier or wetter monsoons or extremes have been related to the ENSO (El Nino-Southern Oscillations) and depend on phase locking between the two events.

In the last 100 years, globally averaged annual surface air temperatures have increased approximately by 0.5°C. If this variation rises to 1°C, throughout the year air temperature decreases in the east of the central part and N–W India. The effects are likely to be more noticeable in N–W India during monsoon.

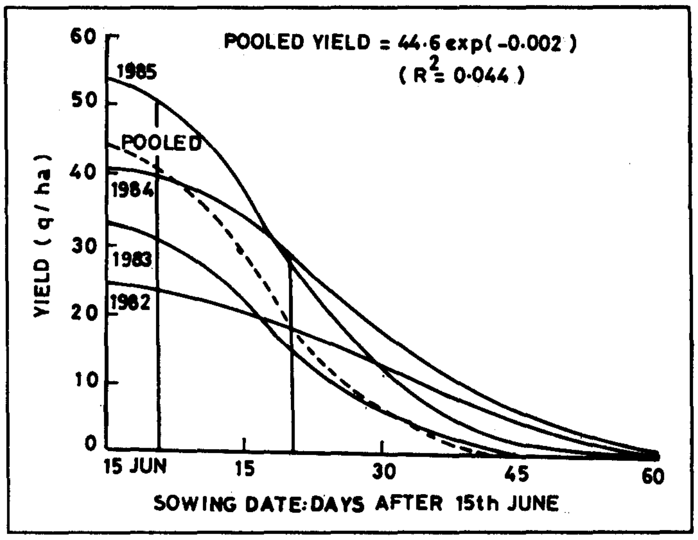

Fig. 7. Relationship between sowing time and yield of kharif sorghum.

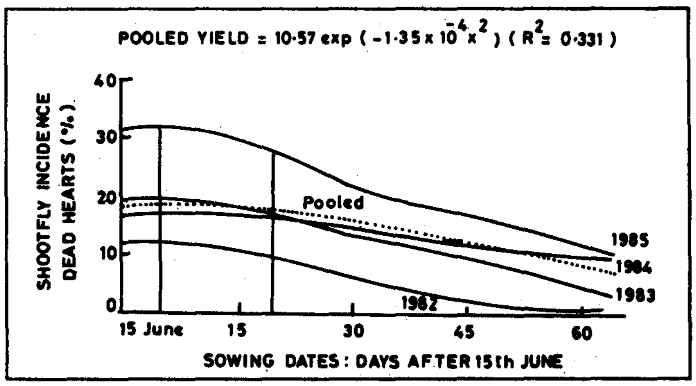

Fig. 8. Relationship between sowing time and yield of pearl millet.

Preliminary estimates of climatic changes in India [4] consequent to limited global warming indicate that during June–August and September–November precipitation is expected to increase along the west coast, and in most of the parts of Northern India increased precipitation might result. In the eastern parts of the subcontinent, including Andhra Pradesh and Orissa, precipitation might decrease slightly. During the September–November period also, the situation is expected to be similar except that rainfall may increase a little. The consequence of this is that during the monsoon season, indications are that rainfall may increase over the major parts of India. In general, the climatic changes are likely to be more favourable to the rainfed lands. Crop improvement programmes have to take cognisance of the impending changes.

COMMODITIES, CROPS AND PRICES

Cereals dominate the production system of dryland agriculture, followed by pulses and oilseeds. The progress in production of various crops and commodities is given in Table 6; and their approximate total area and the proportion of rainfed areas in Table 7. The growth rates of rainfed crops during the Green Revolution era are presented in Table 8. During the period 1967–68 to 1988–89, the areas decreased under all coarse cereals, chickpea and cotton. The productivity gains, though moderate, are positive in all cases. The yield gains are almost entirely a result of the spread of high yielding hybrids and varieties (Table 9).

The growth rate of kharif sorghum was particularly impressive and was as good as wheat till the early 1980s and influenced overall sorghum production. Later it started stagnating.

The possible reason for reduction in the area of coarse grains is the decline in per capita consumption in the rural as well as in urban sectors. Data from National Sample Survey reveal, in the specific case of sorghum, that per capita consumption declined in all the major sorghum growing states of Maharashtra, Karnataka and Andhra Pradesh. In Maharashtra, sorghum's share in total consumption fell from 60 to 45% between 1977–78 and 1986–87. Compared to wheat and rice or pulses and oilseeds, price increases of coarse cereals have been moderate (Tables 10, 11). In case of sorghum, the price rise of fodder was much greater compared to price rise of grain sorghum, resulting in reduction of total returns in case of the dwarf and semidwarf high yielding hybrids. In the mid-1980s,

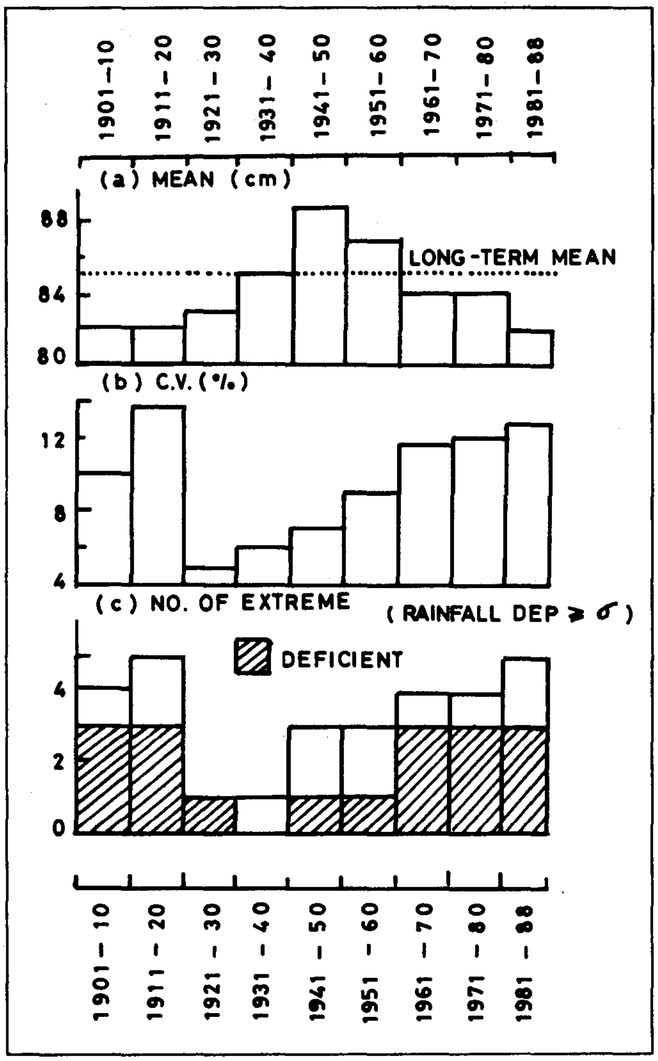

Fig. 9. Decadal variability of Indian summer monsoon rainfall (1901-1988): (a) mean, cm; (b) coefficient of variation; and (c) number of extremes (R. K. Verma, 1990).

the grain: fodder price ratio declined from about 6.0 to 3.0%. During 1975–79, the share of fodder value was reported 0.42, whereas by 82-86, it rose to 0.58. Introduction of irrigation, addition of crops like soybean, and greater attention to pulses and oilseeds resulted in reduced areas under coarse cereals. The area of chickpea got reduced in favour of wheat.

In spite of the high prices of pigeonpea, profitability of this crop continues to be low due to low yields. The estimates of acreage response functions revealed that the impact of prices on acreage response of pigeonpea has been weak. Unless there are production advances, effects of price are likely to be small in advancing production and profitability.

Table 7. Major dryland crops (1986–87)

Crop	Total area (million ha)	Rainfed area (%)
Wheat	23	33
Rice	42	57
Irrigated	18	—
Lowland	16	38
Upland	6	14
Deep water	2	5
Coarse cereals	40	91
Sorghum	16	95
Pearl millet	11	94
Maize	6	80
Total pulses	23	90
Chickpea	7	80
Pigeonpea	3	96
Total foodgrains	127	68
Total oilseeds	19	81
Groundnut	7	85
Rapeseed & mustard	4	45
Cotton	7	70

SORGHUM: PHENOLOGICAL, PHYSIOLOGICAL AND GENETIC CHANGES

Table 8. All-India compound growth rates of rainfed crops in the Green Revolution era (1967–68 to 1988–89)

Crop	Rate of annual increase (%) in		
	area	production	yield
Rice	0.56	2.60	2.06
Wheat	2.02	5.27	3.17
Coarse cereals	–0.97	0.42	1.34
Sorghum	–0.64	1.23	1.88
Pearl millet	–0.86	–0.04	0.81
Maize	–0.10	0.89	1.00
Finger millet.(Ragi)	–0.02	1.52	1.55
Small millets	–2.60	–2.30	0.31
Total pulses	0.30	0.74	0.51
Chickpea	–0.68	–0.45	0.22
Pigeonpea	1.44	1.96	0.51
Oilseeds			
Groundnut	0.08	1.23	1.14
Rapeseed & mustard	1.50	4.01	2.48
Cotton	–0.35	1.83	2.18

The transformation of the traditional, tall, long duration, and climatically vulnerable tropical sorghums into the relatively short statured, early to medium duration cultivars with stable and economic yields even under the worst droughts encountered, is a fascinating story described elsewhere [5]. All-India average yields from 30-40 yield trials conducted each year over a 10-year period are given in Table 12.

From 1968-69 to 1980-81, the compound rates of sorghum production compared well with irrigated wheat (Table 13). If we consider the kharif sorghum only, the growth rate will be even higher. Later in the 1980s, rate of increase in production was slow because of demand and price

Table 9. Certified seed production of hybrids (1990–91)

Crop	Certificed seed produced (q)	State/quanity of seed (q)
Sorghum	237, 821	Maharashtra (156,646); Karnataka (25,775); Andhra Pradesh (24,200); Madhya Pradesh (22,000); Rajasthan (4,880); Gujarat (2935); Uttar Pradesh (2355); Dadar & N. Haveli (10)
Pearl millet	88,742	Gujarat (49983); Rajasthan (15,743); Maharashtra (12,516); A.P. (2000) Haryana (8500)
Maize	83,188	A.P. (18,300); Karnataka (21,440); Bihar (27,558); M.P. (4750); U.P. (2200); Rajasthan (2943); Sikkim (150) Manipur (300); Orissa (50); Gujarat (690); Maharashtra (1102)
Cotton	44,662	Maharashtra (16,433); Gujarat (15,020); M.P. (2839); Karnataka (1102); A.P. (850)
Castor	16,555	Gujarat (15,735); Maharashtra (616); Rajasthan (50); Karnataka (154)
Major Hybrids:		
	Sorghum	CSH 9 (108, 193); CSH 5 (99,201); CSH 6 (10,732); CSH 1 (9644); CSH 11 (5968)
	Pearl millet	BK 560 (44,468); MH 179 (23,574)
	Maize	Deccan 1 (19,680); High Starch (19,324); GS-2 (15,494); Ganga 5 (13,236)
	Cotton	DCH 32 (12,199); Hy 6 (10,420); Hy 4 (8427)
	Castor	GAUCH 1 (7795); GAUCH 4 (6021)

problems. The kharif sorghum production of Maharashtra doubled during the 1970s. The transformation of kharif sorghum in the black soil belt is "Green Revolution in drylands."

Another significant feature concerning kharif sorghum is the control of shootfly and midge, the two major pests, through management practices only without using pesticides. Sowing with the onset of monsoon and enblock coverages of the area with hybrids to avoid spread of varieties with different maturity periods in a given area were successful preventive measures adopted by farmers. The stability of production has been the result of a phenological adjustment of the growth stages with periods of moisture availability and took care of aberrations during the growth period. There was an optimum adjustment of the total dry matter and its distribution between stalk and grain.

While this approach paid rich dividends against subnormal and drought years in the black soil belt, the problem of occasional late rains during October resulted in greater deterioration and reduced grain quality and prices. The new hybrids like CSH 9 do have some in-built resistance to grain moulds and grain deterioration but if the rains happen to be continuous the soaking and drying of mature grain results in loss of grain quality. However, in such years, there is scope for a second crop of safflower to compensate for the loss due to reduced prices of low quality sorghum grain. The problem of grain moulds deserves further attention.

Table 10. Minimum support prices announced by the Govt. (Rs/q)

Crop	1980–81	1986–87	Increase (%)
Paddy	105	146	39
Wheat	130	166	28
Coarse cereals	105	132	26
Gram	165	280	70
Pigeonpea	190	325	70
Mung	200	325	73
Urd	202	325	63
Groundnut (in shell)	206	315	53
Mustard	250	415	66
Sunflower	183	390	
Cotton (kapas)	304	430 (320F)	116
	—	540 (H4)	

Table 11. Behaviour of wholesale prices of foodgrains from 1970–71 to 1984–85

	Annual increase (%)	CV around trend
Coarse cereals	4.95	15.85
Pulses	8.75	14.06
Rice	6.80	11.67
Wheat	5.22	10.98
All cereals	6.12	12.16
All foodgrains	6.55	10.29

In view of the changing consumption patterns of grain sorghum and increase in fodder prices, a reorientation of objectives has become essential. A beginning has been made in this direction. Future efforts in breeding kharif sorghums should be oriented towards:

(1) Slightly taller height (180–200 cm) without sacrificing grain yield. Studies on optimum plant type (Fig. 10) have shown that this is possible in the 70–75 days flowering duration.

(2) Incorporation of greater levels of resistance to shootfly, midge and grain moulds. Stalk rots and striga also need attention.

(3) The zerazera germplasm has served well in contributing to both yield and grain

Table 12. All-India average yields of promising sorghum hybrids

Year	Yield of different hybrids (q/ha)			
	CSH-1	CSH-5	CSH-6	CSH-9
1976	31.38	35.68	30.90	39.16
1977	30.19	29.52	34.18	37.03
1978	35.82	43.07	42.65	50.36
1979	35.22	38.08	36.48	43.53
1980	30.34	34.37	34.80	38.36
1981	34.48	42.78	36.32	43.49
1982	32.88	34.91	34.98	41.39
1983	28.29	31.30	29.01	36.91
1984	28.87	34.34	33.80	41.28
1985	32.34	34.07	32.73	38.89
Mean	31.97	35.81	34.59	41.04

quality. There are indications of zerazera derived males, females and varieties stagnating for yield. A wider germplasm needs to be utilized to get over these yield plateauing tendencies.

(4) Utilization of diverse cytoplasms which have been identified and well characterized. Apomixis, discovered in India, is yet to be used in fixing heterosis and efforts need to be strengthened.

(5) Enhancement of utility base of kharif sorghums through use in cattle and poultry feeds, production of industrial starches, high fructose syrup, malt and malt based foods and brews, energy, gur etc., oriented towards whole plant utilization (Fig. 11).

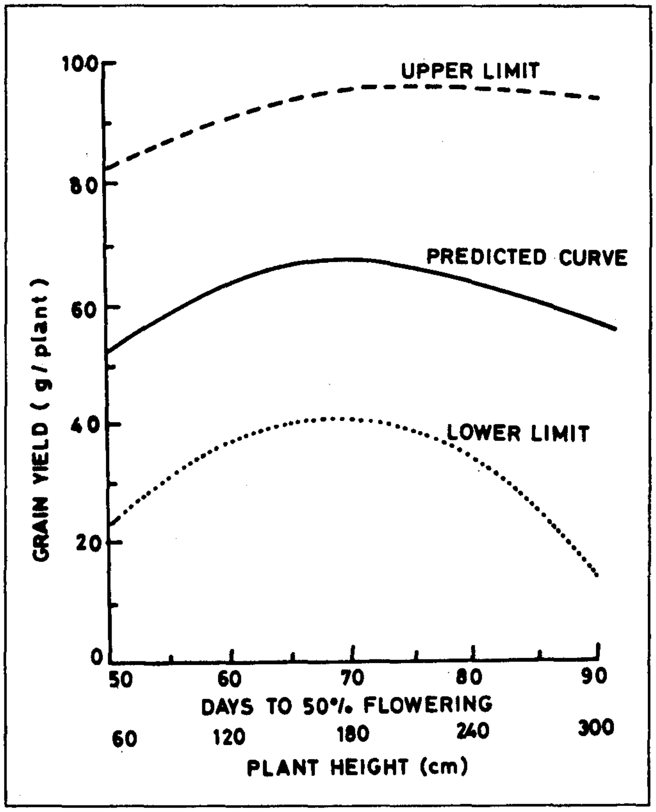

Fig. 10. Optimum phenotype as related to plant height and days to flowering.

(6) The rabi sorghum production has been stagnating. Exploitation of rabi germplasm in developing males, females, and hybrids to overcome the problem of low temperature sensitivity and shoot fly susceptibility of kharif based males and females is required and there are indications of progress in this direction. Improvement of quality rabi sorghum for human consumption is an urgent need.

Table 13. Compound growth rates of sorghum compared to other cereals on all India basis (1968-69 to 1980-81)

Crop	Area (%)	Production (%)	Yield (%)
Rice	0.73	2.20	1.45
Wheat	2.92	5.65	2.64
Sorghum	–1.18	2.06	3.28
Pearl millet	–1.16	–0.34	0.79

The sorghum improvement programmes now need a different orientation to meet the changing consumption and price trends and should provide the basis for agro-industrial development of the black soil kharif sorghum belt.

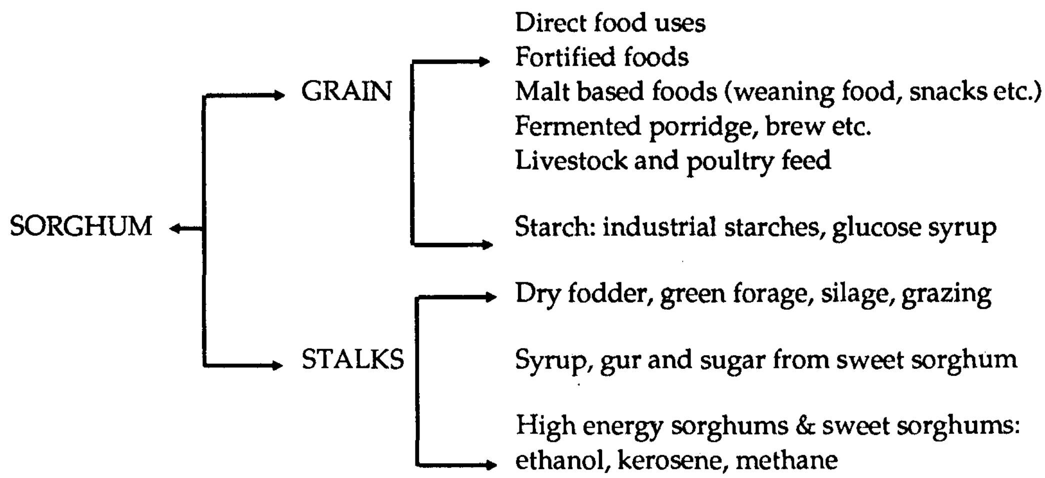

Fig. 11. Whole plant utilization of Sorghum.

PEARL MILLET

The introduction of hybrid pearlmillet in the mid-1960s witnessed rapid growth in its production, but the susceptibility of the hybrids to downy mildew proved to be a major setback. Subsequent efforts in developing new hybrids and populations salvaged the problem to a great extent, but on account of the soil-climatic conditions, the northwestern arid zone, the predominant pearlmillet belt, is inherently vulnerable. This region probably could resort to alley cropping of pearlmillet with perennials. Research on durable resistance of pearlmillet to downy mildew needs strengthening.

COTTON: GAINS AND PROBLEMS OF SPECIES CHANGE

At the time of independence, 97% of the cotton cultivated in the country belonged to the diploid desi type (*G. arboreum*, 65%); and tetraploid American cotton (*G. hirsutum*) constituted only 3%. The tetraploids, both varieties and hybrids, now cover 63% of total cotton area (Table 14). The shift was a result of the policy of meeting the needs of our long staple cotton and avoid imports. Apart from the staple consideration, the shift from desi to American cotton was prompted by:

(1) The realization that potential for high yield did not exist in desi cotton

Table 14. Species composition of cotton in India over different periods

Species	Area in thousand hectares					
	Pre-War	Independence	1955–56	1960–61	1965–66	1989–90
G. hirsutum	150	140	1630	2200	3210	3140
	(2)	(3)	(20)	(29)	(41)	(41.6)
G. barbadense	Nil	Nil	Nil	4	8	10
G. arboreum	5210	2790	4400	3450	2840	1320
	(64)	(65)	(54)	(45)	(36)	(17.5)
G. herbaceum	2710	1390	2050	2030	1780	950
	(34)	(32)	(25)	(26)	(23)	(12.6)
Hybrid	Nil	Nil	Nil	Nil	Nil	2130
						(28.2)

Figures in parentheses indicate percent of total area.

(2) That desi cotton does not respond to irrigation and hence a total shift to the American cotton under irrigation

(3) The advent of pyrethroids for boll worm control

(4) The advent of intra-hirsutum and inter-specific cotton hybrids

(5) The variety and staple oriented price policy favourable to American cotton varieties and hybrids

The consequences of the shift from desi to American cotton varieties and hybrids have been:

(1) Cotton production has gone up primarily because of increased irrigation.

(2) Long staple requirements were largely met saving foreign exchange.

(3) Large increase in the use of pesticides on tetraploid cottons: 55% of the total insecticides are consumed in cotton in India.

(4) Pest resurgence and pest resistance, mainly whitefly and *Heliothes*.

(5) Constant instability and fluctuations in cotton production.

(6) Desi cotton varieties were pushed to less favourable areas, and less effort on desi cotton improvement.

The desi cotton varieties established their superiority in critical comparative trials of improved desi and American varieties, and hybrids in Marathwada/Maharashtra for yield under rainfed and irrigated conditions (Tables 15, 16), under different dates of planting (Table 17), and under irrigation and fertilization (Table 18). Irrigation responses were

Table 15. Average seed cotton yield (kg/ha) in desi, American cotton varieties and hybrids over years and locations under rainfed condition

Year	No. of trials	Mean yield (kg/ha)			Increase (%) of desi over	
		desi	Am. vars.	hybrids	Am. vars.	hybrids
1985–86	10	1946	1293	1442	50.5	35.0
1986–87	15	1701	1065	1278	59.7	33.0
1987–88	20	2045	1458	1608	40.2	27.1
Mean	(45)	1897	1272	1443	49.0	31.4

however low, with the exception of hybrids (Table 18). Under limited and recommended plant protection (Table 19), the desi cotton varieties were superior to American cottons. Pest resurgence on desi cotton was much less compared to the American varieties and hybrids (Table 20). Under all management conditions, the desi varieties proved their superiority.

The fibre properties of some of the improved desi (*G. arboreum*) cotton varieties are compared with the American (*G. hirsutum*) and Egyptian cottons (*G. barbadense*) in Tables 21, 22. The fibre length and ginning outturn of new desi varieties are comparable to those of American cotton varieties and hybrids. The micronaire values are high. If they are brought to the level of American cottons, the desi varieties are likely to spin much better and this aspect should form the primary objective in future cotton breeding.

Table 16. Mean seed cotton yield in Marathwada

Species	Variety/ hybrid	Yield of kapas (kg/ha) irrigated (3 locations)	rainfed (7 locations)
G. hirsutum	SRT 1	1929	747
	Purnima	1559	695
	Mean	1694	721
G. hirsutum (short statured)	PKV 081	2189	856
	NH 262	1931	771
	Mean	2060	814
Hybrid (intra-*hirsutum*)	NHH 44	2086	670
Hybrid *G. hirsutum* x *G. barbadense*	DCH 32	1784	553
G. arboreum	Rohini	2931	983
	Eknath	2904	890
	Mean	2918	937

Table 17. Varietal response to dates of sowing in cotton at Nanded (rainfed)

Species/hybrid	Yield of seed cotton (kg/ha) June 21	July 11	July 31	August 20
G. arboreum	2319	2299	2014	672
G. hirsutum	1358	963	702	419
G. hirsutum (short statured)	1429	1002	764	393
Intra-specific hybrids of *G. hirsutum*	1505	1360	809	301

The desi varieties have also shown considerable variability for plant type, boll size, boll number, length of fruiting branches etc., and could be incorporated into improved cultivars [6].

Table 18. Varietal response in cotton to fertilizer and irrigation applications (1986–87 to 1988–89)

Species/hybrid	N:P:K	Yield of seed cotton (kg/ha)		
		no irrigation	irrigation 125 CPE	irrigation 250 CPE
G. arboreum	50:25:25	2323	2891	2475
	100:50:50	2463	3237	2595
G. hirsutum	50:25:25	1744	1832	1542
	100:50:50	2199	2144	2130
G. hirsutum	50:25:25	1568	1909	1738
(short statured)	100:50:50	2258	2456	2080
Intra-*hirsutum*	50:25:25	1604	2233	1948
hybrids	100:50:50	2326	2872	2479

Cotton is the single crop which is consuming 55% of the total pesticides used in the country, which also posed problems of pest resistance and resurgence. The demand for long and extra long staple being almost fully met, medium and superior medium staples are the need of the country.

Table 19. Varietal response in cotton to plant protection at Nanded (rainfed)

Species/ hybrid	Seed cotton yield (kg/ha)	
	limited plan protection	full plant protection
G. arboreum	1708	2205
G. hirsutum	712	1041
G. hirsutum (short statured)	737	1125
Intra-*hirsutum* hybrids	721	1295

An appropriate cotton policy, which should include pricing of desi cottons, which are currently low as compared to the American cotton varieties, would meet the needs of the country, promote dryland agriculture, and reduce problems of pesticide use and pest resistance and resurgence.

I should not be misunderstood as criticising the policy of promoting American cotton, which is needed to meet our staple requirements and save foreign exchange.

Having met this objective, now it is necessary to establish a balance between desi and American cottons in the irrigated and rainfed sectors in such a way that they meet the current and future staple needs and export requirements, at the same time minimising the ecological problems arising from excessive pesticide use.

PULSES AND OILSEEDS: COMPONENTS OF DRYLAND CROPPING SYSTEMS

Both demand and price situation are favourable to oilseeds and pulses but productivity advances under rainfed conditions continue to be low. High prices, therefore, do not have a long term effect on production.

The rainfed belt of India is predominated by coarse cereals like sorghum, pearl millet, rainfed maize, ragi etc., rainfed wheat and upland rice. There is need for diversification of the range of commodities and crops in this belt. To me, more than stepping up inherent yield potentials of oilseeds and pulses, the work on which, no doubt, should continue, pulses and oilseeds should find an increasing proportion both in inter- and multiple cropping systems.

While delivering the Vasanta Rao Naik memorial lecture, I made a detailed analysis of production and production stability of various crops in Maharashtra during the 1980s. These studies revealed that:

Table 20. Resurgence of whitefly under boll worm control in cotton (1986–87)

Variety/hybrid	Plant protection cover	White flies per leaf	
		limited plant protection	full plant protection
***G. arboreum*:**	0 + 3		
Rohini		1.27	0.98
Eknath		0.98	1.07
***G. hirsutum*:**	3 + 4		
Purnima		5.19	7.37
SRT-1		5.52	7.35
PVK 081 (short statured)		5.07	8.20
NH 262 (short statured)		5.72	8.09
Intra-*hirsutum* hybrids:	3 + 4		
H-4		5.86	8.49
Godavari		8.82	9.83

Table 21. Fibre properties of different cotton varieties and hybrids

Species/hybrid	Variety or hybrid	GOT (%)	MFL (mm)	MIC	MAT coefficient	PSI
G. hirsutum	SRT 1	37.8	23.9	3.8	0.71	8.2
	Purnima	37.1	23.4	3.7	0.69	8.0
G. hirsutum (dwarf)	PKV 081	36.2	22.9	4.0	0.73	7.5
	NH 262	36.6	23.1	3.8	0.71	8.5
Hybrid (intra-*hirsutum*)	NHH 44	35.5	22.9	3.1	0.64	7.8
Hybrid (*G. hirsutum* x *G. barbadense*)	DCH 32	34.1	30.5	2.8	0.53	9.4
G. arboreum	Rohini	37.4	23.9	5.1	0.83	8.5
	Eknath	38.5	22.9	5.8	0.83	8.7

(1) Kharif sorghum and rabi safflower, both rainfed, are the most stable crops, followed by pigeonpea. Safflower responds well even to a single irrigation if water is available. Rainfed cropping systems should, therefore, be designed around these crops.

(2) Of the unstable production systems, cotton during kharif, sorghum during rabi, and sunflower both under rainfed and irrigated conditions proved to be most unstable. Kharif groundnut was also unstable in production.

(3) Sugarcane was most stable among the irrigated crops. The areas planted under

irrigated wheat and summer groundnut exhibited wide fluctuations. While yields of irrigated wheat were stable, the productivity of summer groundnut fluctuated due to uncertain water supplies.

(4) These studies, therefore, pointed out that intercropping systems based on kharif sorghum, with increasing proportion of pigeonpea, groundnut, and soybean are likely to be more profitable and meet the needs of the region and people with respect to food, protein, oil and fodder, and could be optimized for profit. The groundnut-soybean or groundnut-pigeonpea systems are other alternatives.

Table 22. Fibre characters of twelve gaorani (*G. arboreum*) selections as compared to *G. hirsutum* and *G. barbadense* strains

Selection No.	Fibre length 2.5% span length (mm)	(inch)	Pressley strength index 1b/mg	Species
10	29.5	1.16	9.1	*G. arboreum* race *indicum*
11	30.2	1.19	9.2	"
12	30.0	1.18	9.4	"
13	30.0	1.18	9.2	"
14	30.2	1.19	9.2	"
15	31.8	1.25	9.0	"
19	29.0	1.14	9.8	"
26	29.5	1.16	9.8	"
45	30.2	1.19	9.4	"
54	30.2	1.19	9.7	"
102	30.7	1.21	10.1	"
153	30.0	1.18	9.4	"
Sujata	32.8	1.29	8.5	*G. barbadense*
Sea island (Andrews)	29.0	1.14	8.2	"
Hybrid 4	29.0	1.14	8.4	*G. hirsutum*
M.C.U. 5	29.0	1.14	7.7	"

Source. M. R. H. Qureshi and N. G. P. Rao [6].

(5) Safflower has tremendous potential for expansion during rabi in the risky areas of rabi sorghum and as a second crop in the assured rainfall belt of Marathwada, Vidarbha, Malwa plateau and assured rainfall districts of Rajasthan. Safflower comes up well in the black soil regions of M.P. and could be considered as a possible substitute to rainfed wheat. The farmers need to be educated on its cultivation, harvesting and the value of its oil.

(6) The entire groundnut area of black soils of Gujarat can be intercropped with early duration pigeonpea or soybean.

(7) Cotton hybrids, both under irrigated and rainfed conditions, are cultivated in widely spaced rows. Soybean, urd, pigeonpea etc., are the possible intercrops for cotton in the black soil belt.

(8) Incorporation of greater levels of resistance to mosaic will enable mung, urd and early soybean to pervade in vast areas in kharif in the North Indian plains and as a

catch crop in several irrigated situations. The additional opportunities for mung and urd in rice fallows and various other situations need to be further exploited.

(9) Soybean cultivation as a sole crop has vast potential in the assured rainfall situations of kharif in several states and could become an important instrument in diversification of crops in the areas of better rainfall, and could provide sound agro-industrial base.

Table 23. Variability for plant type in gaorani cotton (*G. arboreum*)

Character		Short statured variant	Gaorani 6 (control)
Plant height (cm)	mean	78.4	130
	range	63-92	130-160
Internodal length (cm)	mean	3.2	4.7
	range	2.4-3.6	3.3-5.5
Bolls/plant	mean	18	12
	range	14-26	5-15
Maximum No. of bolls per fruiting branch		4.0	2.0
Mean length of fruiting branches (cm)		9.0	4.0
Days to maturity		130-150	200

Source. M. R. H. Qureshi and N. G. P. Rao [6].

Note. The comparative studies reported above on *G. arboreum*, *G. hirsutum* and hybrids were planned when I was working as the Vice-Chancellor of the Marathwada Agricultural University and conducted by my colleagues, which I respectfully acknowledge.

Our earlier studies on competition of species and stability of sole and intercropping systems [7] have brought out pigeonpea and soybean as important components. The sorghum based cropping systems are most stable and out of them sorghum–pigeonpea and sorghum–soybean were superior. Amongst the groundnut-based cropping systems, groundnut–pigeonpea was most stable. Groundnut–sorghum and groundnut–soybean combinations, though not very stable, are productive and could compen- sate for the pro- duction risks of kharif ground- nut. A summary of these studies are presented in Table 24.

Table 24. Stability parameters for total yield in intercropping systems

Intercrop	Sorghum			Intercrop	Groundnut		
	yield (q/ha)	regression coefficient	deviations		yield (q/ha)	regression coefficient	deviations
Pigeonpea	56.85	0.92	NS	Sorghum	38.77	2.11**	**
Castor	39.57	1.00	NS	Pigeonpea	23.15	0.89	NS
Groundnut	50.53	0.99	NS	Castor	16.54	0.51**	*
Soybean	55.53	1.03	NS	Soybean	17.34	0.49**	**
Mean	53.58				23.95		
SE	61.9				31.1	0.11	

*,**Significant at 5% and 1% levels, respectively; NS—nonsignificant.

Based on several sorghum based intercropping studies in India, Rao and Rana [8] estimated the projected area under intercropping for additional acreages under pulses and oilseeds to meet shortages. These are reproduced in Table 25.

Table 25. Production potential of oilseeds and pulses in sorghum-based intercropping systems (kharif 1972–78)

Intercrop	No. of experi-ments	Average yield (q/ha)				Projected area in million ha for 1 million ton production at		
		sorghum (sole crop)	intercrop (sole crop)	sorghum (in inter-cropping system)	intercrop (in inter-cropping system)	minimum yield potential	average yield potential	maximum yield potential
Oilseed crops:								
Groundnut	57	33.6	10.4*	33.1	4.8	2.60	2.08	1.73
Castor	20	36.7	20.2*	32.9	5.3	2.78	1.90	1.44
Sunflower	10	33.6	16.1	21.7	3.4	8.00	2.99	1.84
Pulse crops:								
Pigeonpea	115	35.8	16.5	32.4	9.4	1.16	1.07	1.00
Soybean	60	33.0	13.9	32.2	5.5	2.08	1.82	1.61
Mung	38	33.5	8.2	33.7	3.0	3.90	3.25	2.78
Urd	30	40.9	9.5*	33.8	2.8	4.58	3.55	2.90
Cowpea	21	43.5	8.2*	38.1	2.7	5.75	3.67	2.69

*Data based on less number of experiments.

The vast amount of data obtained in the country under various projects on different crops and cropping systems, both under inter- and sequence cropping, has not been put to practical use. It is time to give serious consideration and arrive at policy decisions and their implementation on cropping systems.

LOCATION SPECIFICITY AND WIDER ADAPTATION

The lack of progress in dryland agriculture has often been attributed to lack of location specificity in research and developmental efforts.

If we look back to the All-India Coordinated Research Projects, the high yielding varieties of wheat like Kalyan Sona, Sonalika and several HD varieties, the IR rice varieties, the sorghum and pearl millet hybrids were all widely adapted and were the result of testing under diverse agro-climatic conditions both in space (locations) and time (years). Even maize hybrids, which were released zonally to begin with, have now shown wider adaptation. Subsequently, most crop improvement programmes got zonalised with the purpose of meeting regional needs and imparting locational specificity. This approach has naturally resulted in limiting test environments. Even though the number of varieties released have increased, the widely adapted varieties of yesteryears have stood the test of time.

Recently, I made a detailed analysis of the zone x genotype interactions in case of several crops and estimated the proportion of variability accounted by the zone x genotype interaction. The common data sets were limited, yet the results were convincing that the proportion of variability due to zone x genotype interaction accounted for a very small fraction of the total variability.

A recent analysis of the performance and stability of improved rice cultivars revealed that there were no restrictions to adaptability within an ecosystem. Evenson's contention that adaptability and stability are different and if so the rice programmes on varietal development may need a different orientation did not come true.

Adaptability and stability were well correlated and the large location-dependent fluctuations in yield were more due to the production environment and not due to genotypic causes. Locational-dependent specificity is certainly important in developing the cultivation practices, cropping systems, and management norms for the production environment. It became clear that varietal development under wider testing would enable selection of more plastic (adapted) varieties with better buffering and broad based resistance to a range of biotic and abiotic stresses.

If this was so with rice, it is even more relevant for rainfed crops where production is more prone to climatic fluctuations. This has been amply demonstrated in case of sorghum and pearl millet hybrids. I shall illustrate this with some data from sorghum presented in Table 26 and Fig. 12.

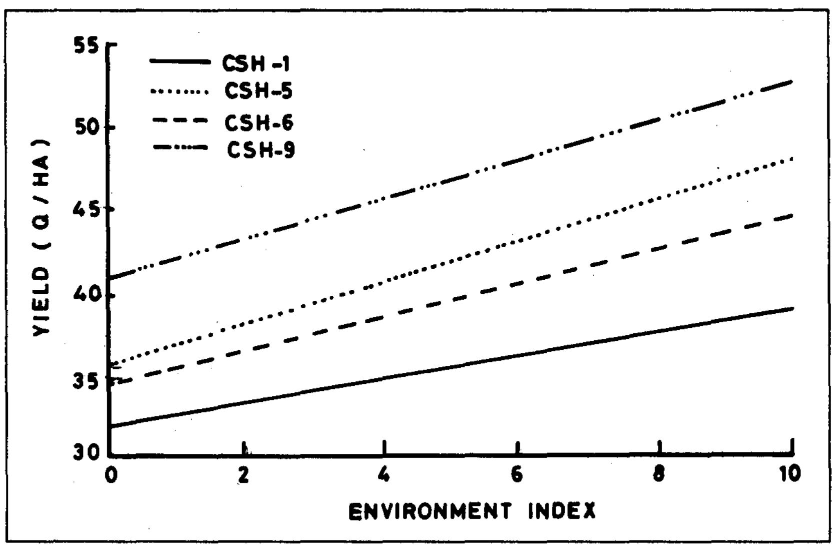

Fig. 12. Yield-environment relationship of sorghum hybrids.

The improved hybrids are superior in all environments. This is further illustrated by the data presented in Table 27, which shows that the really superior genotypes are superior under both low and high management regimes (Table 28). The sorghum work has also proved that compared to improved varieties, hybrids have better buffering capacity against environmental fluctuations as revealed for genotypes and their interactions with environment (Table 28).

Table 26. Stability parameters of sorghum hybrids over years and places (1976–85)

Hybrid	Mean yield (q/ha)	Regression coefficient (b)	Deviation MS
CSH-1	31.97	0.69**	1.459
CSH-6	34.59	0.97**	2.520
CSH-5	35.81	1.20**	2.744
CSH-9	41.04	1.14**	1.147

**Significant at 1% level.

I shall further illustrate this with maize which started with a zonal approach. Tables 29 and 30 provide means and analysis of variance for four diverse check varieties across zones. The zone x genotype component accounted for only a small fraction of the total variability. Maize has now moved towards release of hybrid cultivars on a wider regional basis. The same is true of several other crops.

The wider testing across zones (barring totally different ecosystems like hills, deep water systems, salinity–alkalinity situations etc.) enabled identification of larger genotypic differences, eliminated more sensitive types and favoured genotypes that could stand a range of fluctuating agro-climatic factors. Wide adaptation, adaptability and high yield are not certainly negatively correlated and more stable high yielding genotypes could be identified. This is not to be misunderstood as pleading for one variety for all areas or adaptability for all conditions. The point is that the genotype x environment interactions

Table 27. Mean yield and ranks of some hybrids and varieties under high and low management during kharif seasons of 1974, 1975 and 1977

Hybrid or variety	High management yield (q/ha)	High management rank	Low management yield (q/ha)	Low management rank
Hybrids:				
CSH-1	35.69	4	24.68	4
CSH-5	45.14	1	31.85	2
CSH-6	41.25	3	33.46	1
Varieties:				
CSV-3	32.00	5	19.70	5
CSV-5	26.22	6	17.01	6

Table 28. Estimates of components of variance for grain and fodder yield of kharif sorghum varieties and hybrids

Component of variance	Grain yield varieties	Grain yield hybrids	Fodder yield varieties	Fodder yield hybrids
σ^2_g	20.03	11.22	422.42	487.35
σ^2_{gl}	10.45	4.25	242.71	59.97
σ^2_{gy}	–0.83	0.40	19.61	–5.32
σ^2_{gly}	27.57	21.30	503.02	255.03
σ^2_l	8.36	9.57	120.24	128.74

Table 29. Three years average yields of maize checks in different zones (1983–85)

Zone	Yield (q/ha)				Mean
	J-684	Ganga-5	Agenthi-76	Tarun	
Zone 1	43.9	44.9	44.4	40.5	43.4
Zone 2	39.2	35.3	36.4	31.0	35.5
Zone 3	32.3	34.6	35.3	31.2	33.4
Zone 4	34.0	38.2	36.4	28.8	34.4
Zone 5	26.1	24.8	26.3	23.9	25.3

Table 30. Pooled analysis for three years (1984-1986) of the grain yield of maize (q/ha)

Source	d.f.	Variation (%)
Years (Y)	2	3.70
Zones (Z)	4	44.74
Genotypes (G)	3	4.90
Z x Y	8	3.60
Z x G	12	2.60
Y x G	6	0.56
Y x G x Z	24	39.85

should be understood well by organising the testing programmes across diverse situations and based on data appropriate release recommendations could be made.

The immediate production environment would provide the base for the development of manage- ment practices and cropp- ing systems, and should account largely for the location specificity. The need is for a synthesis and balance between varietal testing, wide adaptation and area specifics.

In conclusion, I would like to plead that certain aspects of dryland agriculture have witnessed dynamic changes in their varietal composition and resource management perceptions. They contributed prominently to yield advances, though not to the extent desired. The time is ripe to charter our coarse for future. This is an analysis in that direction. The future is optimistic.

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Plant Breeding - Mendelian to Molecular Approaches
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3

Plant Breeding Science and Practice in the Twentieth Century: Some Landmarks

N.G.P. Rao[1]

Abstract

This paper attempts a brief analysis of the growth of the science of plant breeding and some of its landmarks. Advances in our understanding of evolutionary and population genetics have significantly influenced the theory and practice of plant breeding. Pure line selections among the domesticated land races of crop plants in the various eco-geographic regions and selections from crosses between elite lines yielded cultivars, which helped to increase agricultural production during the 20th century. Induced mutations, chromosome manipulations and distant hybridization involving wild species and genera, generated lot of interest but their direct contribution to improved cultivars has been limited. Transgenics to date have succeeded largely in incorporating relatively simply inherited traits. The breeding procedures have become more and more reductionist as compared to an integrated individual as the unit of selection under evolution. Among the landmarks in plant breeding are: pure line selections in land races and selections from elite crosses in almost all crops; inter-specific cultivars of sugarcane grown across continents which became feasible because of their vegetative propagation. Recent improvements for yield and fibre characters in *G. arboreum* cotton resistant to sucking pests and tolerant to boll worms has been a significant development; other significant developments include exploitation of wider germplasm sources including dwarfing genes as in rice, wheat and sorghum to develop semi-dwarf, high yielding varieties with marked changes in adaptability, input responses, leading to more productive cropping systems like that of rice-wheat; exploitation of heterosis employing male sterility and other systems in crops like maize, sorghum, pearl millet, cotton, sunflower and castor. The performance of hybrid sorghum, pearl millet, cotton and sunflower in rainfed agriculture has been a major contribution.

Introduction

The first principles of plant breeding were enshrined in the process of evolution of species and origin of crop plants in nature. Plant breeding is man made evolution. Except for the rates and direction of genetic change the principles of evolution in nature are valid for plant breeding. Nature is the first plant breeder.

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The origin of settled agriculture is lost in antiquity. Subsequently, with the passage of time, increasing need of food and fibre prompted man to rendering cultivated forms more distinct from their wild ancestors. Land races developed during migration and domestication under diverse eco-geographic situations as an adaptive response through both natural and human selection. Farmers are the second generation plant breeders. Farmers are known to select novel forms even today.

Sexuality of plants was known and influenced crop hybridization in the pre-Mendelian era. Tobacco hybrids of Koelreuter, progeny tests of Vilmorin and improvement of sugar content in sugar beet from 6 to 16 % by mass and pedigree selection, and novel fruit and ornamental plants derived from hybridization are early examples of human endeavour from Europe. Plant breeding has come to be known as the Art of Plant Breeding. The artistic aspect of plant breeding continues inspite of application of science.

The enumeration of Mendel's laws (1865) and their rediscovery independently by Correns, De Vries and Tschermak in 1900 provided the genetic basis for plant breeding. Subsequent developments in various branches of genetics, cytogenetics, population genetics, quantitative genetics and molecular genetics enhanced our knowledge and opportunities to genetically modify crop plants. Allied sciences - plant physiology, biochemistry, entomology, plant pathology, statistics, etc., further influenced breeding efforts and procedures for multi-trait improvement and breeding efficiency. The era of science of plant breeding is the journey from phenomics to genomics.

Plant breeding is now both a public welfare and market oriented economic activity. Public and private sectors are involved. Globalization, market economy, plant variety rights, IPR, genetically modified organisms (GMOs) bring in ethical, social, commercial and legal implications.

Evolution: Significance to Plant Breeding

Evolutionary changes have been taking place in life forms since the origin of life on earth, resulting in diversity of species. Evidences from different disciplines indicate that early agricultural economies must have developed during late Mesolithic and Neolithic ages (15,000-10,000 BC), independently in different parts of the world (Harlan, 1992).

The principles of evolution emanating from Darwinism and neo-Darwinism are important to present day plant breeding. Darwin's (1859) theory of origin of species by means of natural selection and the preservation of the favoured ones focused on the dynamic processes and changes in plant populations leading to the formation of species, intra-specific variants like races, ecotypes and even higher taxa.

Huxley's (1942) evolutionary synthesis and Mayr's (1991) discussion attempt to reconcile Darwin's theory of natural selection with Mendelian hereditary principles. The consequence is the emergence of "neo-Darwinism." The Darwinian theory postulated that selection targeted individuals. In the reductionist genetic hypothesis independent genes play a larger independent role in fitness and evolution and involve largely allelic frequencies in populations.

The early works of De Candolle (1886) and Vavilov (1926) led to the concept of centres of diversity of crop plants as also the centres of origin. Vavilov recognised 12 such centres. Tropical West Africa which did not find a place in Vavilov's map has now emerged as an important area of diversification for several crops. Also the lack of coincidence between the areas of wild ancestors, areas of domestication and evolutionary diversification in several instances warranted changes in the geography of crop evolution. Harlan (1992) preferred to designate the centres of origin as 'Ecological Regions of Diversity'.

Genetics, Population and Adaptation Processes : Basis for Plant Breeding

The story of twentieth century plant breeding science is the travels and travails from Mendelian factors to heredity molecules; from genotype to phenotype through the environment and refinements in tools and breeding plans to meet agricultural needs of ever increasing mankind in the twenty-first century.

Genetic Processes

The genetic studies based on natural populations provided the scientific basis for plant breeding. Mendel (1865) hypothesized that traits were transmitted by factors and follow a predictable pattern of inheritance. About the same period East (1908) and Shull (1909), observed inbreeding depression on selfing and restoration of vigour on crossing in maize. This led to the development of concept of heterozygote advantage and the role of dominance, 'overdominance' and gene interactions in heterosis and led to its utilisation in cross pollinated crops. The concept was later extended to self-fertilised crops. First observations on the role of cytoplasm in inheritance were also observed during this period.

The occurrence of spontaneous mutations in nature during evolution was an important source of variation. Gene mutations or point mutations are sudden changes at a major locus and are generally recessive in nature. Mutations are alterations in base sequence in the DNA in situations that lead to altered polypeptides and hence phenotypic effects. The word mutation was conceived by De Vries (1900) from his observations on *Oenothera*, which later proved to be a structural heterozygote.

Both ionising and non-ionising radiations induce mutations. Several chemicals which are alkylating agents like sulphur mustard, nitrogen mustard, epoxides, ethyleneimines, sulphates and sulphonates, diazoalkenes and nitrous compounds have been used to induce mutations. Several induced mutants have been reported, but only very few went into large scale cultivation. Aruna castor from Indian Agricultural Research Instute (IARI) centre at Hyderabad and TG Groundnut mutants from Bhabha Atomic Research Centre, (BARC) at Trombay entered into large scale cultivation in India.

Apomixis is emerging as a potential tool for improving grain crops in future. To-date apomixis does not appear to have been transmitted from wild to cultivated crops. Two approaches being pursued are direct transfer of apomixis and gene isolation, or both. Two molecular markers, RFLP and RAPD, were reported to be linked to apospory in *Pennisetum*. A review of the current state of apomixis in relation to genetics and plant breeding will be found in Savindan (2000).

Cytological and genetical studies on *Drosophila* and maize by Morgan (1911), Muller (1927), Sturtevant (1913) and McClintock (1951) led to the location of genes on specific chromosomes, operation of linkages between genes on a chromosome which led to the chromosome theory of heredity and development of genetic and cytological maps. The 1930-1950 period was dominated by cytogenetic researches in all crops. The studies involved chromosome pairing and structural changes in chromosomes, particularly in wide crosses and were related to wild gene transfer. Studies on changes in chromosome number led to the development of autopolyploids and allopolyploids and the use of aneuploids like trisomics, monosomics and nullisomics in gene location and developing substitution lines. Sears developed genetic stocks to locate genes for rust resistance in wheat and were used extensively in breeding for rust resistance. Chromosome 5B in wheat also attracted attention because it has genes controlling homeologous pairing. Cytogenetic studies laid particular emphasis in gene transfer from wild species and genera. The most successful example is that of sugarcane where crosses of *S. officinarum* × *S. spontaneum* resulted in many commercial varieties widely cultivated. Efforts at inducing translocations have resulted in some genes transfer across species as in the case of leaf rust from *Aegilops* to bread wheat. Frey (1984) reported that introgression of wild genes into cultivars enhances variability for yield considerably and hence offers scope for yield improvement. But there seem to be no examples of developing high yield cultivars through wild gene incorporation. There was considerable interest in synthesizing amphi-diploids and allopolyploids as in cotton, *Brassica* etc. They did provide proof of their origin, but no where near natural amphi- diploids. Synthetic *Triticale* and *Raphano-brassica* generated considerable interest but could not become commercial.

Several colchicine induced autopolyploids with doubled chromosome numbers have been synthesised in many crops and again there are no examples of commercialisation. Autopolyploid grape only raised some expectations. The synthesised autopolyploids were no more successful than the diploids. Haploids occur in nature. Haploids have also been induced through wide hybridization and through anther culture. The techniques of producing haploids and doubled haploids have been improved (Raina, 1997). However in commercial breeding the conventional inbreds are ruling.

Plant breeding has now entered the era of molecular biology. Discoveries of the structure of DNA and genetic code gave molecular basis to the Mendelian 'factors' or 'genes'. The DNA from one organism can function in another and leads to transformation systems and transgenics. The availability of alternative transformation systems such as *Agrobacterium*, Biolistics, Silicon fibre, Electroporation, etc., enabled development of transgenics. Traits like herbicide resistance, insect resistance and virus resistance from bacteria and viral pathogens have been incorporated. First generation transgenic crops of maize, cotton, potatoes, soyabeans, etc., made commercial impact in USA, Canada, Argentina and some other countries. Quality trait improvement has also potential as in the case of golden rice, quality protein gene of *Amaranthus* isolated in India, etc. The release of transgenics (genetically modified organisms) raised issues of environment, bio-safety and led to regulatory and legislative measures. Concerns have also been expressed on genetically modified food crops. India is yet to develop transgenics with the exception of *Bt* cotton on which trials are being conducted. Transgenics may have a great potential in altering amino acid profile of oils and orientation to end products for industrial processing and nutritional attributes. The transgenics derived till today largely involve simply inherited traits like herbicide/insect/disease resistance and they are also subject to breakdowns due to changes in pathogen or environment, as has been the case with traditional methods of major gene transfer.

The DNA markers have emerged as an important tool for selection. Among the marker assisted selections (MAS), the first marker system developed was the RFLP (Restriction Fragment Length Polymorphism). This was followed by the RAPD (Randomly Amplified Polymorphic DNA), SSRs (Simple Sequence Repeats) and Microsatellite based markers.

The genetic mapping of QTLs with DNA markers provides a quantitative perspective. These tools are expected to be more precise and effective compared to traditional selection criteria. The DNA markers are significant in basic studies, but they are yet to reach a stage when they could replace present approaches.

The era of functional genomics, a new phase of genome analysis has arrived. Massive relational data bases and computational approaches are taking their places alongside banks of automated sequences, and arrays of biochips as the tools of this new science. Comparative genomics is offering unparalleled opportunities to link biological kingdoms, enabling crossing species and genera. Genome based data bases are available and the success of the genome projects depends on the availability and use of the data bases.

Population Processes

Fisher's *Genetical theory of natural populations*, Wright's *Evolution in Mendelian populations* and Haldane's *The causes of evolution* laid the foundations for population genetic-theory. The Hardy-Weinberg law concerning equilibrium population under random mating enumerates the role of mutation, migration and selection in diploid random mating populations in changing gene frequency.

Unlike simply inherited traits most economic traits are governed by a large number of genes called polygenes with minor effects relative to environmental variation, result in measurable continuous variation and hence such traits are known as metric traits. An analytical approach to plant breeding based on quantitative genetic theory revolves around the concepts of phenotype, genotype, environment and genotype × environment interactions. The basic model is:

$$P = G + E + (GE) \quad \text{and} \quad \sigma^2 P = \sigma^2_G + \sigma^2_E + \sigma^2_{GE}$$

Plant breeding is based on this model amplifying genetic, environmental and G × E interaction components and maximising gain from selection through appropriate breeding plans. This basic model has been adopted to replicated, randomised, field experiments conducted over single/multiple locations/years/environments, etc.

Sprague and Tatum (1942) coined the words 'general combining ability' (gca) and 'specific combining ability' (sca). Parent offspring regressions, graphic methods like Vr-Wr graphs, methods of partitioning the mean from segregating generations, mating designs like diallel and its modifications have been more conveniently used for estimating the genetic parameters, particularly in self-pollinated crops. Comstock and Robinson, 1952 developed I, II and III designs and partitioned the genetic variation into various components in the open pollinated populations.

The estimation and understanding the role of genetic variances and the findings that intermating results in dissipating repulsion phase linkages besides changes in gene frequencies led to development of efficient breeding plans, such as pedigree and mass pedigree methods. The intra- and inter-population improvement procedures, composites, synthetics, gene pools and high yield inbreds from diverse populations to maximise heterosis were developed.

Adaptation Processes

Another aspect of genetic parameters pertains to the estimation of g × e interaction variances and regression methods of Finlay and Wilkinson (1963); and Eberhart and Russell (1966) enhanced our understanding of the concepts of adaptation and adaptability of cultivars, and phenotypic stability. The g × e studies led to demarcating adaptation zones, variety testing procedures and the relative significance of the various g × e interactions in variety development plans. A review of genotype-environment interactions and their significance for cultivar development will be found in *Kang* (1998). The changes in adaptation concept is a landmark of the century. Irrespective of the tools used in crop breeding, adaptation processes will have a permanent place in cultivar development.

Plant physiologists (Wallace and Yan, 1998) refer to the whole system crop physiology and the constant capacity plant system hypothesis. The focus has been on system output and its near fully integrated components of yield-biomass and biomass per day, yield and yield per day, days to flower and maturity and harvest index.

Adaptation and productivity are complexly inherited traits and are much affected by the environment. Allard (1996) observed that population behaviour can be explained on the basis of selecting chromosomal segments, in which the marker loci reside and that marker assisted dissection of the genetic basis of adaptation is feasible. Thus, discretely inherited markers often provide breeders with effective ways of identifying, tracking and incorporating regions of chromosome with favourable effects on adaptation into elite materials. Changes in crop duration, dry matter production and distribution and crop phenology have reduced seasonal yield failures and fluctuations and conferred greater stability of performance across years and geographies (Rao, 1982; Rao *et al.*, 1989).

The genetics of resistance to plant diseases and insect pests received attention from early 1900s. Plant defence mechanisms for disease resistance-avoidance, resistance, tolerance and durable resistance have been exemplified. Breakdown of simply inherited resistances due to new pathogen races has been a frequent occurrence. To get over this, the concept of components of partial resistance equivalent of quantitative resistance has been used to move towards durable resistance. Such examples will be found in case of barley leaf rust, late blight of potato, bacterial leaf blight of rice, etc. (Parlevliet, 1992). Similarly, in case of insect pests, the resistance mechanisms - non-preference, antibiosis and tolerance have been used in breeding programmes.

Plant modifications to tolerate environmental stresses such as drought and water-use efficiency, soil toxicities and beneficial host - soil-microbe interactions are also features of adaptation. Water-use efficiency reflects in greater dry matter production or economic yield per unit of water in a given evaporative environment. This has been estimated from gas exchange by measuring the ratio of CO_2 fixed to water transpired. C_3 plants tend to have lower water-use efficiency than C_4 photosynthesis, as in maize or sorghum. In case of drought resistance, dehydration, avoidance and tolerance have been the major mechanisms. Improved root depth, cuticle thickness and increased production indicate tolerance to dehydration (Boyer, 1996).

Toxic soil conditions such as salinity, aluminium toxicity, etc., have been successfully handled by genetic manipulation of correlated physiological traits. Plant soil-microbe interactions in the rhizosphere are significant. They may enhance growth or provide protection from pathogenic micro-organisms. Symbiotic *Rhizobia* and non-symbiotic or associative BNF by *Azotobacter*, *Azospirillum*, etc., contribute to soil fertility. The role of nodulins, flavonoids and plant lectins in BNF is being investigated. With molecular genetic approaches, the efforts could lead to more success.

With limitations on cultivable land and water, there is considerable emphasis on crop diversification, crop intensification through multiple cropping and on inter-crops, with the twin objectives of promoting productivity per day and sustainability of production. In this context, competition between crops in space and time assumes importance. Differences in intra- and inter-plant competition within a species, competition between species for water, nutrients and sunlight is critical. Plant densities and duration, and architecture becomes significant in adaptation to cropping systems. The stability of cropping systems across years and seasonal fluctuations also need to be considered. Rao *et al.* (1981) and Rao (1991) reported these aspects in relation to sorghum based cropping systems. A review of competitive ability and plant breeding has been done by Fasoula (1997).

Some Significant Landmarks in Plant Breeding

The plant breeding history in India could be considered under two broad periods:

1. Pre-green Revolution (before 1965)
2. Green Revolution (1965-2000)

Pre-Green Revolution Period

By and large, the native tropical cultivars are characterized by tallness, photosensitivity, relative lateness compared to duration of rainy season, low harvest indices, low economic yields, local adaptation and low response to increasing fertilizer and population levels. Yields in India were not only low, but vulnerable to climatic fluctuations resulting in food shortages and even famines in drought prone areas.

(a) The Significant Role of Land Races

Cultivars selected from locally domesticated land races, spontaneous mutants and some induced mutants, and products of hybridization, largely between closely related cultivars and a few involving distant hybridization, dominated the agricultural scene of the pre-green revolution era. Consequent to these plant breeding efforts and increasing fertilizer use and cultivation practices during the first 20 years after independence, crop production doubled from 51 to 108 m tonnes between 1950 and 1970 (Table 1). A few landmarks in plant breeding during this period are focussed as follows.

Table 1. Progress of production of some agricultural commodities in India (M.tons)

Crop/Commodity	1950-1951	1960-1961	1970-1971	1980-1981	1990-1991	1999-2000
Foodgrains	50.82	82.02	108.42	129.59	176.39	201.56
Rice	20.58	34.58	42.22	53.63	74.29	88.55
Wheat	6.46	11.00	23.83	36.31	55.14	70.10
Coarse cereals	15.38	23.74	30.55	29.02	32.70	29.36
Grains legumes	8.41	12.70	11.82	10.93	14.26	13.55
Oilseeds	5.16	6.98	9.63	9.37	18.61	21.54
Cotton (m. bales)	3.04	5.60	4.76	2.01	9.84	10.45
Jute (m. bales)	3.31	5.26	6.19	8.16	9.23	9.53
Sugarcane	57.05	110.00	126.37	154.25	241.05	292.64
Potato	1.66	2.72	4.81	9.67	15.21	24.64
Tobacco	0.26	0.31	0.36	0.48	0.56	0.70
Coconut (m. nuts)	35.82	46.39	60.75	57.20	97.30	149.25

Wheat: Some of the prominent land races from which pure line selections were made included: *Sharbati, Dara, Karachi choice, Lal Kanthi, Lal pissi*, etc., in bread wheat; *Bansi, Malwi, Khandwa, Hara, Jalelia*, etc., in *durum* and *Khapli* etc., in *dicoccum*.

Systematic pure line selection in land races of wheat was initiated in 1904 at Pusa, Bihar by Howards (1910) and later pursued by B.P. Pal and his colleagues. Pusa 4 (NP 4), a selection from *Mundia* (awnless) was known for its quality and was awarded first prize in several international exhibitions (1916-1920). It was also reported to have been cultivated in South Africa, Rhodesia, Australia, Hungary, etc. Several promising selections were made in the local land races and released for cultivation at Layalpur, Kanpur, Nagpur, Niphad and Parbhani, etc., to suit local needs.

Hybridization between land races for incorporation of specific traits was the next step and several hybrid derivatives were cultivated in different parts of the country. NP 52 and a series of NP wheats from Pusa; PbC 518, PbC 591, etc., from Punjab; Niphad 4, etc., from Maharashtra were well known in different parts of the country.

The use of exotic varieties in hybridizations for combining yield and rust resistance formed the next important stage in wheat improvement. Varieties like Thatcher, Federation, Gabo, Hofed, Timstein, Chinese and Kenyan in the bread wheat group; Gaza and Arabian durums and some exotic dicoccums were used for improving the respective species. The NP 700 and 800 series wheats, kenphad wheats, etc., were the result of hybridization and selection.

This period was also marked by the use of cytogenetic approaches, distant hybridization, translocations, monosomics, nullisomics, radiations, etc., in wheat improvement. The transfer of leaf rust resistance from *Aegilops* sp. to wheat by Sears (1956) and his colleagues using ionising radiations to produce translocations between wheat and *Aegilops* carrying a gene for leaf rust resistance is cited as a classical example. The *Lr.9* was found resistant to several wheat rust pathotypes across the world. Knowledge of the genetic control of chromosome pairing in wheat enabled transfer of genes from alien species to wheat. In wide crosses, progenies lacking chromosome 5B have high level of pairing and recombination.

Another very significant contribution in wheat improvement pertains to the development of knowledge about the wheat rusts and their management. The identification of 45 *Sr* genes for stem rust, 47 *lr* genes for leaf rust and *29 lr* genes for stripe rusts and their manipulation provided an ideal example of pathologist-breeder cooperation in containing rust epidemics. Critical epidemiological studies of wheat rusts, the genetics of rust resistance aided breeders to successfully develop resistant cultivars, gene deployment to create genetic diversity in large geographic areas, furnishing a strategy for rust control and management. The works of Howard (1928), Pal (1966) and Sawhney (1998) summarize wheat-breeding efforts in India.

Rice: Pure line selection in land races of agro-ecological regions and agro-ecosystems began in early 1900s and continued till the sixties as the main method for the genetic improvement of rice. Some inter-varietal hybridization was also practised for incorporation of specific traits. Before 1960s, of the 450 improved varieties selected in India, only 25 were of hybrid origin. Thus, selection in land races was the main avenue for cultivar improvement under various situations, which ruled rice fields in various states. Particular mention may be made of GEB 24 selected at Coimbatore, which combined moderate yields, good grain quality and wider adaptation. Also, these land race selections provided the mainstay for securing resistance for various biotic and abiotic stresses and were used as donors in later years. Mention may be made of varieties like TKM 6 for stem borer resistance; PTB 21 for tungro virus resistance; SR 26B for salt tolerance; *Jala-magna* and FR 43B for deep water and flood prone conditions. The list of such donors from land race selections will be large and could be retrieved from rice germplasm catalogues and breeders.

The *indica-japonica* hybridization program to improve yield levels of *indica* rice was initiated in several countries. Success during the pre-green revolution period was limited. ADT 27 developed at Coimbatore was a successful example. The Korean breeders seem to have had more success with *indica-japonica* crosses. *Mahsuri* a derivative from *indica-japonica* crosses of Malaysia and introduced into India combined high yields, good grain quality and wider adaptation and was extensively cultivated. Several variants of *Mahsuri* were selected in various parts of India. Besides, *Mahsuri* provided the parental material in later breeding programs. The adaptation of *Mahsuri* in India is a landmark. Gangadharan (1985) and Siddiq (2001) provide a comprehensive account of rice breeding researches.

(*b*) The Success of Interspecific Crosses in Sugarcane

The establishment of the Sugarcane Breeding Station at Coimbatore, India during 1912 was a significant step, which laid the basis for sugarcane improvement and a stable sugar industry not only in India but across many countries. Mention should be made of three sugarcane species which played a vital role in developing commercial hybrid canes, *Saccharum officinarum* (2n = 80), *S. barberi* (2n = 81, 82, 83, 91-92, 105) and *S. spontaneum* (2n = 40 to 128). Barber (1916) at Coimbatore crossed a *S. officinarum* clone *vellai* with locally available *S. spontaneum*, which gave rise to commercially accepted Co. 205 and replaced *S. barberi*. In India intercrossing of elite derivatives of the basic crosses between the three species led to development of varieties like Co 290, Co 312, Co 313 for sub-tropical India and Co 419 for tropical India, which became to be known as the 'Wonder Cane of India'. The breeding philosophies of almost all sugarcane growing countries were on similar lines. Sugarcane is one example where hybridization with wild species led to the development of widely cultivated varieties across the world. This example of sugarcane is certainly a landmark in the early Plant Breeding History of India. Barber (1916) and Sir T.S. Venkatraman (1938) pioneered these breeding efforts.

Green Revolution Period

(*a*) Exploitation of Dwarfing Genes in Wheat and Rice

Exploitation of dwarfing genes in wheat and rice initiated the green revolution. The dwarf forms furnished lodging resistance, superior harvest indices and better utilization of environmental resources. Plant modifications due to major changes at a few loci associated with pleiotropic effects led to changes in form, function and adaptation. The discovery of the Norin-10 dwarfing genes in wheat and the *Dee-geo-wu-gen* (DGWG) dwarfing genes in rice led to marked plant modification in wheat and rice. *Rht-B1* and *Rht-D1* of Norin source which are partially dominant, largely contributed to advances in wheat. In rice, the *Sd1* gene from the *Dee-geo-wu-gen* (DGWG) was the main contributor. A comprehensive review of the dwarfing genes will be found in Milach and Federizzi (2001).

The Semi-dwarf Wheats: *Gains* was probably the first semi-dwarf variety released in USA during 1962 using Norin-10 dwarfing genes. This line subsequently entered the CIMMYT wheat breeding program. CIMMYT introduced several breeding populations carrying the dwarfing genes into the programs of North America, Europe and Asia, which initiated transformation of the wheat scenario.

In India, the bulk introduction of the Mexican semi dwarf spring wheats - Sonora 64, Lerma Rojo took place in 1965-66. The initial introductions because of red grain colour were not acceptable to the Indian consumer, for whom the preference is amber coloured grain. Selection for amber grain in later introductions led to the development of popular varieties like Kalyan sona and Sonalika released in 1967, which spread rapidly and paved the way for further improvement in yield, quality and disease resistance. Thus, Kalyan sona and Sonalika may be considered as landmark in wheat improvement. Subsequent breeding efforts at IARI and various agricultural universities of India led to a number of varieties including HD series, reflecting improvements in yield, quality and disease resistance. Semi-dwarf *durum* and *dicoccum* wheats have also been developed. Similarly, all the wheat growing states developed semi-dwarf high yield wheat varieties.

Semi-dwarf Rice: The era of short-statured *indica* varieties in rice began with the advent of Taichung Native-1, Taichung 65, Tainan 3, etc. But it is the development of IR 8 at the International Rice Research Institute and its introduction into several national research programs of Asia that heralded the transformation of the rice scene. IR 8 has been mentioned as the miracle rice and is certainly a landmark in rice breeding. A number of IR varieties have been developed at IRRI and introduced into several National Research Programs, which became useful directly or indirectly by furnishing parental material and by release of several new varieties in the respective states/countries. Similarly, the rice variety Jaya, developed in India, set a benchmark for its yield level in the mid-late maturing group. A number of medium duration and mid-early varieties attained the yield levels of Jaya. What is more significant is the improvement of grain quality to suit local conditions at high yield levels. The aromatic rice, *Basmati*, characterized by super fine grain, pleasant aroma, extra elongation of kernel and soft texture of cooked-rice rendering it a delicacy, is in demand in India and abroad. Pusa Basmati, Pusa Sugandh, semi-dwarf Basmati rice varieties have high yields compared to traditional Basmatis. A review of rice breeding will be found in *Siddiq* (2001).

(*b*) Exploitation of Heterosis

Maize: Historically, commercial exploitation of heterosis began with maize in USA during 1930 through double cross hybrids. Extensive quantitative genetic studies involving open pollinated varieties of maize and population improvement methods by exploiting additive genetic variance led to development of high yield inbreds, which in turn promoted commercial single-cross hybrids. Single-cross hybrids were cultivated since 1960 and today almost the entire hybrid corn in USA is single-cross. The quantitative genetic studies during 1950s and 60s at the Universities of North Carolina, Nebraska and Iowa constituted a landmark in global maize improvement and provided the quantitative genetic base for crop improvement. Hybrid maize in India became a commercial success from the beginning of the green revolution era and today, double-cross, three-way-cross, and single-cross hybrids are cultivated extensively. Quality protein maize has also been developed and released.

Sorghum: The discovery of cytoplasmic genetic male sterility in sorghum enabled development of commercial sorghum hybrids in USA and later in other countries, notably India. Commercial sorghum hybrid CSH 1, based on male sterile combine kafir 60, was released in 1964 and stood the test of time. Yellow endosperm short statured derivatives from African × American dwarfs provided the male parents. The development of restorers like CS 3541, a dwarf zerazera, and 296A, a *milo* based sterile involving *karad* a local Indian variety marked significant steps in breeding CSH 5 and CSH 9, which were widely adapted and stable across rainfed environments. Converted zerazeras like CS 3541 and 296 A are extensively employed in several breeding programs of private and public sectors and are landmarks in parental development.

Pearl Millet: About the same time in 1960, the availability of male steriles in pearl millet led Indian breeders to develop commercial hybrids. The modified HB 3 (BJ 104) and HB 4 (BK 560) became widely adapted with some tolerance to downy mildew. Extensive work on downy mildews had led to the release of downy mildew resistant hybrids and populations.

Cotton: India is the first country to grow cotton hybrids on a commercial scale. Cotton Hybrid-4 developed in Gujarat during 1970 and the demonstration that hybrid seed could be produced on a commercial scale through hand emasculation and pollination by C.T. Patel initiated the hybrid cotton era. A number of intra-*hirsutum* hybrids and a few *hirsutum* × *barbadense* hybrids rule over 30 % of the cotton area in India.

Castor: Gujarat also took the lead in the development of castor hybrids, which turned Gujarat into the number one castor growing state in India.

Rice: China took the lead in developing rice hybrids. The discovery of 'Wild Abortive' or WA and the WA-based CMS lines led hybrid rice to be commercially feasible. The first hybrid was released in China during 1976. During the last decade India made extensive efforts to develop commercial rice hybrids. The first Indian basmati scented quality rice hybrid, Pusa RH-10, developed by IARI, scientists was released in the year 2001 for commercial cultivation in India.

The advent of commercial hybrids in various crops led to the growth of private sector investments for research and development of hybrids in various crops. The contribution of hybrids of sorghum, pearl millet, cotton and sunflower in improving yields in rainfed agriculture is a significant landmark (Rao, 1991). During 1970s the growth rates of rainfed sorghum and pearl millet were even higher than wheat and rice. A comprehensive review of 'Heterosis and plant breeding' will be seen in Stuber (2000).

(*c*) Species Change in Cotton

Before 1950s the entire cotton in India was *desi* diploid (*G. arboreum* and *G. herbaceum*). Currently the American tetraploid cottons and their hybrids constitute over 70-80 %, a near reversal of the situation after the visit of S.C. Harland, a renowned cotton scientist/consultant from UK during 1950.

It was believed that diploid *desi* cottons are short-stapled, low yielding and non-responsive to irrigation and that their replacement with American tetraploids was the only solution to enhance yield and quality. That long staple *arboreums* could be bred was demonstrated by Rao (1960) and Qureshi and Rao (1973). Recent work in Andhra

Pradesh, Maharashtra and Karnataka and multilocation trials have consistently proved that *arboreum* cottons out yield American cottons and their hybrids under rainfed as well as irrigated situations. The fibre properties including staple length, strength, fibre maturity are equal or superior to the currently cultivated American cottons and their hybrids. Besides, they are resistant to sucking pests and more tolerant to boll worms. *Arboreum* improvement is likely to have significant consequences on the future scenario of Indian cottons and initiate a trend towards more areas under *arboreums* and also provide an alternate scenario for the pest management processes of cotton.

(*d*) Introduction of New Crops in India

Soybean: The introduction of soybean into India during 1890 and 1932 was not of much consequence. But the introduction of soybean varieties Brag and Clark 63 by the Jawaharlal Nehru Krishi Viswavidyalaya, Jabalpur initiated efforts to adopt and improve soybean in Indian agriculture. Madhya Pradesh leads in soybean cultivation and it is rapidly spreading into Maharashtra, Andhra Pradesh, Karnataka and other states, rendering soybean a major constituent of several rainfed agricultural systems. Export of soya meal has become an important source of Indian agricultural exports. The area increased from 0.5 m. ha in 1979-80 to > 6.0 m. ha in 1999-2000 and the production rose from 0.25 m.t to 6.6 m.t during same period.

Sunflower: The initial introduction of sunflower did not strike root. But later as the edible oil situation became critical, with the introduction of EC 68414 and EC 68415, the early maturing variety Morden and sunflower hybrids, changed all this and sunflower got established as a commercial crop in Karnataka and other states. Refining sunflower oil is also a major industry. The area increased from 0.12 m. ha in 1979-80 to > 2.00 m. ha in 1999-2000 and the production increased from 0.07 m.t to 1.17 m.t during the same period.

Outlook

The decade of 1990s witnessed declining yield growth rates of almost all crops and experimental yields appeared plateauing. The twenty first century is an era of free trade and open markets. Comparative and competitive advantages become primary concerns in the global village. Quality criteria and standards and consumer needs of both domestic and export sectors will be of prime concern. This may warrant drastic changes in the crops scenario. Added to this, cropland and water will be in short supply. There are forewarnings of climate change leading to global-warming, changes in rainfall patterns and so on. This demands for new strategies.

In tropics, time will become an important resource. To maximize per day productivity, crop intensification has to be optimized commensurate with resources. Short season varieties including grain legumes, which provide opportunities for crop intensification and crop diversification may even meet challenges of climate change. Problems associated with short season crops may have to be solved through grain drying and other means.

The concept of food security is changing. In addition to productivity concerns micronutrients have to be incorporated in staple food grains. The food grain demand may double. Agriculture has to become more inclusive and address the entire food chain from primary production to processing, marketing and consumer needs. End product orientation and designer crops will become breeding objectives. Cost cutting and cost efficiency will warrant greater precision. Specialized crop specific/system specific zones or focal areas with processing and market infrastructure may have to emerge.

The host-pathogens relationships are continuously evolving. The pest-disease scenario and host-pest interactions will change over time. Holistic approaches towards broad based resistances rather than single traits will be needed.

The breeders genetic tool kit is rapidly changing. The advent of molecular tools seem to have reflected in the neglect of field work and traditional tools. We should realize that there is no substitute for field selection, population and adaptation processes and integrated plant systems. The experimental approaches may be reductionist, but the holistic approach to integrated plant systems should not be overlooked. The plant breeder has more challenging tasks and he needs to remain close to earth.

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APOMIXIS IN GRAIN SORGHUMS

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Although apomictic form of reproduction is known in the grass family including the tribe Andropogoneae (Brown and Emery, 1957, 1958), no such instance seems to be on record in the cultivated sorghums. Since one of the major advances in the improvement of this cereal has been the commercial exploitation of heterosis, apomictic development of seed would be of considerable use to the plant breeder in maintaining and perpetuating heterozygosity. This paper is a record of apomictic form of reproduction in grain sorghum (*Sorghum vulgare* Pers.).

Materials and Methods

During the *kharif*, 1964, one of the early maturing cultures, in the breeding nursery, R. 78, which was selfed was checked for seed set about a week after anthesis. In a few plants the stigmas looked fresh and the plants were suspected to be male sterile, but symptoms of seed set were noticed later with the stigmas still remaining fresh, On further examination of the breeding nursery this phenomenon was found to be prevalent on a wide scale in some F_4 progenies of crosses involving Indian varieties and dwarf exotics. Microscopic examination revealed well stained and apparently fertile pollen grains. To find out whether the stigmas were merely of the persistent type or whether they were really unfertilised and receptive, pollen of tall Indian varieties B.P. 53 and M. 35-1 was dusted two to three days after complete anthesis of the earhead took place in a few lines and the seeds were collected.

During 1965 and 1966 (1) pollen germination and pollen tube growth on selfing of suspected lines, (2) cross compatibility of pollen from such lines on male sterile combine *kafir* 60, (3) seed set under emasculation, (4) proportion of maternals and hybrids realised from pollinations with foreign pollen after anthesis was complete and (5) embryology of one such progeny, R. 473, were studied.

For embryological studies, the material was fixed in Carnoy's fluid and after 24 hours they were transferred to 70 per cent. alcohol. Customary methods of dehydration, infiltration and embedding were followed. Sections were cut on Leitz Minot microtome at a thickness of 8–12 microns and stained in

Ehrlich's hematoxylin using basic fuchsin as counter stain. Drawings were made at the table level using Zeiss drawing mirror.

Results

The preliminary observations leading towards suspicion of possible apomictic development of seed are described below :

(1) The stigmas and styles of the plants showing prolonged receptivity were fixed after self-pollination and studied microscopically. There was no germination of the pollen in a majority of the cases. Occasional germination and incipient growth of the pollen tube was observed only in very few cases.

(2) To establish the functional normalcy of pollen from such plants, male sterile combine *kafir* 60 was pollinated using R. 78 and R. 473 as pollinator parents. These crosses resulted in good seed set and the progeny were all true hybrids.

(3) Emasculation alone and emasculation followed by pollination with foreign pollen from maize or sorghum pollen killed by heavy doses of radiation resulted in only stray seed set. The stigmas remained fresh, the ovaries appeared as though they were enlarging but ultimately aborted. Out of about 15 emasculations, each involving 40–50 florets, a total of only 4 mature seeds were realised.

(4) The progenies grown from seeds which were obtained through pollinating with tall Indian types two to three days after 'self pollination' has taken place resulted in both genuine hybrids as well as 'selfed' or 'maternal' plants. The resulting hybrids were found to be diploid, fully fertile and some of them very vigorous. The proportions of hybrids and 'selfed' or maternal plants are presented in Table 1.

Table 1

Proportion of maternals and hybrids obtained by pollinating a suspected apomict two to three days after completion of 'self pollination'

Cross	Total No. of plants raised	Maternal	Hybrids	% of Hybrids	Year of study
R. 473 × B.P. 53	77	31	46	60	1965
,,	167	148	19	11	1966

(5) The F_4 progenies concerned did not exhibit clear segregation patterns. Most of them were intermediate in height and apparently true breeding for earhead type although the crosses involved may be considered wide. Shrivelling of seeds was noticed in some cases.

Suspecting apomixis, the embryology of one of the progenies, R. 473, was studied. This was the most uniform progeny associated with excessive receptivity of the stigmas followed by good seed set (Fig. 1) and the seeds were well formed and showed no signs of shrivelling.

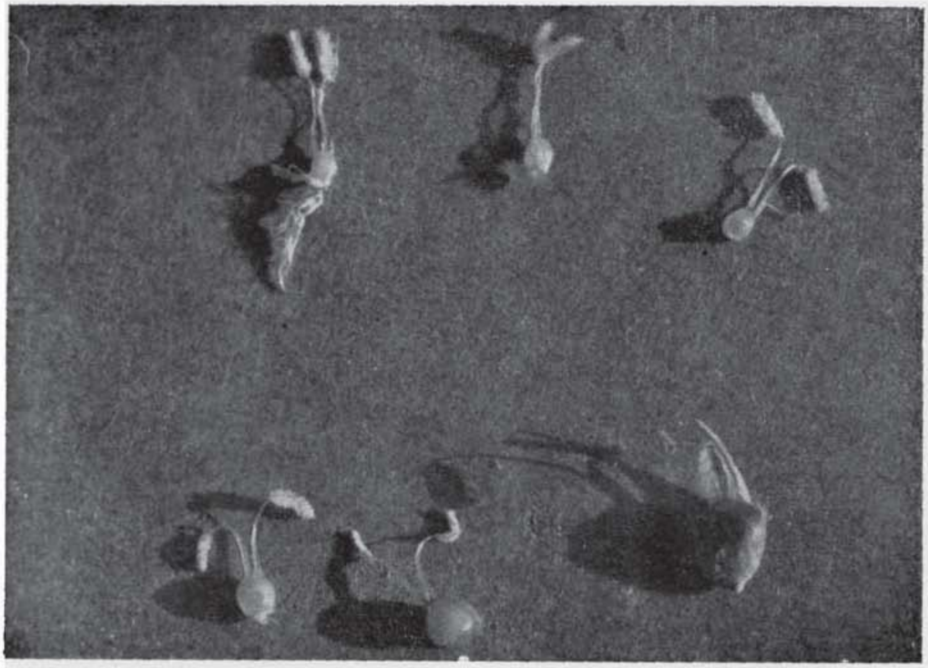
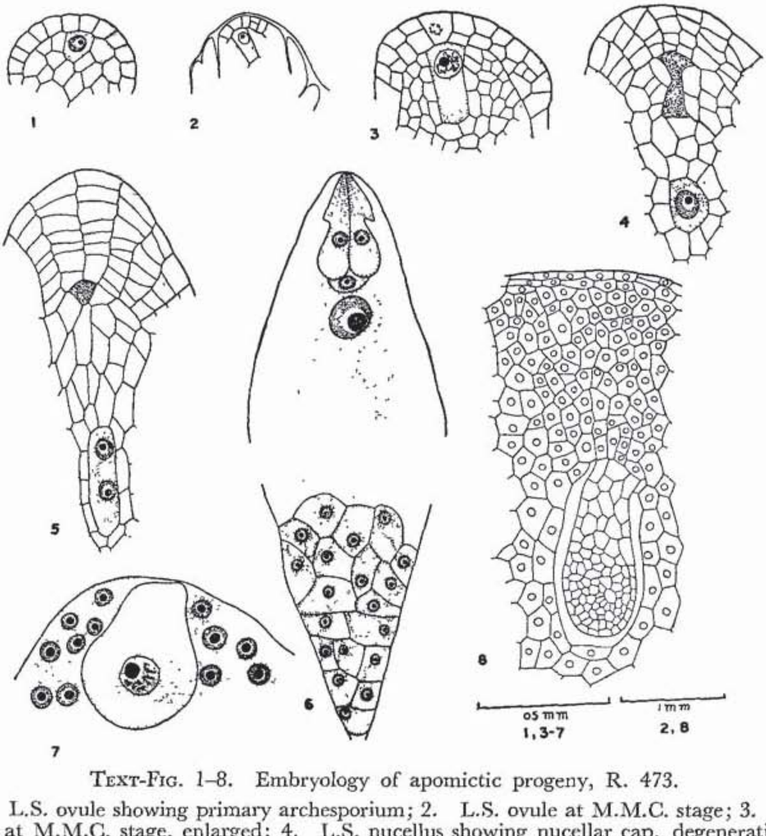


FIG. 1. Developing seed at various stages with stigmas remaining fresh .

Megasporogenesis and female gametophyte : The ovule primordium in R. 473 arises as a globose structure from the base of the ovary. It consists of a homogeneous mass of undifferentiated meristematic cells. At about the time the integumentary primordia appear, the archesporium differentiates at the tip of the nucellus. The archesporial cell can be distinguished by its larger size, prominent nucleus and deep staining cytoplasm (Text Fig. 1). This directly becomes the megaspore mother cell without cutting off a primary parietal cell (Text Figs. 2 and 3). At about this time, the cells of the nucellar epidermis in the region of the micropyle undergo repeated periclinal divisions to form a nucellar cap which is 6–8 layered (Text Figs. 4 and 5). The megaspore mother cell does not undergo further development and gradually begins to degenerate. As this degeneration sets in, one of the cells of the nucellus enlarges and becomes more prominent than the rest (Text Fig. 4). This acts as the emrbyo sac mother cell. Its nucleus divides mitotically to form two nuclei which are separated by a prominent central vacuole (Text Fig. 5). At this stage the degenerating megaspore mother cell can be seen as a darkly stained structure below the nucellar cap. The two nuclei remain near the poles and undergo two more free nuclear divisions resulting in a micropylar and a chalazal quartet. Out of the four nuclei forming the micropylar quartet, three organise into the egg apparatus and the fourth one functions as the upper polar nucleus. The egg apparatus consists of two hooked synergids which show filiform apparatus and prominent basal vacuoles and an egg which slightly extends beyond the synergids (Text Fig. 6). From the four nuclei at the chalazal end three organise into antipodals and the fourth one acts as the lower polar nucleus. The polar nuclei fuse to form the secondary nucleus which lies near the egg apparatus. The antipodals increase in number and form a tissue of 15–25 cells. The cells of this tissue show conspicuous nuclei and vacuolate cytoplasm (Text Fig. 6). Thus the embryo sac develops from a nucellar cell without meiosis and is diploid.



TEXT-FIG. 1–8. Embryology of apomictic progeny, R. 473.

1. L.S. ovule showing primary archesporium; 2. L.S. ovule at M.M.C. stage; 3. L.S. nucellus at M.M.C. stage, enlarged; 4. L.S. nucellus showing nucellar cap, degenerating M.M.C. and enlarging nucellar cell which functions as the embryosac mother cell; 5. L.S. nucellus showing nucellar cap and 2 nucleate stage of embryosac. Note degenerating M.M.C. below the cells of the nucellar cap; 6. Mature embryosac; 7. Upper part of the embryosac showing free endosperm nuclei and undivided egg cell; 8. Upper part of embryosac showing embryo surrounded by cellular endosperm.

Fertilization.—In none of the preparations, the entry of the pollen tube into the embryo sac was observed.

Endosperm.—The endosperm is *ab initio* nuclear. Since pollen tubes have not been observed entering the embryo sac, it may be presumed that the development takes place autonomously or as a result of stimulus of pollination. The egg remains undivided till a large number of endosperm nuclei are formed (Text Fig. 7). At about the time the proembryo attains the globular stage the endosperm becomes cellular and surrounds the embryo (Text Fig. 8). At maturity the endosperm cells are packed with starch grains.

Embryo.—Like the endosperm, the embryo also develops autonomously or as a result of the stimulus of pollination.

In some ovaries degenerating ovules with collapsing embryo sacs were met with. It may be presumed that these ovules contained embryo sacs which were haploid, formed as a result of meiosis in the megaspore mother cell. In such cases, when fertilization fails to take place the embryo sacs and ovules degenerate.

Discussion

Hybridity, polyploidy, disturbed meitoic behaviour, polymorphic species structure and perennial habit have been usually associated with species having apomictic reproduction (Brown and Emery, 1957). In the present study, the aposporous progeny R. 473 and other suspected cases are of hybrid origin. The pollen grains though developmentally normal since they are functional on alien stigmas, were non-functional on the stigmas of the same plant. In other words these plants may be self-incompatible, the restriction to pollen germination again being attributable to their hybrid origin.

The origin of self-incompatibility system presupposes the evolution of weakly functioning serological types as a first step (Bateman, 1952). If, as a result of such a development, a one-locus-two-allele system of self-incompatibility results, then a diploid individual would face extinction. Such an individual would thus be forced to develop an alternate mode of reproduction and the apomictic form would be an obvious choice. This explanaton also presupposes that the capacity to reproduce through other forms like vegetative reproduction by rhizomes, has been lost in the plant and consequently places the time of this evolutionary step of apomixis later than the differentiation of the non-rhizomatous *Arundinacea* and the rhizomatous *Halepensia* taxa from an ancestral taxon. A comparative case of self-incompatibility mechanism giving rise to a sexual mode of reproduction is illustrated by foliar vivipary that has been described in *Cardamine* species (Salisbury, 1965).

In the progeny R. 473, the nature of apomixis is somatic apospory. The progeny has now been observed to be stable with almost the entire seed in the panicles being aposporous. Evidence is available to show that the aposporous reproduction is genetically controlled. In the small percentage of flowers where reduction division took place during megasporogenesis, self pollen did not function and if foreign pollen is not available, as is the case under selfing, the reduced megagametophytes abort.

Direct evidence on the development of endosperm is not yet available. Barring isolated instances, pollen germination was not noticed under selfing. Emasculation of R. 473 followed by pollination with related sorghum pollen also did not result in seed set indicating a pre-fertilisation barrier. However, the presence of abundant pollen with its possible stimulus is essential for seed development. It is reported that unlike sexual forms, there is no functional relationship between the endosperm and embryo in apomicts and the development of the one does not influence the development of the other. Autonomous development of the endosperm has, therefore, been indicated (Brink and Cooper, 1944). Aposporous embryosacs have frequently been observed to be 4-nucleate, but the occurence of 8-nucleate embryosacs have also been reported by several workers and Narayan (1961) suspects the possibility of an association between 8-nucleate unreduced embryosacs and autonomous development of the endosperm.

Burton and Forbes (1960), while reporting obligate apomixis of the apospory type in Pensacola Bahia grass, observed that while in the F_1 generation the sexual and apomictic plants were not significantly different, in F_2 and F_3 generations apomictic offspring was superior to the sexual progenies in height, leaf length, leaf width and factors associated with yield. Taliaferro and Bashaw (1966) worked out the genetics of obligate apomixis in buffel grass and discussed the manipulation of obligate apomixis in buffel grass breeding programmes.

Harlan, Brooks, Borgaonkar and De wet (1964) observed that sexual or asexual reproduction in a given ovule depends on the synchronization of the various embryological processes which are under complex genetic control, but the overall mechanism of apomixis was rather simply inherited. This synchronization of events, the failure of meiosis, the stimulus provided by its own pollen, the possible autonomous development of the endosperm, a reduction in the competition of sexual embryosacs through selection under selfing, seems to have played a role in the evolution of apospory in R. 473, which is a derivative of the cross between *Aispuri* and the yellow endosperm *kafir* I.S. 2942.

The above observations indicate the material under study to be of both theoretical and applied interest. In a material like sorghum, which is often cross pollinated, and with only feebly developed barriers of gene exchange with related species (Magoon, 1966), development of self-incompatibility leading to apomixis is a feature of interest to geneticists studying the evolution of mating systems. From applied interest, as has been suggested by Stebbins (1957), the problem of fixing heterosis has been answered by nature in two ways, namely, apomixis and permanent structural hybridity using balanced lethals as in *Oenothera*. Somatic apospory may preserve at least certain amount of heterozygote advantage in grain sorghums where commercial hybrids based on cytoplasmic-genetic male steriles have today contributed to substantial yield increases.

Summary

The existence of apomixis in grain sorghums has been established. Restriction to pollen germination under selfing, the stimulus provided by its own pollen, the possibly autonomous development of the endosperm and a reduction in the competition of sexual embryosacs under selfing seem to have been responsible for the evolution of somatic apospory in this material. Embryological studies have shown that as the megaspore mother cell degenerates one of the cells of the nucellus enlarges and acts like the embryosac mother cell. This nucellar cell divides mitotically giving rise to the diploid embryosac. This mechanism of somatic apospory, which appears to be genetically controlled, is expected to provide the means to preserve heterozygote advantage.

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Apomixis in Breeding Grain Sorghums

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34. APOMIXIS IN BREEDING GRAIN SORGHUMS

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Introduction

Apomixis has been reported originally in grain sorghum (*Sorghum bicolor* L. Moench) in the F_4 segregates of a cross involving the tall Indian *Aispuri* to dwarf yellow endosperm derivatives. This report was based on non-germination of self pollen and the development of embryo sacs from diploid nucellar cells in the culture R473 (Rao and Narayana, 1968). Recently, Hanna *et al.*, (1970) reported facultative apomixis in a male-sterile polygynaceous sorghum line and contended that the evidence presented by Rao and Narayana (1968) was not conclusive enough to confirm apomixis. Rao and Murty (1972) have subsequently presented direct evidence for the presence of unreduced embryo sacs, the autonomous development of the endosperm and the diploid nature of the young endosperm in R473. They have also observed a family segregating for apomixis, male-sterility and self-incompatibility. The present report outlines the behaviour of the available apomictic cultures and the scope of their utilization in sorghum breeding.

Contribution from the All India Co-ordinated Sorghum Improvement Project.

Embryological Behaviour of R473

There is some variation both in time and method of origin of embryo sacs in the different ovules of even the same plant in this line. Embryo sacs are almost always 8 nucleate *Polygonum* type with an egg apparatus formed of an egg and two synergids, two polar nuclei and 3 antipodals. The antipodals undergo proliferation which is characteristic feature of the family Gramineae and form a cluster of usually binucleate cells (Fig. 34-1A). Four nucleate embryo sacs are extremely rare (Rao and Murty, 1972). Either a single embryo sac or 2 embryo sacs were observed in different ovules (Figs. 34-1B and C). About 2-3% of the ovules had 2 embryo sacs.

The method by which these embryo sacs arise has been studied by both the conventional method and also from an extensive acetocarmine squash technique. Material for the microtomy was fixed from the winter crop of 1970. In serial sections about 200 young ovules were observed. Embryo sacs predominantly at the 2- 4- and 8- nucleate stages of development were encountered. In a few ovules, however, the archesporial cell and in 3 ovules the MMC were observed. The two cells were distinguished on the basis of the extent of nucellar tissue at the micropylar end. In 5 ovules a degenerating cell in the micropylar region was observed below which there is an enlarged cell with a large nucleus and abundant cytoplasm (Fig. 34-1D). Since in no case, a megaspore tetrad was observed, it appears that the degenerating cell is the MMC and the large cell below it a nucellar cell destined to produce the unreduced embryo sac. Since the enlarged cell can as well represent the chalazal megaspore and the degenerating mass, the other three megaspores, a comparison was made of the development of the embryo sac in an indigenous normal sexual variety *Karad local*. Here the megaspore tetrad was observed in several cases. Also, the chalazal megaspore was close to the degenerating megaspores. In the case of R473, the degenerating cell and the enlarged cell below it which is presumed to be the nucellar initial were separated by several intervening layers of cells ruling out the possibility of normal development.

A large number of ovules were also examined in acetocarmine squashes based on a technique outlined by Reddy and D'Cruz (1967). Material for the squash study was fixed from the *kharif* crop of 1971, at 16.00 to 18.00 hours in the case of young ovules and at 1/2 hour intervals in the case of ovules after pollination from 10.00 to 18.00 hours. About 1,500 young ovules were examined prior to anthesis. In about 26% of

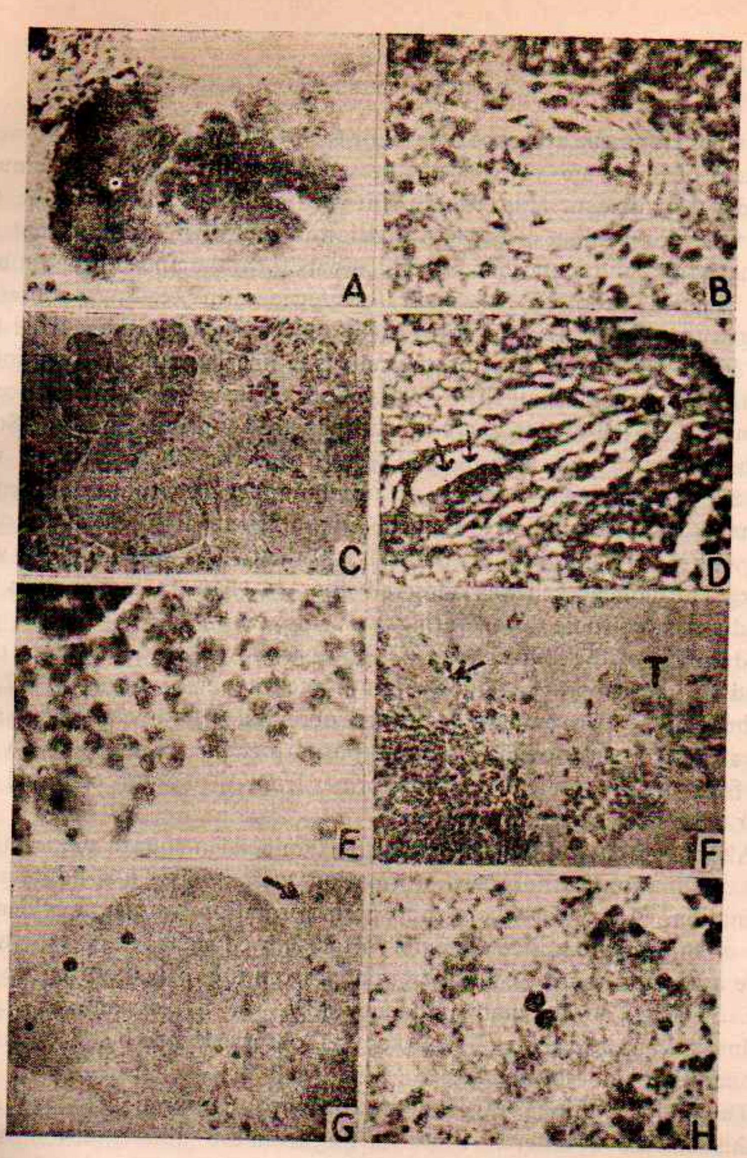

Fig. 34-1.

A. Mature polygonum type of embryo sac with an egg apparatus (synergids have already degenerated), 2 polar nuclei and a mass of antipodals.

B & C. Two embryo sacs in a single ovule. B is a section and C is a squash preparation.

D. Degenerating MMC (arrow) and nucellar aposporous initial (double arrow).

E. Aposporous and sexual initials.

F. Sexual tetrad of megaspores (T) and aposporous initial (arrow).

G. A degenerating embryo sac and an aposporous initial (arrow).

H. Five nucleate embryo sac. Note the absence of antipodals.

the ovules either the archesporial cell or the MMC was observed. Twenty per cent of the ovules revealed the presence of two cells with large nuclei and dense cytoplasm (Fig. 34-1E). It was not clear whether these two cells were the product of the first division of the MMC or represent the normal MMC and a nucellar cell which may form the aposporous embryo sac. Since in another 5% ovules, a degenerating cell was observed along with a large cell with sporogenous appearance, it was presumed that in at least some ovules one of the cells is a nucellar aposporous initial and the other the normal MMC which degenerates at least in some cells.

In 2% of the ovules, there is a linear tetrad of megaspores. Some of the tetrads could be observed just before the completion of wall formation and in such cases, the reduced number of chromosomes could be made out. This indicates that there is some sexual potential although to a very low extent. In less than 1% of the ovules a tetrad along with a large prominent cell was observed (Fig. 34-1F). In some cases the tetrad appeared to be degenerating.

Majority of the ovules (43.8%), however, revealed the presence of a tetrad of megaspores together with a 2 nucleate embryo sac. In 2.5% of the ovules, two embryo sacs were observed per ovule. This may indicate that in such ovules both an aposporous and sexual embryo sac can form in the same ovule, the former from a nucellar cell and the latter from the chalazal megaspore.

About a thousand ovules were also examined in squash preparations after pollination. Endosperm formation was evident 6-8 hours after pollination. In ovules where endosperm formation was not evident, it was often observed that the embryo sac showed signs of degeneration while a very prominent cell differentiated from the neighbouring tissues (Fig. 34-1G). In a small frequency (3%) of ovules one day after pollination, a healthy embryo sac was observed side by side with a degenerating embryo sac.

These observations suggest that aposporous embryo sacs can arise in this culture at different times starting from the differentiation of the archesporial cell upto the formation of the sexual embryo sac and sometimes even after pollination. In a particular ovule, either a sexual embryo sac alone or both can form. In ovules where only sexual embryo sac has formed, since there is no fertilization in this culture (Rao and Murty, 1972) it cannot develop further. The occurrence of an enlarged prominent cell near the degenerating embryo sac after pollination seems to indicate that the ovule has the potential for the production of unreduced embryo sacs at any stage of its development.

Origin of Embryo Sacs in Male-Sterile Apomicts

Some of the families in the breeding nursery were observed to segregate for male-sterility. On close examination it was found that these male-steriles do set seed ranging from 0 – 100% under bag. In some of the fertile sister plants, the stigmas remained fresh as if they were unpollinated similar to the culture R473. On close examination it was found that they were self-incompatible. Self-pollen did not germinate at all or only to a little extent. A few such plants were tagged and checked for seed set under bag. Some of them gave full seed set while some failed to do so. It is apparent, therefore, that these families are segregating for male-sterility, self-incompatibility and apomixis. While it can be said with certainty that some of these self-incompatibles and male-steriles are presumably reproducing through apomixis nothing can be said about the fertile plants. They may be normal sexuals or apomicts.

Embryology of these plants has not been worked out in any great detail. Only mature embryo sacs were examined in a single plant in squash preparations. Out of 28 ovules examined, 22 contained a single embryo sac. Of these 22, twenty have 8 nucleate and 2 have 4 nucleate embryo sacs. The rest of the 6 ovules had two embryo sacs each. Four of them had one 8 nucleate and one 4 nucleate embryo sac. In the remaining two, there is one 8 nucleate and one 5 nucleate embryo sac. Self-incompatible plants of this family also had 4 nucleate and 5 nucleate embryo sacs in addition to normal 8 nucleate embryo sacs (Fig. 34-1H).

Apomictic panicoid grasses generally have 4 nucleate embryo sacs although 8 nucleate embryo sacs are not rare (Narayan, 1962). Also some apomictic embryo sacs of the same plant can have 8 nucleate as well as 4 nucleate unreduced embryo sacs (Reddy and D'Cruz, 1969). Five nucleate embryo sacs have also been reported (Carnahan and Hill, 1961). The 4 nucleate embryo sacs generally have a single polar nucleus but two polar nuclei are not uncommon, having been reported in *Sorghum* itself (Hanna *et al.*, 1970).

Development of the Embryo and Endosperm in Aposporous Embryo Sacs

Information is available for only R473. Rao and Narayana (1968) suspected that the formation of embryo and endosperm is autonomous. The development, however, requires the stimulus of pollination. In the aposporous embryo sac 3-4 hours after pollination the egg and polar nuclei start division. No divisions take place in the embryo sacs of un-pollinated ovaries. At first they enlarge giving the impression that they may form the seed but ultimately they get aborted. The embryo sacs degenerate after 6 days. In pollinated ovaries, although there is no fertilization, division of the egg and polar nuclei commence. Both the egg and polar nuclei are diploid and contain 20 chromosomes each. The polar nuclei do not fuse with each other, but divide independently to form the endosperm (Rao and Murty, 1972). The older endosperm nuclei 2-3 days after pollination were found to be diploid.

Apomixis in Breeding

Apomixis can be utilized in breeding, as in Buffel grass (Tiliaferro and Bashaw, 1966). Although the inheritance of this phenomenon is different in different groups of plants, extensive studies on apomictic groups suggest that apomixis is controlled by a number of genes forming a genetically balanced system and that the overall process of apomixis is recessive to sexuality (Gerstel and Mishanec, 1950; Muntzing, 1958; Burton and Forbes, 1960). In grasses, however, there are indications of a certain degree of dominance (Harlan *et al*, 1964; Tiliaferro and Bashaw, 1966). In *sorghum* recessive gene action is suspected. Some complementary gene action also seems to be involved, since neither of the parents of the apomictic cultures were apomicts themselves. Behaviour of the offspring of crosses involving the two different types of apomixis (self-incompatibility based and male-sterility based) may provide some information on the genetics of this phenomenon and provide guidelines for its utilization in preserving heterozygosity. For detection of apomixis, studies of pollen germination in the case of "self-incompatible apomicts" and pollen fertility in the case of "male-sterile apomicts" may help confirm apomixis.

Apomixis may also help in tetraploid breeding. Autotetraploid sorghum has some desirable attributes but its cultivation is hampered by its sterility. Meiotic irregularities no doubt are reponsible either in part or whole for this sterility. Since meiosis is circumvented in the apomicts, theoretically autotetraploid apomicts should be more fertile than those of sexuals. Diverse autoploid apomicts may be synthesised and a tetraploid breeding program could be developed.

Summary

Detailed embryological development of aposporous embryo sacs was presented in R473, a line of sorghum which is self-incompatible. Both aposporous and sexual embryo sacs were of the *Polygonum* type. Some male-sterile cultures of sorghum which are also apomictic have 4 and 5 nucleate aposporous embryo sacs in addition to the normal 8 nucleate embryo sacs. Studies of pollen germination and growth, coupled with seed set may help confirm apomixis. Apart from its utility in preserving heterozygote advantage, apomixis may also be utilized in tetraploid breeding.

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INDUCTION OF TETRAPLOIDY IN APOMICTIC GRAIN SORGHUM

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Artifical tetraploids have been induced in almost all important grain crops with apparently least success in practical breeding. Almost always it has been the decreased fertility and slower growth of the colchiploids which brought down their direct or indirect use, inspite of an increase in grain size and other advantages. In grain sorghum, tetraploids have been repeatedly induced but in all cases they were induced in sexual strains only. The existence and mechanism of diploid apomixis in grain sorghum has recently been established (Rao and Narayana, 1968; Murty and Rao, 1972 and Rao and Murty, 1972). The present study gives an account of the morphology, cytology and fertility status of tetraploids of diploid apomictic grain sorghum.

Materials and Methods

The diploid apomictic line R473 of grain sorghum has been used in this study. Seeds were germinated in pots and the seedlings, when they were 2-5 cms in length, were taken out, washed and treated with aqueous colchicine solution of concentration varying from 0·1–0·5%. The shoots were dipped in the solution for 12 hours, washed for 8 hours and were transplanted in the field. Some plants were also grown in pots. One tetraploid plant was obtained out of about 100 seedlings treated with 0·5% solution and grown in the field. Three tetraploids were obtained out of 100 plants grown in the pots in the treatment with 0·4% solution. Standard iron acetocarmine technique was used in the cytological preparations.

Results

Morphologically it was not possible to distinguish the tetraploids from the diploids. They had a slower growth rate but it was not possible to isolate them on this criterion. The foliage appeared in general darker. Leaf margins were also wavy instead of the usual type. All of them were shorter at all stages of their growth compared to the parent due to short internodes. The stem is thicker The field grown tetraploid plant flowered 20 days later than the diploid while the pot grown plants flowered 45–60 days later. All the tetraploid plants were heavily attacked by stem borer and only one of them survived till seed set.

Chromosome configurations were studied at MI in 2 of these plants (Table 1). In general, the frequency of univalents and trivalents was quite low. All the trivalents were chains (type 7 of Darlington, 1937) with two chias-

TABLE 1

Frequencies of chromosome configurations in the tetraploid plants at MI

Plant	No. of PMC analysed		I	II	III	IV
1	20	Range	0–3	0–18	0–2	0–6
		Total	11	265	9	58
		Mean	0·55	13·25	0·45	2·90
4	32	Range	0–4	0–18	0–2	0–6
		Total	19	400	19	101
		Mean	0·59	12·50	0·59	3·16
Grand total	52	Total	30	665	28	159
		Mean	0·60	12·81	0·54	3·07

mata. Trivalent types 8, 9 and 10 were not encountered. Quadrivalents were predominantly chains (type 11) with three chiasmata or rings (type 17) with four chiasmata. Type 18 occurred in a very rare frequency while the other possible types of quadrivalents were not encountered.

The 2 tetraploid plants had a mean chiasma frequency of 1·58 and 1·61 at MI. The corresponding value of the diploid parent was 1·47 only. The differences in the chiasma frequencies of the diploid parent and the tetraploids are highly significant ('t' = 3·73 and 3·61).

AI distribution of chromosomes was studied in 126 and 98 cells in tetraploid plants 1 and 4 respectively; 77·8% of cells in the former and 83·4% in the later had a regular segregation of 20 . 20.

Pollen fertilities ranged between 80–100% and are comparable to that of the diploid. The surviving tetraploid plant had 72 hermaphrodite spikelets and 61 seeds were set (84·72%).

DISCUSSION

An interesting feature of the autotetraploid sorghum in the present study has been the low percentage of univalents and trivalents in general and that of the quadrivalents in particular (3·07/cell). This is in agreement with the previous reports. Schertz (1962), for example, reported a mode of 3·0 per cell, although Doggett (1964) reported a rather high frequency of 6·22 per cell. However, even this is low compared to maize where Randolph (1935) has reported 7–9 quadrivalents per cell.

The pollen fertility of the autotetraploid is also quite high and is comparable to that of the diploid parent. Earlier Chin (1964) has also reported a rather high pollen fertility (81%), although Schertz (1962) found only 35% of stainable pollen. The seed set observed in the present study (84·72%) is probably the highest so far recorded for any raw autotetraploid. Schertz (1962) has reported only 10% mean seed set. Differences in fertility of autotetraploids have been ascribed to variations in chromosome behaviour (Darlington, 1937) at meiosis or where no cytological irregularities were discernible to genetic differences (Morison and Rajathy, 1960a & b). The higher seed fertility of the raw autotetraploid observed in the present study is as expected and is not surprising. The diploid parent of these tetraploids is characterised by an obligate subsexual method of reproduction. Apomixis in this line of grain sorghum has been established on the basis of non-germination of self-pollen and development of embryo sacs from diploid nucellar cells (Rao and Narayana, 1968). Subsequently, Rao and Murty (1972) have presented direct evidence for the presence of unreduced embryo sacs, the autonomous development of the endosperm and the diploid nature of the young endosperm. In the formation of embryo sac, meiosis does not occur and the resulting embryo sac cells will contain the regular somatic chromosome number (in this case $4n = 40$). No fertilization is required for the autonomous development of the embryo and endosperm. This phenomenon, therefore, accounts for the high seed set.

The surprisingly high male fertility, however, deserves explanation. Ross and Chen (1962) observed a slightly smaller number of quadrivalents, a slightly greater number of bivalents, a markedly smaller number of univalents at diakinesis and a smaller frequency of laggards at AI and micronuclei at the quartet stage in the more fertile autotetraploids and concluded that a gene mutation might have occurred and this together with the lesser chromosome unbalance in the gametes resulting from the decreased number of univalents might have accounted for the higher fertility. Doggett (1964) concluded that there are differences in the genotypic fertility control systems of sorghum which result in slight differences at the tetraploid level. Garber (1944) hypothesized that if a species does not display directional orientation of the chromosomes in an interchange complex at MI, the quadrivalents in an induced or spontaneous tetraploid of that species will likewise not display a directional orientation at the same stage. Observations of earlier workers (Chin, 1946; Endrizzi, 1958) in autotetraploid grain sorghum suggested that directional segregation is a characteristic feature of the Eu-sorghums. In view of these observations, the very high percentage of regular segregation at AI recorded in the present study probably substantiates the existence of such a genetically controlled regular segregation. The increased chiasma frequency of the tetraploid can also be partly responsible for the regular disjunction of the chromosomes.

Murty and Rao (1971, 1972) have suggested that tetraploid sorghum from apomictic lines should be more fertile than that from sexual strains and that tetraploid breeding in sorghum may be worthwhile to pursue. The present study lends support to such a suggestion.

Summary

Autotetraploids induced from diploid apomictic grain sorghum exhibited a lower number of univalents, trivalents and quadrivalents and a greater number of bivalents. The chiasma frequency of the autotetraploids is also higher than their diploid parent. Tetraploids exhibited remarkably high male and female fertilities. The possible application of tetraploids in grain sorghum breeding is discussed.

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APOMIXIS AND ITS UTILIZATION IN GRAIN *SORGHUM*-I. EMBRYOLOGY OF TWO APOMICTIC PARENTS

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INTRODUCTION

In earlier reports on apomixis in the *Sorghum* variety R473, attention was paid to the development of the embryosac and endosperm leading to the establishment of somatic apospory (RAO and NARAYANA 1968). HANNA, SCHERTZ and BASHAW (1970) observed that the evidence produced by RAO and NARAYANA (1968) was inconclusive. Subsequent work by RAO and MURTY (1972) confirmed the earlier observations of RAO and NARAYANA (1968). Further attempts led to the identification of an additional apomictic variety 302 and efforts are in progress to obtain a greater understanding of the phenomenon of apomixis in *Sorghum* and its utilization and perpetuate heterozygosity. The present paper describes the embryology of two apomictic *Sorghum* varieties R473 and 302 which show several similarities. The *Sorghum* variety 302 is of commercial importance and has been released for general cultivation in India.

MATERIAL AND METHODS

The material at suitable stages was fixed in carnoys fluid and transferred to 70% alcohol after 24 hours. Conventional methods of dehydration, infiltration and embedding were followed. Sections cut at 8-12 μ were stained in Haematoxylin and counterstained in Basic Fuchsin.

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OBSERVATIONS

Microsporogenesis and male gametophyte. Previously no attention has been paid to the structure of the anther and the development of the male gametophyte. The present study reveals that the differentiated anther shows an epidermis, endothecium, a middle layer and the tapetum (Fig. 1). The tapetum is of the secretary type and the cells ultimately become binucleate (Fig. 1). Meiosis in pollen mother cells leads to the formation of isobilateral pollen tetrads. Cytokinesis takes place by successive method. Pollen is 3-celled at the shedding stage (Fig. 2). A high percentage of pollen is healthy and viable and such grains when mounted in Iodine, water or acetocaramine become stained deeply. Approximately 90% of the pollen grains are fertile. Abortive pollen grains were also observed in some of the anthers (Fig. 3).

There is an accumulation of dark bodies of unknown nature in some of the pollen grains. Germination studies of the pollen grains have been carried out at room temperature in Brewbaker and Kwack's medium prepared in distilled water. When placed in the culture medium the pollen grains emitted out pollen tubes after 30 minutes. The germinability is upto 60-65%. After growing for a short length the tubes become blunt and curved. After this no further growth takes place. Coiling of pollen tubes has also been observed (Fig. 5). This indicates that the pollen retains the capacity to germinate but pollen tubes do not grow for lengths necessary for reaching embryosac. As a result, fertilization fails to take place.

Ovule, Megasporogenesis and female gametophyte. The ovule is anatropous, bitegmic and tenuinucellate, with the micropyle formed by the inner integument only. At about the time the integument primordia appear the hypodermal female archesporium becomes differentiated in the tip of the nucellus. The archesporium is always single celled. The archesporial cell enlarges and functions as the megasporemother cell without cutting off

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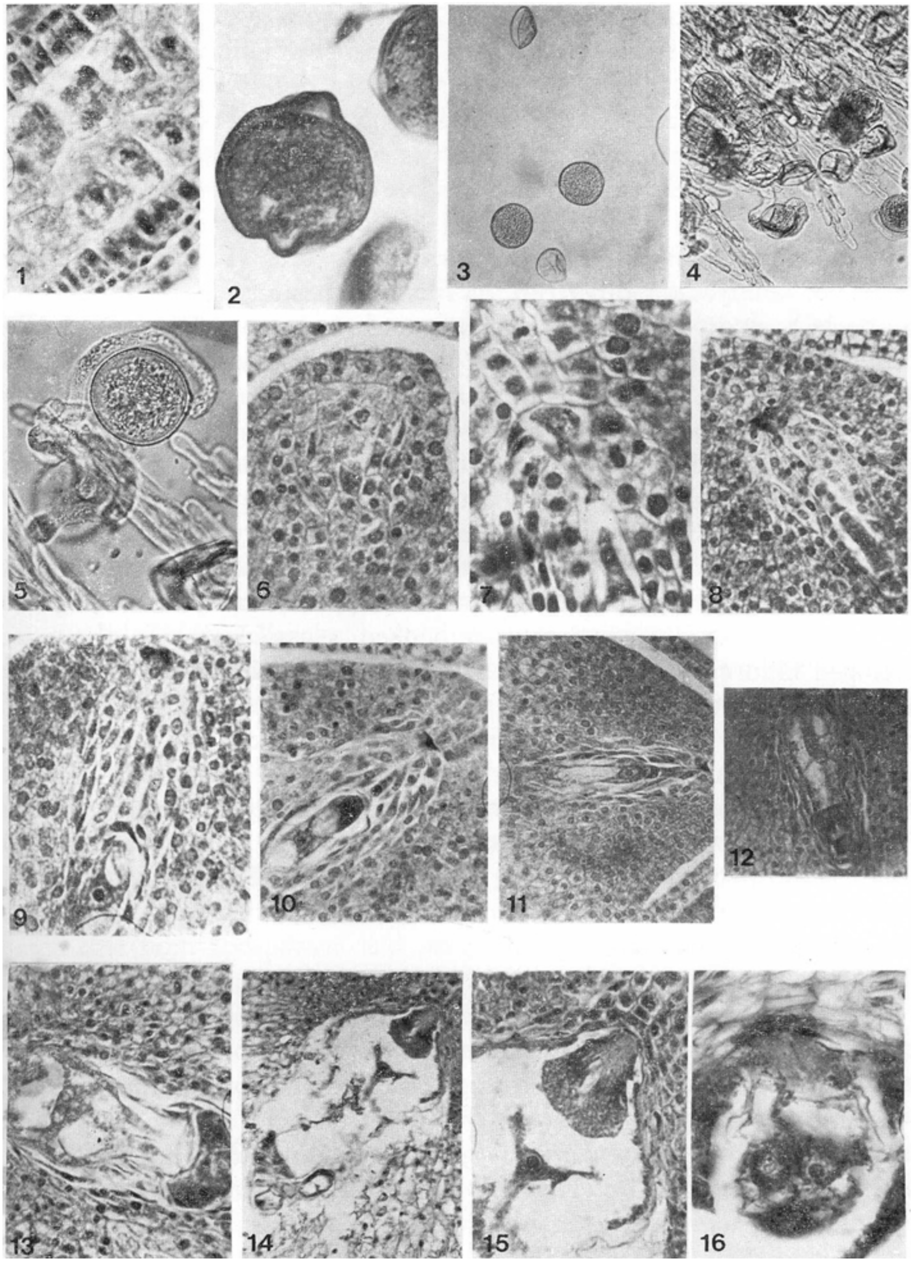
Figs. 1, 6, 8, 11 and 13. — R473.
Figs. 2-5, 7, 9, 10, 12, 14-16. — 302.
Fig. 1. — L.S. of anther showing epidermis, hypodermis, middle layers, tapetum and sporemother cells. x 960.
Fig. 2. — 3-celled pollen grain. x 1340.
Fig. 3. — Fertile and sterile pollen grains. x 190.
Fig. 4. — Fertile and sterile pollen grains on stigma. x 180.
Fig. 5. — Germinating pollen grains. x 755.
Fig. 6. — L.S. of nucellus showing enlarging nucellar cell and archesporial cell showing signs of degeneration. x 710.
Fig. 7. — L.S. of nucellus showing degenerating MMC and enlarging nucellar cell. x 1270.
Figs. 8 and 9. — L.S. of nucellus showing the remnants of MMC and enlarging nucellar cell. x 570, x 515.
Figs. 10 and 11. — 2-nucleate embryosac. Note remnants of MMC. x 590.



Figs. 12 and 13. — Embryosac. showing fusion of polar nuclei. x 760, x 555.
Fig. 14. — Mature embryosac showing the egg apparatus, antipodal tissue and secondary nucleus. x 310.
Fig. 15. — Magnified portion of the embryosac showing egg apparatus and secondary nucleus. x 650.
Fig. 16. — 4-celled proembryo with persisting healthy looking synergids. x 1080.

a primary parietal cell (Figs. 6 and 7). At about this time the nucellar epidermal cells, as result of repeated periclinal divisions, give rise to a nucellar cap of 6-8 cells (Figs. 6-11). Further development in the megasporemother cell is arrested and shows signs of degeneration (Figs. 6 and 7). In 302, in one instance, the MMC was seen at the first stage of meiosis. But in neither of the plants a megaspore tetrad has been observed. At about this time one of the centurally located nuclellar cells enlarges and becomes more prominant than the sorrounding cells (Figs. 6-9). This cell acts as the embryosac mother cell. At first vacuoles appear on either side of the nucleus as in the case of a functional megaspore (Figs. 7-9). First mitotic division of nucleus results in the 2-nucleate stage of the embryosac (Figs. 10 and 11). The two nuclei are separated by a prominant vacuole (Figs. 10 and 11). The remanants of the degenerating megasporemother cell persist as a deeply staining mass below the calotte upto this stage of development (Figs. 8-11). The two nuclei remaining at the poles divide twice leading to the formation of an 8-nucleate embryosac (Fig. 12). Out of the four nuclei of the micropylar quartet, three organise into the egg apparatus and the fourth functions as the upper polar nucleus (Fig. 12). The egg apparatus consists of two hooked synergids which show well developed filiform apparatus, and the egg cell (Figs. 14 and 15). From the chalazal quartet three organise as antipodals and the fourth functions as the lower polar nucleus (Fig. 12). There is a secondary increase in the number of the antipodals and their number ranges from 8-15 (Figs. 13 and 14). The antipodals are uninucleate and the cytoplasm is vacuolate (Figs. 13 and 14). The polar nuclei fuse to form a secondary nucleus, which lies in the vicinity of the egg apparatus (Figs. 12-15). Thus embryosac develops aposporously from a nucellar cell without meiosis and all the cells of the embryosac are diploid.

Fertilization. Stigmas of bagged flowers stained in basicfuchsin showed germinating pollen grains. The pollen tubes were short and the tips are curved and blunt obviously indicating that they are non-functional (Figs. 4 and 5). In 302, in few instances, the synergids were found in a healthy state at the early pro-embryonal stages indicating that no pollen tube has entered the embryosac (Fig. 16). In none of the preparations the entry of the pollen tube has been observed. These observations clearly show chat no fertilization takes place.

Endosperm. The endosperm is of the nuclear type. Fertilization having been ruled out it may be presumed that under the stimulus of pollination endosperm develops autonomously. The diploid egg remains undivided till a large number of free endosperm nuclei are formed and the endosperm ultimately becomes cellular.

Embryo. The diploid egg under the stimulus of pollination develops autonomously into the embryo.

DISCUSSION

In none of the earlier publications on the embryology of R473 the development of the male gametophyte has been reported. The anther wall conforms to the Monocot type (DAVIS 1966) in R473 as well as 302. Cytokinesis takes place by successive method. Fertility tests using iodine water, acetocaramine revealed that 90% of the pollen is fertile. But culture studies revealed only 60% germinability. The pollen tubes grow only for a short length and the tips become curved and blunt indicating arrested growth.

The archesporial cell functions as megasporemother cell which degenerates, and takes no part in the formation of the embryosac. One of the centrally placed nucellar cells enlarges and functions as the embryosac mother cell. Thus the embryosac arises as a result of somatic apospory and comes under Hieracium type (BATTAGLIA 1963). The mature embryosac is 8-nucleate and the there is an increase in the number of antipodals. However, MURTY and RAO (1972) reported formation of megaspore tetrads in 2% of the ovules they examined and in less than 1% of the ovules observed a megaspore tetrad and an enlarging nuclellar cell. They also observed two nucleate embryosac and a tetrad of megaspores. In some ovules they observed twin embryosacs. From these observations they concluded that both aposporous and sexual embryosacs can be formed in the same ovule. As a result of the occurrence of megasporetetrads. MURTY and RAO (1972) suggested that in R473 the potential for sexual reproduction still persists. In the present study no megaspore tetrads or twin embryosacs have been observed. But the potentiality for sexual reproduction is indicated by the development of the archesporium upto the megaspore mother cell stage. Probably in this line there is a gradual elimination of the potentiality for sexual reproduction under continued selfing as also suggested earlier by RAO and NARAYANA (1968).

The ovule is bitegmic and tenuinucellate with a prominently developed nucellar cap. DAVIS (1966) described such ovules as pseudocrassinucellar, in which no primary parietal cell is formed but in which the apical cells of the nucellar epidermis divide periclinally and give rise to a nucellar cap. In such instances although the MMC appears to be deeply buried, the overlying cells are epidermal derivatives and are arranged in radiating rows.

There is no evidence of fertilization as no pollen tubes were observed entering the ovules in any of the preparations. Examination of styles and stigmas from selfed plants revealed germinating pollen grains. But the pollen tubes grow only for a very short lengths with their tips becoming curved and blunt. The pollen grains behaved in a similar way in the culture medium.

However, the endosperm and embryo develop autonomously. Presence of germinating pollen grains on the stigmas associated with normal seed set indicates that a stimulus of pollination is necessary for the development of endosperm and embryo. Unlike in sexually reproducing plants there is no functional relationship between endosperm and embryo development in apomicts (BRINK and COOPER 1944). MURTY and RAO (1972) reported the occurrence of sexual embryosacs as well as aposporously developed ones in some ovules. In such instances the haploid embryosac degenerates because of the absence of fertilization. No such instances were encountered in the present study.

HANNA *et al.* (1970) in a male sterile line of *Sorghum* recorded a case of facultative apospory. They claimed that the studies of RAO and NARAYANA (1968) in the progeny of R473 were inconclusive and the features presented by them could be interpreted in terms of normal development.

Absence of pollen germination and good seed set under selfing suggest that the seed development in R473 is aposporus. The present study as well as those by MURTY and RAO (1972), RAO and MURTY (1972) confirm the first report of somatic apospory and autonomous development of endosperm and embryo, by RAO and NARAYANA (1968). It may be pointed out here that apomixis in R473 is associated with self incompatibility, while the material of HANNA *et al.* (1970) was male sterile.

Acknowledgements. — We wish to express our thanks to Dr. B. S. RANA and V. J. M. RAO for their kind assistance in the collection of the material. Thanks of one of us (RNR) are due to the I.C.A.R. for the research fellowship under the scheme Apomixis in Grain Sorghums. Our thanks are also due to Prof. U. B. S. SWAMI, Head of the Department of Botany for facilities and encouragement.

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SUMMARY

The embryology of two apomictic parents, R473 and 302 has been investigated. The anther structure conforms to the Monocot type. Cytokinesis takes place by the successive method. Ripe pollen is 3-celled. Though 90% of the pollen is fertile the germination is only about 60%. The embryosac developes aposporously from a centrally located nucellar cell. Fertilization does not take place. The development of embryo and endosperm takes place autonomously under the stimulus of pollination. The present study confirms earlier report of somatic apospory and autonomal development of endosperm and embryo in R473 by RAO and NARAYANA (1968). In addition an additional case of somatic apospory in 302 variety is now reported.

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Apomixis and its utilisation in grain sorghum—II; embryology of F_1 progeny of reciprocal crosses between R473 and 302

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Abstract. The embryology of F_1 progeny of reciprocal crosses between R473 and 302 has been investigated. The anther wall development follows the monocotyledonous type. Successive cytokinesis in the microspore mother cells results in the formation of isobilateral pollen tetrads. Pollen grains are 3-celled at the shedding stage. Although 90% of pollen are fertile, the germination is only about 70%. Abortive pollen grains are noticed in some anthers. The ovule is anatropous, bitegmic and pseudocrassinucellar. Archesporium or megaspore mother cell, if formed, degenerates. The embryo sac developed aposporously from a nucellar cell, is always 8-nucleate with a secondary increase in the antipodal cells. Fertilisation does not take place. The autonomous development of embryo and endosperm occurs under the stimulus of pollination. Like the two parents the F_1 progeny exhibit apomixis of the nature of somatic apospory associated with self-incompatibility.

Keywords. Embryology; apomixis; grain sorghum.

1. Introduction

Search for apomixis in grain sorghums started about a decade ago. Rao and Narayana (1968) investigated the embryology of a *sorghum* variety, R473 and they reported aposporous origin of embryo sac and observed that the autonomous development of endosperm and embryo required the stimulus of pollination. Hanna *et al* (1970) studied the embryology of a polygynaceous line of *sorghum bicolor* and doubted the findings of Rao and Narayana (1968). Rao and Murty (1972) reinvestigated the emb yology of *sorghum* variety R473 and confirmed the findings of Rao and Narayana (1968) though their observations differed in certain minor respects. Recently Rao *et al* (1978) studied the embryology of R473 and confirmed the earlier findings of Rao and Narayana (1968). They also investigated the embryology of 302, another variety of *sorghum*. In the present study the embryology of F_1 progeny of the reciprocal crosses between R473 and 302 has been undertaken to establish the reproductive status of the progeny.

2. Material and methods

Flowering and fruiting material of F_1 progeny of reciprocal crosses between R473 and 302 at various stages of development was fixed in Carnoy's fluid. After 24 hr of fixation it was transferred to 70% alcohol. Customary methods of dehydration, infiltration and embedding were followed. Sections were cut at a thickness of 5–12 μ, stained with haematoxylin and counterstained with basic fuchsin.

Pollen fertility tests using iodine solution and acetocarmine, revealed that 90% of the pollen are healthy and fertile. Ripe pollen is 3-celled and the germinability estimated on the basis of the observations on the styles and stigmas is 70%.

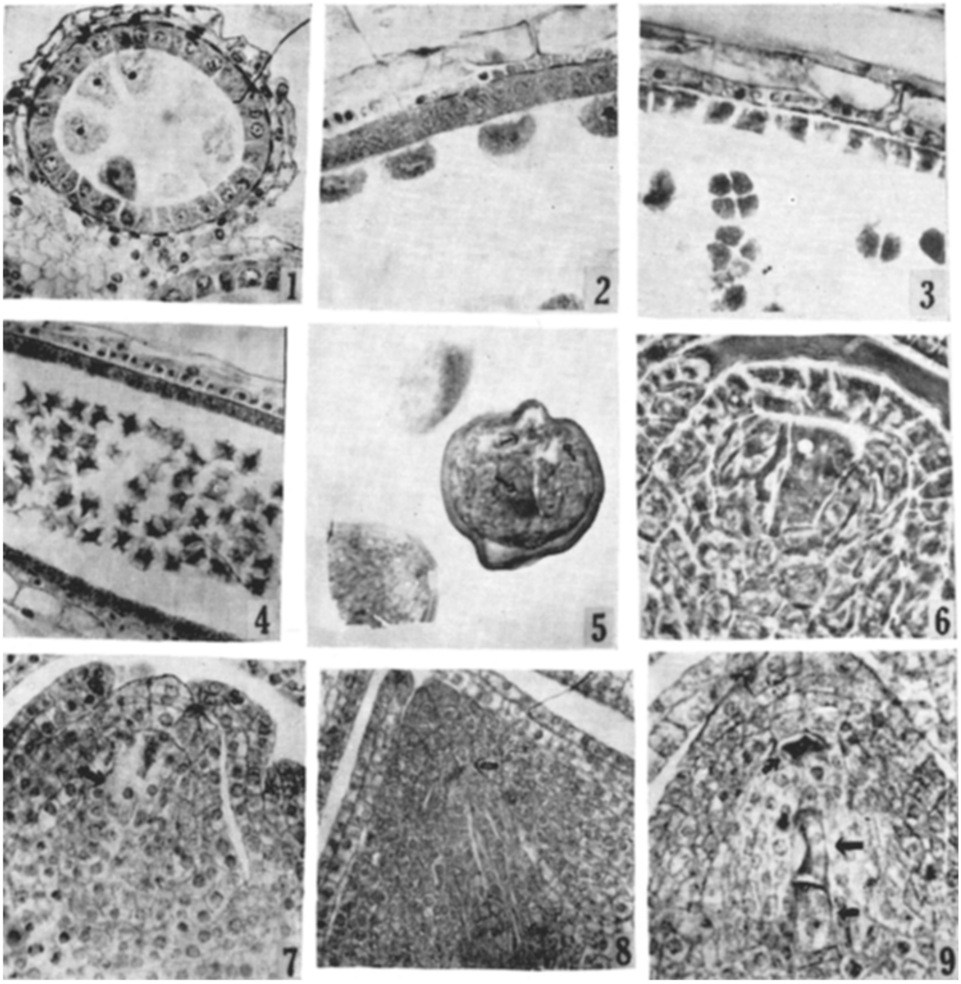
3. Observations

3.1. *Microsporogenesis and male gametophyte*

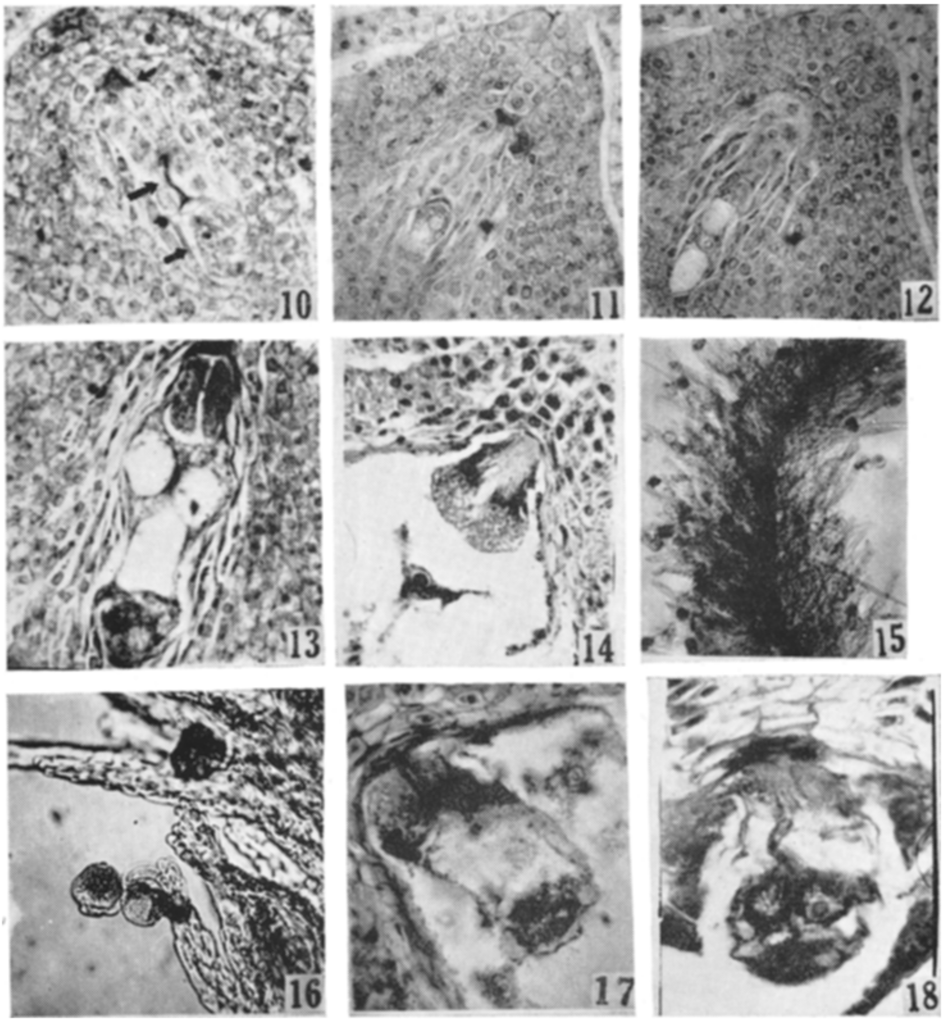
The development of anther wall follows the monocotyledonous type. The differentiated anther shows an epidermis, hypodermis, a middle layer and the innermost tapetum (figure 1). The tapetum is of the secretory type. To begin with the tapetal cells are uninucleate but later become binucleate (figures 1, 2). The microspore mother cells undergo meiotic division resulting in the formation of isobilateral pollen tetrads (figure 3). Cytokinesis is successive. The mature pollen grains are 3-celled at the shedding stage (figure 5). In some anthers the pollen grains appear shrivelled and irregular (figure 4) and are presumably non-functional.

3.2. *Ovule, megasporogenesis and female gametophyte*

The ovule is anatropous, bitegmic and tenuinucellate. The micropyle is formed by the inner integument only. At about the time the integumentary primordia are laid down the hypodermal archesporium becomes differentiated and it directly functions as the megaspore mother cell (figure 6), without cutting off a primary parietal cell. At the same time the nucellar epidermal cells undergo periclinal divisions resulting in a 6–8 layered nucellar cap (figures 7–10). As a result the megaspore mother cell becomes deep seated making the ovule pseudocrassinucellar (Davis 1966). The megaspore mother cell does not undergo meiosis but degenerates (figures 7–10). The remnants of the degenerating megaspore mother cell persist up to the 2-nucleate stage of the embryo sac development (figure 11). At about this stage either one of the nucellar cells situated directly below the megaspore mother cell (figure 7) or one or two cells away from it, enlarge become conspicuous and show prominent nuclei and take up deep stain (figures 8–10). This cell acts as the embryo sac mother cell (figure 8). By three successive free-nuclear divisions it gives rise to an 8-nucleate embryo sac (figure 13). The egg apparatus consisting of two hooked synergids with filiform apparatus (figure 14) and an egg, and the upper polar nucleus are organised from the micropylar quartet. The antipodal cells and the lower polar nucleus are organised from the chalazal quartet (figure 13). The polar nuclei fuse to form the secondary nucleus which lies near the vicinity of the egg apparatus (figure 14). There is a secondary increase in the antipodal cells which may vary from 8–16. Thus the embryo sac develops apo-



Figures 1–9. 1–4. T.S. and L.S. of anther (× 310) showing **1.** epidermis, hypodermis, a middle layer and tapetum with uninucleate cells; **2.** binucleate tapetum. **3.** isobilateral pollen tetrads. **4.** shrivelled pollen grains; **5.** 3-celled pollen grain (× 435). **6–9.** L.S. of nucellus showing **6.** megaspore mother cell (× 900). **7.** degenerating megaspore mother cell and enlarging nucellar cells below it (× 300). **8.** remnants of the degenerating megaspore mother cell and enlarged nucellar cell (× 310). **9.** degenerating remnants of megaspore mother cell and two enlarging nucellar cells (× 310).



Figures 10–18. **10–12.** L.S. of nucellus showing degenerating remnants of megaspore mother cell and **10.** two enlarged nucellar cells. Note degeneration of the upper nucellar cell (× 310). **11** and **12.** $2n$ embryo sac (× 335). **13.** $8n$ embryo sac (× 375). **14.** Micropylar part of the embryo sac showing hooked synergids and secondary nucleus (× 410). **15.** Stigma with germinating pollen grains (× 40). **16.** Part of the stigma with germinating pollen grains enlarged (× 40). **17.** 2-celled proembryo with persisting healthy looking synergids (× 335). **18.** 5-celled proembryo with persisting healthy looking synergids (× 335).

sporously from a nucellar cell. Meiosis is completely eliminated, and presumably all the cells of the embryo sac are diploid.

In some instances enlargement of two nucellar cells situated one above the other and removed from the megaspore mother cell has been observed (figures 9, 10). In two instances degeneration of the upper enlarging nucellar cell has been noticed (figure 10). Twin embryo sacs have not been observed in any of the preparations.

3.3. *Fertilisation*

Under bagging, self-pollination takes place. Stigmas dissected out from the selfed flowers were stained in polyglyce tinted with basic fuchsin to study the germination of the pollen grains (figure 15). The pollen grains give out pollen tubes but these had a limited growth (figure 16). The pollen tubes remained short and the tips became curved and blunt. The synergids remained intact and healthy even during the early proembryonal stages indicating that no pollen tube had entered the embryo sac (figures 17, 18). These observations clearly indicate that fertilisation has not taken place.

3.4. *Endosperm*

The endosperm is of the nuclear type. Since fertilisation has been ruled out, it is presumed that under the stimulus of pollination endosperm develops autonomously. As a result of the division of the endosperm premordium a number of free endosperm nuclei are formed before the unreduced egg cell undergoes the first division. The endosperm eventnally becomes cellular.

3.5. *Embryo*

Under the stimulus of pollination the diploid egg cell develops autonomously into the embryo.

4. Discussion

The embryology of F_1 progeny of the reciprocal crosses of R473 and 302 has been studied to establish the reproductive status of the offspring.

The anther development proceeds normally and conforms to the Monocot type (Davis 1966). Meiosis in the pollen mother cells is apparently normal and cytokinesis takes place by successive method.

The bitegmic ovule is tenuinucellate and the cells of the nucellar epidermis undergo periclinal divisions giving rise to a prominent nucellar cap. Thus the ovule is pseudocrassinucellar (Davis 1966).

The embryo sac is of aposporous origin and the development conforms to the Hieracium type (Battaglia 1963). The potentiality for sexual reproduction is indicated upto the megaspore mother cell stage. It may be noted that while the pollen development proceeds normally, the embryo sac develops aposporously, indicating that the factors governing the development of male and female gametophytes are independent. According to Bhojwani and Bhatnagar (1974) pollen development in aposporous types takes place normally. However, in *Themeda triandra* (Celarier and Harlan 1954) somatic apospory is associated with meiotic irregularities in the pollen mother cells. Thus apospory may not always be associated with normal development of pollen grains.

The available data on the embryology of apomictic grain sorghums show that the aposporous embryo sac is always 8-nucleate (Rao and Narayana 1968; Rao and Murty 1972; Rao *et al* 1978) unlike in the other apomictic graminaceous members like *Cenchrus* (Snyder *et al* 1955); *Panicum* (Warmke 1954); *Paspalum* (Smith 1948); *Pennisetum* (Narayan 1951); and *Setaria* (Emery 1957) in which the embryo sacs are 4-nucleate. According to Warmke (1954) the 8-nucleate condition of an embryo sac in apomicts results in an imbalance between the embryo, endosperm and maternal tissues leading to a $2n$ embryo, $5n$ endosperm and $2n$ maternal tissues. The situation in apomicts producing 4-nucleate embryo sacs leads to a $2n$ embryo, $3n$ endosperm and $2n$ maternal tissues and is important for the normal development of embryo. This may be true in case of those apomicts in which the formation of endosperm involves the participation of a male gamete. But in the present study on grain sorghum the endosperm develops autonomously without participation of a male gamete though, however, the stimulus of pollination is necessary. Thus in apomicts like grain sorghum where the endosperm development is autonomous, the formation of an unreduced 8-nucleate embryo sac does not seem to result in any imbalance between the embryo ($2n$), endosperm ($4n$) and maternal tissue ($2n$). Thus the speculation of Warmke (1954) does not seem to be applicable to those instances of autonomous endosperm development.

Although germination of pollen grains was observed on the stigmas, the pollen tube grows only to a limited length. Not a single instance of the entry of the pollen tube into the embryo sac has been noticed. Further the synergids remain healthy during the early stages of embryogeny. This indicates that pollen tubes have not entered the embryo sac. On the basis of this evidence fertilisation can be ruled out. However, Artschwager and McGuire (1949) in *Sorghum vulgare* and Brown and Emery (1957) in *Bothriochloa ischaemum* observed granular cytoplasmic strands inside the mature embryo sacs and interpreted them as the remnants of the pollen tubes. In the present study, however, no such structures were noticed in any of the preparations.

The endosperm and embryo develop autonomously. The presence of germinating pollen grains on the stigmas associated with normal seed set indicates that the stimulus of pollination is necessary for the development of embryo and endosperm.

Thus the F_1 progeny of the reciprocal crosses between R473 and 302 exhibit apomixis of the nature of somatic apospory and is associated with self-incompatibility.

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We wish to express our thanks to Dr B S Rana, and Mr V J M Rao for their kind assistance in the collection of the material. One of us (RNR) acknowledges a fellowship from the Indian Council of Agricultural Research. We are grateful to Prof. U B S Swami for his interest and to Mr S Sreenivasa Rao of Department of Botany, CKM College, Warangal, for help in photography.

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PROGENY TESTS ON APOMICTIC *SORGHUM BICOLOR* (L.) MOENCH.

In the first report on the occurrence of apomixis in the sorghum line R473, Rao and Narayana[1] concluded that apomixis was entirely due to apospory. They assumed that unreduced embryo sacs were produced from nucellar cells through mitosis. Recently, Murty *et al.*[2] observed that in R473, unreduced embryo sacs may arise not only from apospory but sometimes through direct and indirect diplospory as well. The frequency of each of these phenomena is not known at present. The frequency of apomixis in an organism resulting from asposporу and direct diplospory can be estimated through progeny tests. Originally, progeny tests could not be performed because R473 would not set seed when used as the female. R473 is an F_4 derivative of the cross (Aispuri × IS 2942). Murty *et al.*[2] observed that some seed set could be obtained on R473 when an F_1 (white seed × R473) is used as the male. The parental line white seed is true breeding, its progenitor being a mutant obtained in C. J. Franzke's colchicine treatments. In the present study, it was observed that plants in the F_4 generation of the F_1 of white seed × R473 were also effective in inducing seed set on emasculated spikelets of R473.

The female parent was drawn from the bulk population of R473 maintained by selfing through several generations since 1968. The pollen parent was (WS × R473)–27, supplied by K.F. Schertz of the US Department of Agriculture. Four single plants of R473 were emasculated one day before anthesis and each was dusted with abundant pollen from four individual plants of (WS × R473)–27.

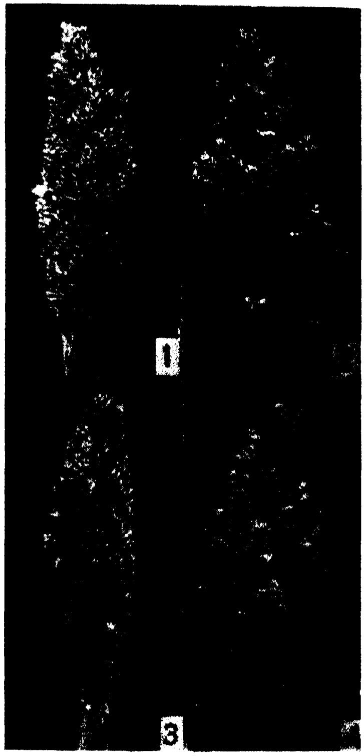
There was varying seed set in the different crosses (10–30%) and the progenies disclosed either hybrids or maternals only or varying proportions of maternal and F_1 plants (Table I). Maternals could be identified from the number of days taken to flowering, compactness of the panicle, awn length and plant height. R473 flowered later, had more compact panicle with shorter awns and was taller in stature than (WS × R473)–27.

Table I

Seed set and frequency of maternals in different hand pollinations on R473 plants

Cross	Seed set (%)	Maternals (%)
1. R473 × 5–65*	20·9	100
2. R473 × 5–67	30·5	0
3. R473 × 5–79	18·5	37
4. R473 × 5–80	10·9	50

* Single plants of (WS × R473)–27.



Figs. 1–4. Earheads (1/3rd original size) of R473; Fig. 1. (WS × R473) 27. Fig. 2. Maternal. Fig. 3. Hybrid. Fig. 4. From progeny tests on R473.

It was apparent that the maternals resulted from apomixis. Unless R473 is heterozygous, these maternals could represent products of not only pseudogamous diplospory and apospory but indirect diplospory as well. These maternals, however, do not represent products of accidental selfing, since the hand crosses were made with utmost care. Moreover, emasculated heads of R473 do not set seed unless there is an abundance of self-pollen and even then, never more than about 12·5%.

The wide variation in the frequency of maternals (0–100%) in the progeny tests on R473 may indicate genetic differences between the female or male parents, Recently, Murty and Rao (unpublished) have observed differential behaviour in two lines of R473: R473-1-2 and R473-6-1. The former presented higher frequencies of multiple embryo sacs and ovules without pollen tubes following sibbing and gave no seed set on crossing with a tester line MK8. The second line, R473-6-1, on the other hand, entailed some seed set on crossing with MK8.

It is possible that these two lines may differ in the degrees of expression of apomixis. If such is the case, the variation in the frequency of maternals realised in progeny tests on R473 is more likely to arise from the deviation in the genotype of the female parents. Attempts are in progress to perform progeny tests on the R473 variants as well.

This report summarizes the preliminary findings of a National Research Project of the Indian Council of Agricultural Research. The authors are thankful to Drs. M. S. Swaminathan and H. K. Jain for their interest and encouragement.

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MECHANISM OF CROSS STERILITY IN SORGHUM

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THE inability of certain varieties of maize to set seed under cross-pollination was designated as cross sterility (Demeric, 1929). In maize this cross sterility was governed by the gametophytic factor '*ga*'. In *Sorghum bicolor* (L.) Moench, a grain sorghum line, R473 was reported to be apomictic and unable to set seed under cross pollination (Rao and Narayana, 1968; Rao & Murty, 1972; Murty & Rao, 1972). The behaviour of this line in so far as it does not set seed with other lines is more or less analogous to that of corn. In corn, the cross sterile lines set seed with at least some other lines but in sorghum, no other line has so far been found to set seed normally with R 473.

In the first studies on apomixis by Rao and his colleagues, it was thought that neither self-nor cross pollen germinates and/or penetrates the stigmas and styles of R473. However, (Murty *et al.*, 1979) observed that under selfing pollen grains do germinate and enter the embryo sacs, although it is not clear whether they effected fertilization Under crossing, there is no information available on the post-pollination events.

The phenomenon of cross sterility has hampered progress in studies of apomixis in sorghum. Simple progeny tests on R473 could not be made because of the existence of this interfering cross sterility. In addition, the evidences supporting apomixis were looked upon with some amount of skepticism and have prompted some very inconclusive studies (Marshall and Downes, 1977). An understanding of the mechanism of cross-sterility should be helpful in future investigations of apomixis in sorghum. The present study was undertaken to find out the post pollination reproductive events under cross pollination in R473.

MATERIALS AND METHODS

The following lines of sorghum were used in the present study; 1. R-473 (Bulk); 2. R-473-6-1; 3. R-473-1-2; 4. R-473-1-2-7; 5. R-473-1-2-9; 6. Kafir A, and 7. Kafir B. Spikelets were emasculated one day prior to anthesis and were sibbed or crossed at the time of anthesis. The following materials were employed in making a cytological study of the post pollination reproductive events:

1. R-473 (Bulk) — Cross pollinated spikelets, at 2-hour intervals upto 24 hours and then 1, 2, 3 and 4 days after cross-pollination and 2 hours after sibbing.
2. R-473-6-1 —2 hours after sibbing
3. R-473-1-2 —2 hours after sibbing
4. R-473-1-2-7 —2 hours after cross pollination
5. R-473-1-2-9 —2 hours after sibbing
6. Kafir A —2 hours after crossing by Kafir B.

Seeds of R-473-1-2 and R-473-6-1 were generously supplied by J. R. Quinby. In studying the reproductive events, whole embryo sacs were examined in acetocarmine squashes. Details of the technique are given in Murty *et al.* (1979).

Results

In all the materials examined after sibbing, pollen tubes were found to have entered the embryo sac. This entry of the pollen tube was facilitated by the degeneration of one of the synergids. In all the embryo sacs, the entry of the pollen tube was always through this degenerating synergid. The pollen tube lost its identity after its entry into the synergid. Under the light microscope, it appeared that the degenerating synergid has ruptured towards the inside and discharged its contents into the embryo sac cytoplasm (Fig. A). Male nuclei were seen with difficulty as granular dots. In the sexual material, one

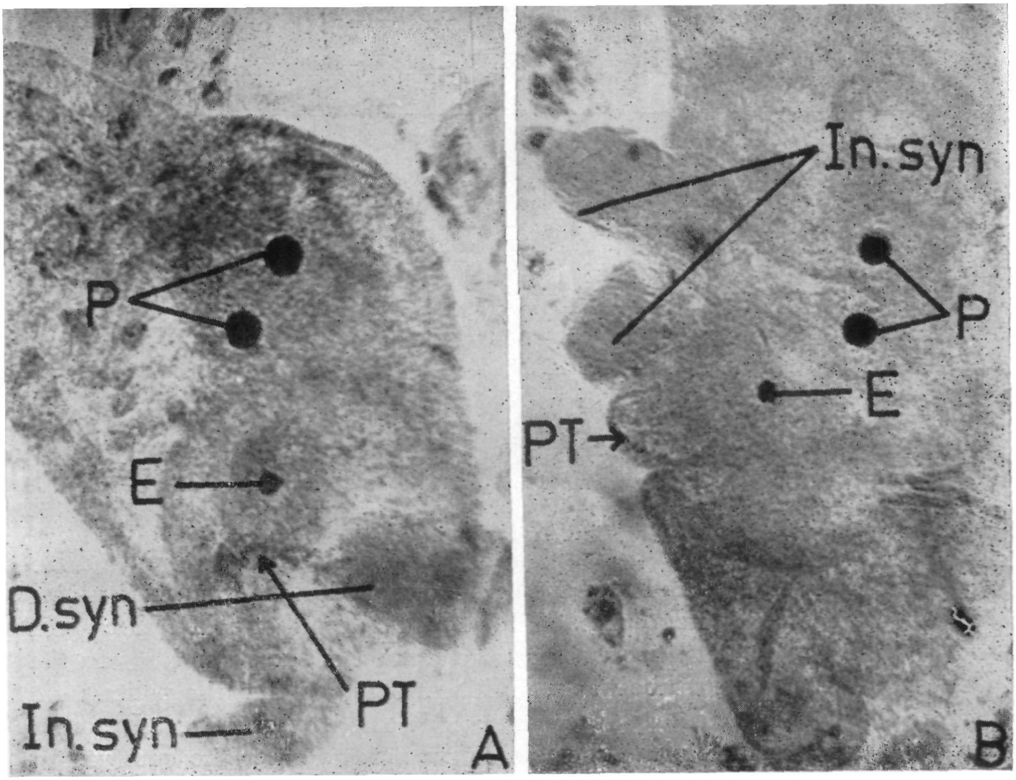

Fig. A. Embryo sac in Kafir B, 2 hrs after self pollination. The pollen tube has entered the sac through the degenerating synergid. ×700.

Fig. B Embryo sac in R-473, 4 hrs after cross pollination, pollen tube penetrating the sac by growing around the egg ×700
(P, polar nuclei; E, egg, D.syn, degenerated synergid, In syn, intact synergid; PT, pollen tube).

male nucleus was observed near the egg and the other near the polar nuclei. Also, in the sexual material, entry of the pollen tube and degeneration of the synergid were 100%. In the R-473 lines, however, the results were different. Pollen tubes could be seen only in some of the ovules. In addition, these lines exhibited a varying frequency of multiple embryo sacs. The frequency of multiple sacs and of ovules without pollen tubes were more in R-473-1-2 than in R-473-6-1 (Table 1).

TABLE 1

Results of the embryo sac squash study on cross sterile sorghum after sibbing

Line	Ovules with single sac	Ovules with more than one sac	Ovules with pollen tubes	Ovules without pollen tubes	Total
1. R-473-1-2	15 (71.66)*	6 (28.56)	16 (76.19)	5 (23.81)	21
2. R-473-6-1	20 (92.31)	1 (7.69)	20 (80.77)	1 (19.23)	21
3. R-473 (bulk)	29 (87.88)	4 (12.12)	14 (42.42)	19 (57.58)	33
4. R-473-1-2-9	14 (51.85)	13 (48.15)	6 (22.22)	21 (77.78)	27

*Percentages given in parentheses.

Cross pollination: Under cross pollination there appeared to be an inhibition of pollen tube growth, because pollen tubes did not reach the embryo sac as under sibbing. In R-473 (bulk), out of 16 ovules examined at 2 hours, there were no pollen tubes. After 4 hours, pollen tubes were seen in 4 out of 28 ovules examined. In R-473-1-2-7 at 2 hours out of 34 ovules squashed, pollen tubes could be seen only in 2 ovules. The rest were devoid of pollen tubes. In contrast to self-pollination there was no degeneration of the synergids. In the few ovules where a pollen tube was seen, it was observed that the pollen tube has tried to penetrate the embryo sac wherever it could by growing all around the sac (Fig. B). The pollen tube was never seen to enter the embryo sac through the synergid. In a few cases, where it has entered the sac near the synergids, it has penetrated across or in between the cells of the egg apparatus.

In a few cases, development of endosperm could be seen. In such cases, a male nucleus was seen to persist near the egg for as long as 20 hours. An extremely rare development of the embryo is seen 2–3 days after pollination. In 250 ovules examined, 2 days after cross-pollination, 8·37% had both embryo and endosperm and 13·15% had only endosperm. Development did not proceed any further from the 3rd day onwards. Degeneration of the endosperm started at this time. Degeneration of the embryo preceded that of the endosperm and degeneration was almost complete by the 4th day. The effect of self and cross-pollination on embryo and endosperm formation in R-473 bulk are given in Table 2.

TABLE 2

Embryo and endosperm formation following self and cross pollination in R-473 (*bulk*)

Stage	Embryo and Endosperm	Endosperm only	Neither
At anthesis	—	—	100.00
1 day after self pollination	93.02	—	6.98
2 days after self pollination	100.00	—	—
1 day after cross-pollination	12.16	36.48	51.35
2 days after cross-pollination	8.37	13.15	78.49

DISCUSSION

The non-functioning of self-pollen in fertilization and its functional normalcy on alien stigmas had led (Rao and Narayana, 1968) to the conclusion that R-473 is self-incompatible. However, in self-incompatible organisms, cross-pollination alone results in seed set while in R-473, the situation is reverse. Seed set is obtained only under selfing although fertilization may be absent. The phenomenon in R-473 is, therefore, better designated as cross sterility.

It is apparent from the present study that the cytological mechanism of cross sterility in *Sorghum* has 3 aspects : 1. an inhibition of the pollen tube growth somewhat similar to that in corn (House and Nelson, 1957) 2. a mechanical obstruction for the entry of the pollen tube brought about by the nondegeneration of one of the synergids under cross pollination and 3. as yet unknown physiological processes. The existence of some physiological factors is suspected since in spite of the first two inhibitions, a few eggs get fertilized but then, no seed is formed and embryo and endosperm degenerate.

The study of the mechanism of cross sterility in R-473 is of significance in the general field of pollination and fertilization in plants. Although several people agree that there exists an intensive metabolic interaction between the growing pollen tube and the conductive tissue of the style, the precise sequence of events leading to fertilisation is not clear. Cass and Jensen (1970) concluded that after pollination some stimulation precedes the pollen tube tip travelling at a much faster rate than the pollen tubes and conveys a message to one of the synergids, that responds by beginning to degenerate.

The differential effect of self-and cross-pollination in cross sterile sorghum has brought about this relation very clearly. Degeneration of one of the synergids after pollination but before fertilization was recorded in sorghum (Vazaart, 1955; Murty *et al*, 1979) and several other plants (Cass & Jensen 1970; Mogensen, 1978). Cross-pollination did not bring about such a degeneration with the result that pollen is unable to enter the embryo sac. Although there is an inhibition of the pollen tubes under crossing, in a few cases, they have tried to reach and penetrate the embryo sac. This observation shows that the factors controlling the growth of the pollen tube are probably independent of those controlling the events leading to fertilisation in cross sterile sorghum. This differential effect of self and cross pollen seems to be the first of its kind so far reported in plants although other differential effects in protein metabolism were noted earlier, presumably, in *Petunia hybrida* (Deuremberg, 1976). A difference in protein metabolism, detected after self-and cross-pollination, indicated that a signal has to be sent from the stigma or style towards the ovary which induces the changes in metabolic activity. Obviously, the signal must be different for cross and self pollination. In R473, probably the response to receive the signal is lost through mutation.

The evolution of cross sterility in sorghum is of significance to plant breeders interested in exploiting apomixis for fixing heterozygosity. If cross sterility has originated before apomixis, the apomictic line R473 may no longer be apomictic in the absence of cross sterility.

Summary

Growth of the pollen tube and its entry into the embryo sac were examined in normal and cross sterile *Sorghum bicolor* (L.) Moench. In normal sorghum, pollen tubes reached the embryo sacs by 2 hrs after pollination. One of the synergids of the embryo sac degenerated before the entry of the pollen tube but after pollination. Entry of the pollen tube into the embryo sac was always through the degenerating synergid. In cross sterile sorghum, growth of the pollen tube was nearly normal following self-pollination. However, pollen tube growth was arrested when foreign pollen was used. Very few pollen tubes reached the embryo sac 4 hrs after cross pollination. The synergids were normal and the pollen tubes could not enter the embryo sacs. In a few cases where they entered the sac, it was not through the synergid. Pollen tubes travelled all over the sac and some of them could enter the sac through the embryo sac wall. Cross sterility in sorghum was brought about by an arresting of the pollen tubes and a mechanical inhibition to fertilization manifested through failure of degeneration of one of the synergids.

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APOMIXIS IN GRAIN SORGHUMS: ANALYSIS OF SEED SET AND EFFECTS OF SELECTION

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Inspite of several reports on the occurrence of apomixis and cross-sterility in grain sorghums (Rao and Narayana, 1968; Rao, Narayana and Narasa Reddy, 1978; Murty, Schertz and Bashaw, 1979; Murty and Rao, 1980), our understanding of the phenomenon is far from complete before it could be exploited in breeding programmes. The precise nature and extent of apomixis in these sorghums is also not known and is under detailed study.

The present investigation summarizing the results of seed set behaviour of 'R473' and '302' over several generations provides some evidence on plant to plan variation, the effects of selection and the role of nuclear and cytoplasmic factors in the development of seed.

Materials and Methods

Two sorghum lines, 'R 473' and '302' were selected for the present study. 'R 473' was derived in advanced generations from a cross of 'IS 2942', a yellow endosperm *kafir* line, and an Indian local variety, *Aispuri*. Line '302' was derived from the cross of 'IS 3922' × '*Karad* Local'. The purity of these lines was maintained through selfing.

Cross-fertility was determined in terms of seed-set by pollinating the emasculated heads with different lines. Forty-eight crosses comprising 31 single crosses, 9 back-crosses and 8 three-way crosses were attempted in '302' as female during winter 1971 and summer 1972. One to four heads were emasculated per cross. Some of the crosses, where seed was obtained, were further advanced.

Seed set was also examined in unpollinated emasculated heads of these crosses. Subsequently, seeds developed on unpollinated emasculated heads were planted and seed set was again examined and this process was repeated for several generations. Progenies of the families where some autonomous seed set was obtained were also maintained subsequently through selfing.

Seed set in 'R 473' and '302' in relation to pollination time was examined in summer 1977 and in 1978. 'R473' and '302' were used as female parents as well as pollinators. A normal sexual line, '168' (CSV-5) was also used as pollinator. Pollinations were done at anthesis time between 7 AM to 8.30 AM, immediately after emasculation (0 hr) and after 24 hrs. Each head was pollinated with ample pollen. Emasculated spikelets ranged from 250–800 per head. Total number of emasculated spikelets and seed set were counted to determine the percentage seed set.

Results

Plant to plant differences for seed set were observed in 'R 473'; 54·6% of the plants did not set seed at all in crosses (Table 1). In summer 1978, the average seed set was 0·5% and 8·8% when emasculated heads of 'R 473' were pollinated with '302' pollen at 0 hr and 24 hr, respectively. Seedo btained in crosses of 'R 473' with '302' were grown in field in the subsequent season and found to be genuine hybrids and no maternals were observed. Further studies of F_2's and back crosses showed clear segregation for morphological characters.

The behaviour of '302' for seed set in single crosses, back crosses and three-way crosses was examined during winter 1971 and summer 1972. The average seed set in emasculated heads was low with all pollinators; 2·9% in single crosses, 4·1% in back crosses and 5·3% in three-way crosses. Cross sterility was very high in '302', since there was no seed set in 60% of the plants in single crosses, 45·5% in back crosses and 32·5% in three way crosses. Over all, 56% of '302' plants were cross-sterile. By summer 1977, the fertility status of '302' in crosses had been improved and the average seed set in emasculated heads of '302' was 34% with pollen from 'R 473' and 37·5% with '168'. During summer 1978, the frequency of cross fertile plants in '302' was quite high since 91·9% plants set seed with 'R 473' pollen though the average seed set was 11%, when pollinated after 24 hr. (Table 1).

TABLE 1

Seed set in crosses of 'R 473' and '302' (Summer, 1978)

Type of cross		Polli-nation time (hr)	No. of heads emas-culated	Heads with seed set (%)	Average seed set (%)
Female Parent	Pollinator Parent				
R 473	302	0	16	18·8	0·5
		24	28	46·4	8·8
302	R 473	0	12	0·0	0·0
		24	37	91·9	11·1

When F_1 (R 473 × 302) was pollinated either by 'R 473' or '302', the average seed set was 4·1% and 4·6%, respectively, whereas in the reciprocal cross, 302 × R 473, the seed set was 13·6% with 'R 473' pollen. When back cross, '302 (302 × R 473)' was used as female, seed set was quite high with both 'R 473' (62·2%) and '302' pollen (21·0%).

Some progenies selected from crosses of '302 × Swarna', '302 × IS 11167' and '887 × 826' showed some seed set in emasculated, unpollinated heads (Table 2). Several heads were emasculated but few unpollinated heads spontaneously produced seed. Frequency of such seed was 1–9 per head in early years. It increased upto 12 seeds per head in EMS (emasculated unpollinated heads) progenies, 57·5 seeds in selfed progenies of '302 × Swarna' and 16·3 seeds per head in '302 × IS 11167'. Progenies of '887 × 826' which showed autonomous seed set in earlier generations split into sterile and fertile progenies later. Averaged over all the families, different crosses showed an increase in

TABLE 2

Seed set in emasculated heads without pollination (EMS)

Parent/Cross	Rabi 1973		Summer 1974		Kharif 1974		Summer 1974	
	No. of heads*	No. of seeds set	No. of heads*	No. of seeds set	No. of heads*	No. of seeds set	No. of heads*	No. of seeds set
302	2	3	—	—	—	—	—	—
Swarna	—	—	—	—	2	2	—	—
302 × Swarna F_1	5	18	5	15	7p	22	1	9
302 × Swarna F_2—7	4	7	5	6	7p	86	5	60
							2p	115
302 × Swarna F_2—8	8	35	4	18	—	—	—	—
302 × Swarna F_2—9	3	13	3	3	—	—	—	—
302 EMS × Swarna	1	9	—	—	1	4	—	—
302 × IS 11167	—	—	—	—	2	15	11	179
877 × 826	—	—	—	—	3	154	st	—
							F	—
Total	23	85	17	42	22	283	19	363
No. of seed/head		3·69		2·47		12·86		19·11

*Only where seed set was obtained; p = Selfed progeny; st = Sterile; F = Fertile.

autonomous seed set in unpollinated emasculated and selfed progenies after repetitive process of selection.

DISCUSSION

The two sorghum lines 'R 473' and '302' derived through hybridization and selection in exotic and Indian crosses have been observed to exhibit apomictic mode of reproduction (Rao and Narayana, 1968; Rao, Narayana and Narasa Reddy, 1978). Murty, Schertz and Bashaw (1979) confirmed the presence of multiple embryo sacs in 'R 473' and showed its potential for apomictic reproduction. They also observed that some seed set could be obtained on 'R 473' when F_1 (white seed × R 473) was the male, and concluded that 'R 473' functions as a facultative apomict. More recently, Murty and Rao (1979) reported the occurrence of varying seed set (10–30%) in different crosses of 'R 473' with some segregants from an advanced generation of the cross 'White seed × R 473'.

The results of the present investigation summarizing the seed set behaviour of 'R 473' over several generations indicate that a change in fertility status of 'R 473' might have occurred since its origin. The results of the other investigators, where there was no seed set (Rao and Narayana, 1968; Murty and Rao, 1972;

Rao and Murty, 1972) in earlier generations of 'R 473' in crosses leading to some seed set in crosses with alien pollen (Murty, Schertz and Bashaw, 1979; Murty and Rao, 1979) lends support to such an hypothesis of change in the fertility status of 'R 473'. Also, the present study reveals that plant to plant differences for seed set exist in 'R 473' populations, since 55% of plants did not set seed at all in crosses. Murty and Rao (1979) also have observed differential behaviour of 'R 473' for seed set, one line with no seed set in crossing with a tester line 'MK 8' and the other with some seed on crossing with it. Establishment of 'R 473' from F_4 segregants consequent on continued selfing and selection (Rao and Narayana, 1968) brings out the role of selection in maintaining the frequency of apomixis. Since 'R 473' is being selected for better seed set under selfing, it is expected that 'R 473' has undergone certain changes in fertility status, but this shift has been considerably low. Hence there is possibility for the existence of different strains of 'R 473', some cross sterile obligate apomictic and others with varying degrees of facultative apomixis. A conscious selection for no seed set after cross pollination or sibbing would help to isolate obligate strains from facultative forms.

Seed set behaviour of '302' in earlier generations appeared to be analogous to 'R 473', since seed set in 56% plants of '302' was absent and rest of the plants showed very low seed set during the years 1971 and 1972. Cross fertility status of '302' subsequently changed after five years of continued selection for high yield (two generations per year) under selfing. Continuous fixation of high yielding genes isolated by inbreeding appears to be the primary reason for increasing fertility in '302'.

Some of the recessive genes in heterozygous form survive in low frequency in populations inspite of the fact that selection operates against them (Jain and Suneson, 1964; Ross and Shaw, 1971). It is particularly true in pedigree breeding where within-head pollination could not be ruled out during the process of selfing. Since sexual forms are dominant over apomixis (Stebbins, 1950; Bashaw, 1962; Harlan *et al.*, 1964; Taliaferro and Bashaw, 1966), variability for obligate and facultative and other unperceptible characters continues in populations until rigorous selection operates. Variation in the enzyme, malate dehydrogenase, locus (**Mdh 1**) reported by Marshal and Downes (1977) in 'R 473' may, therefore, be due to incipient variation maintained in bulk population due to some degree of sexuality rather than non-apomictic nature of 'R 473'. Segregation in facultative forms of 'R 473' will be a natural phenomenon since sexual florets set the seed in outcrossing. It does not rule out the presence of high frequency of obligate apomixis in 'R 473'.

Low seed set in 'R 473' when used as female irrespective of pollinator and time of pollination, in addition to the highly significant reciprocal differences between 'R 473 × 302' and '302 × R 473' crosses clearly indicate that 'R 473' cytoplasm reduces (—) cross fertility and '302' cytoplasm promotes (+) fertility. The variety '302' when used as pollen parent reduces (—) fertility, in single, back and double backcrosses as compared to other pollinators in both cytoplasms. Hence, '302' carries fertility reducer (—) nuclear genes. 'R 473' as pollinator has shown relatively higher seed set in its own cytoplasm as well as in '302' cytoplasm. 'R 473' pollen, hence carries seed promoter (+) genes. Based on these findings, cross fertility is explained in Table 3.

TABLE 3

Cytoplasmic effects on seed set

Female cytoplasm	Female parent	Effect	Pollen parent R 473 (+)	Pollen parent 302 (—)
R 473	R 473	—	— + (3·0)*	— — (2·2)
302	302	+	+ + (34·3)	+ — (27·0)
R 473	R 473 × 302	—	— + (4·1)	— — (4·6)
302	302 × R 473	+	+ + (13·6)	— — (NA)
302	302 (302 × R 473)	+	+ + (62·2)	+ — (21·0)

*Parenthetic numbers indicate observed seed set percentage.
NA =Data not available.

The effect of 'R 473' cytoplasm is much stronger than '302' nuclear genes in reducing the cross fertility. Due to the cytoplasmically controlled cross fertility in 'R 473', the changes due to selection under selfing are very low as compared to '302', where manipulation of nuclear genes has been fast and selection for higher yield under selfing has increased the fertility promoter genes.

Examination of seed set under emasculation only indicated that certain amounts of autonomous seed set is also feasible although continued selection did not bring about higher levels of seed set without pollination. Whether this seed is entirely due to autonomous development of embryo sacs, whether such embryo sacs are unreduced or reduced could not be said with certainity at this moment.

SUMMARY

Seed set pattern in reciprocal crosses in two apomictic grain sorghum lines, 'R 473' and '302', was investigated. The seed set in 'R 473' was very limited in crosses. Plant to plant variation for seed set in crosses is present in 'R 473'

indicating possibility for existence of different strains, some cross sterile obligate apomictic and others with varying degrees of facultative apomixis.

'R 473' carries the fertility reducer (—) cytoplasm and fertility promoter (+) nuclear genes, whereas '302' carries fertility promoter (+) cytoplasm and fertility reducer (—) nuclear genes. Therefore, 'R 473' as pollinator results in higher seed set in '302' cytoplasm while seed set in 'R 473 × 302' is the least.

'302' was also cross-sterile like 'R 473', but after several generations of selfing and selection for better yield (seed set), the cross fertility status of '302' has considerably improved. Changes in cross fertility status of 'R 473' even after several generations of selfing is low probably due to its cytoplasmic control. There is evidence of some seed set under emasculation without pollination.

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BREEDING VYBRIDS FROM FACULTATIVE APOMICTS - A NEW CONCEPT IN SORGHUM BREEDING

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SUMMARY

Facultative apomixis occurs in Sorghum bicolor (L.) Moench through various ways. So far this was not put to practical application in the fixation of heterozygosity. In the present study several facultative apomicts were synthesized using the original facultative apomict, R 473. The F_1 hybrids between these synthesized lines behaved in a manner different from that of normal sexual F_1's. Each time the F_2 progeny contained a mixture of F_1 looking heterotic plants and sexual segregates, the former occurring in a greater frequency. This resulted in formulating a new concept in sorghum breeding viz., breeding vybrids. Vybrids were defined as the progenies obtained from crossing two facultative apomicts, which reproduce through facultative apomixis. Yield level of these vybrids is expected to be intermediate between pure line varieties and hybrids. Vybrids could be perpetuated through seed harvested from F_1 looking plants in each generation.

Additional index words : Sorghum bicolor (L.) Moench, Facultative apomixis, F_1 hybrid, Vybrid, Heterosis, Heterozygosity.

INTRODUCTION

In self-fertilizing species, heterotic hybrid combinations provide the means to circumvent several selection barriers. But spread of hybrids particularly in developing countries presents practical difficulties. Obligate apomixis enables the fixation of heterosis and consequently makes F_1 hybrid cultivation as easy as that of varieties. Such a possibility was discussed by Navashin and Karpachenko as early as the thirties (Solentzeva, 1978). It is believed that apomixis is present in important cereals like wheat, rice, maize (Bashaw, 1980), potato etc., and elaborate schemes for its utilisation have recently been suggested (Asker, 1980; Hermsen, 1980). However, practical exploitation of this phenomenon has not been made so far in grain crops. A notable achievement in apomixis breeding has been the manipulation of obligate apomixis in buffel-grass (Taliaferro and Bashaw 1966).

Sorghums in India and Africa are predominantly cultivated as rainfed crops and are frequently subjected to environmental stress (Rao, 1972). The conclusion of Griffing and Langridge (1963) and Pederson (1968) that in self-fertilized species, homozygotes and heterozygotes differ little in fitness under optimum conditions, but under unfavourable conditions, heterozygotes have greater advantage, has been proved to hold good for sorghum (Rao and Hari Naryana 1968; Singhania and Rao, 1976 a&b; Rao et al. 1981). These findings emphasize the advantages of heterozygotes particularly under moisture stress.

Apomixis occurs in sorghum (Rao and Naryana, 1968; Hanna et al. 1970). The detailed studies of Murty and his associates have characterized in detail, the nature, mechanism and applicability of apomixis in sorghum breeding (Murty & Rao, 1972; Rao and Murty, 1972; Murty et al. 1979; Murty and Rao, 1979; Murty et al. 1981). The present report deals with the results obtained in the studies on apomixis in relation to the development of the concept of breeding 'Vybrids of Sorghum'.

MATERIAL AND METHODS

The following materials were used in the present study:

1. R 473 : a facultative apomict(Rao and Naryana, 1968)
2. White Seed
3. Kafir A

Standard crossing techniques were used. Ovule squashes were made as per procedures described earlier (Murty et al. 1979).

RESULTS AND DISCUSSION

Apomixis in sorghum occurs to the extent of 30% under cross pollination and upto 80% under self pollination (Murty et al. 1979; Murty and Rao 1979; Murty et al. 1981). Apomixis in sorghum has the following three essential elements:

1. The production of unreduced and/or diploid female sex cells.
2. The prevention of fertilization, and
3. Embryo and endosperm formation from unreduced and/or diploid sex cells without fertilization.

Apospory and/or diplospory, and synkaryogenesis are the three phenomena that result in the production of unreduced and/or diploid sex cells.

Cross sterility, the inability to set seed on cross pollination, prevents fertilization.

Seed making ability on emasculated spikelets of R473 is under genetic control. Sometimes the embryo is formed autonomously even before the formation of the triple fusion nucleus. But generally the polar nuclei get fertilized independently by separate male nuclei. After this, the embryo starts developing.

Apomixis in sorghum is pseudogamous i.e., a stimulus of pollination is needed to produce viable embryos and endosperm. Single plants from advanced generation progenies of sexual x apomictic crosses have been found to induce seed set on emasculated spikelets of facultative apomicts (Murty et al. 1979; Murty and Rao, 1979).

Details of all these processes can be obtained from the extensive publications of Murty and his associates cited earlier.

In the present study the original facultative apomict R473 was crossed to white seed (a true breeding colchicine mutant). The F_2 progeny was screened for facultative apomixis through ovule squashes. Four facultative apomictic plants could be identified (23, 26, 32,and 35). These lines were also tested for their cross sterility reaction by crossing them to an unrelated line M 35-1. All of them were good cross steriles and never gave seed in such crosses.

These four lines along with R473 provided the materials used in this study. They were mated in all possible combinations. For each cross atleast 100 spikelets were emasculated and pollinations were repeated for three consecutive days. However, several crosses gave no seed. Also most of the seed obtained was defective and failed to germinate. Only 20 progenies containing varying number of individuals were obtained from these crosses. These progenies comprised either maternals or true F_1 hybrids or a mixture of both (Table-1). In the next generation, the maternals gave rise to perfectly uniform progenies. But the hybrids behaved in a different manner. A total of 32 hybrid progenies were raised. Twelve of them segregated freely as is normally the case with sexual F_1's. Twenty progenies carried a varying frequency of individuals which were not only similar to each other but also identical to their parent

Table 1. Frequency of maternals and hybrids in crosses among facultative apomicts.

Progeny	Total no. of plants	Maternals	%frequency	Hybrids	%frequency
1. R473 x 32-5	3	—	-	3	100
2. 49-2 x R473	1	—	-	1	100
3. 50-3 x R473	13	—	-	13	100
4. 50-6 x R473	23	16	69.57	7	30.43
5. 49-3 x 23-1	6	3	50.00	3	50.00
6. 50-5 x 35-1	10	6	60.00	4	40.00
7. 81 x R473	16	12	75.00	4	25.00
8. 93 x R473	7	4	57.14	3	42.85
TOTAL :	79	41	51.90	38	48.10

i.e., the F_1 (Table-2). In most cases F_1 rows were grown side by side with the F_2 progenies. The similarities included plant height, leaf characters, flowering time and panicle, spikelet and grain characters in addition to the heterotic vigour exhibited by the parental F_1's. Such plants were cross sterile and on embryological examination revealed the same apomictic potential as in the parental facultative apomicts. In addition to these maternal type plants, a varying number of off-type plants were also obtained. These are obviously the products of sexual reproduction or those arising from synkaryogenesis.

The behaviour of such progenies has led to the concept of 'vybrids'. We define vybrids as the progenies obtained from crossing two facultative apomicts which reproduce through facultative apomixis again. Thus they are super varieties with a characteristic performance that is intermediate between F_1 hybrids and pure line varieties. Their yield level remains constant if they are perpetuated through F_1 looking plants in each generation. The performance of vybrids has been illustrated in Fig.1. The appearance of a typical vybrid in relation to a sexual F_2 progency has been shown in Fig.2. The Vybrids behaved similarly in the next generation as was apparent in our earlier preliminary studies.

Table 2

Frequency of F_1 genotypes in the F_2 progenies of Vybrids

Sl No	Progeny No	Total No. of plants	No. of F_1 genotypes	%Frequency	No.of F_2 genotypes	%Frequency
1.	93-1	23	8	34.78	15	65.22
2.	93-2	9	3	33.33	6	66.67
3.	93-3	29	9	31.03	20	68.97
4.	93-4	24	7	29.17	17	70.83
5.	93-5	31	19	61.29	12	38.71
6.	93-6	32	10	31.25	22	68.75
7.	93-7	29	21	72.42	8	27.59
8.	93-8	27	15	55.56	12	44.44
9.	93-9	31	19	61.29	12	38.71
10.	93-10	37	16	43.24	21	56.76
11.	93-11	34	15	44.12	19	55.88
12.	93-12	29	19	65.51	10	34.48
13.	93-13	33	16	48.48	17	51.52
14.	96-1	12	4	33.33	8	66.67
15.	96-3	23	11	47.83	12	52.17
16.	105-3	32	5	15.63	27	84.37
17.	105-4	37	9	24.32	28	75.68
18.	105-5	34	11	32.35	23	67.65
19.	105-8	32	22	68.75	10	31.25
20.	105-9	27	9	33.33	18	66.67
	TOTAL :	565	248	43.89	317	56.11

The vybrids produced by us so far were agronomically inferior to the released commercial sorghum varieties and hybrids. They are based on exotic x exotic crosses and were susceptible to the insect pests and diseases. However, their yield levels were superior to those of the parents from which they were produced. These Vybrids were produced only for testing the theoretical possibility.

The following steps are involved in the production of agronomically desirable vybrids :

1) Select adapted and desirable genotypes and cross them with one or more facultative apomicts.

2) Produce and grow large BC F_1 (reciprocal B_2) progenies and make individual selections.

3) Grow ear to row progenies. Select lines for uniformity of characters like plant height, flowering time, ear and grain characters. Test for 1. Pre-fertilization

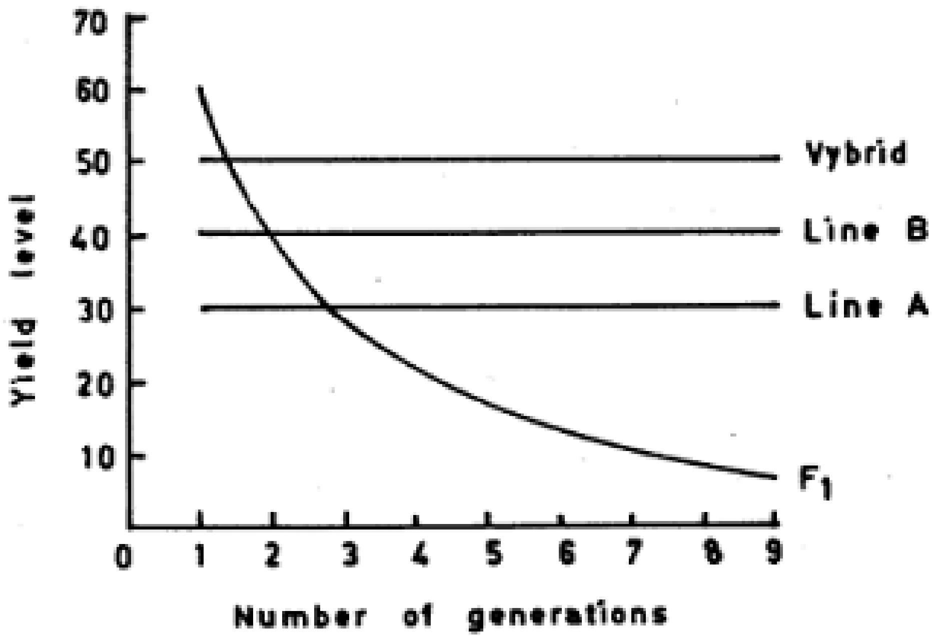

Fig. I- Comparative performance of vybrids, F_1 and pure lines

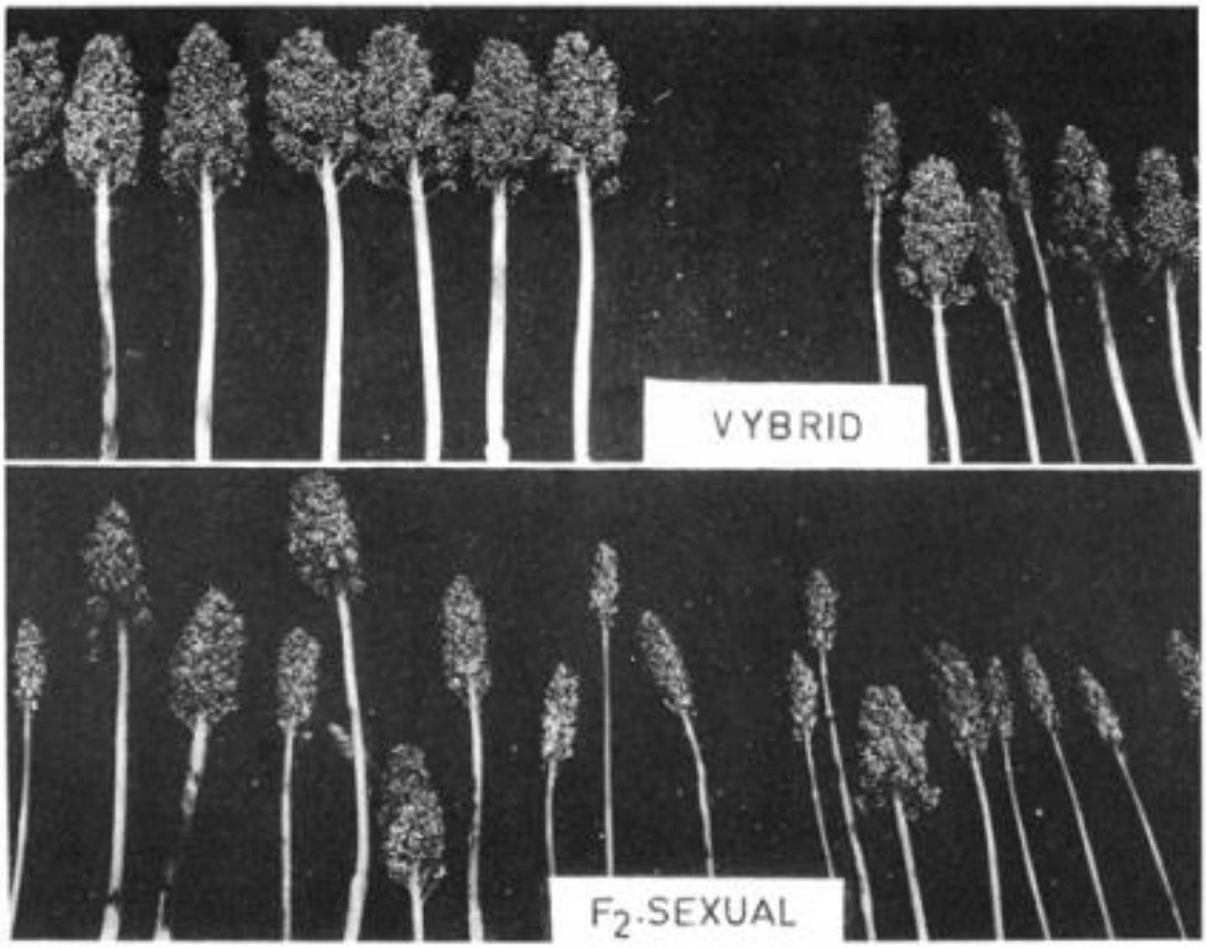

FIG.2 TYPICAL APPEARANCE OF VYBRID AND SEXUAL F_2 PROGENIES

apomictic potential through ovule squashes, 2. Cross sterility through cross pollinations, and 3. Post-fertilization apomictic potential through progeny tests. The same plant can be used for all the three tests through careful planning.

4) Using the remnant seed or selfed seed of selected plants, make as many crosses as possible.

5) Select agronomically desirable F_1's.

6) Carry over to F_2. Reject completely segregating sexual progenies. Select only those vybrids that have a high frequency of F_1 like vigorous plants.

7) Carry over to next generation and repeat the process.

8) Yield test good vybrids. Good vybrids should have: (a) a high frequency of apomixis, (b) a high degree of yield heterosis, and (c) a minimum of negative transgressive segregation.

At any time, the frequency of F_1 type plants will be equal to the frequency of apomixis. While obligate apomixis could result in fixation of 100% heterosis, facultative apomixis results only in a partial fixation. At present this is the only method of utilizing facultative apomixis. If increasing levels of apomixis could be obtained by one or more of the experimental approaches suggested by Murty et al. (1981), heterosis could be exploited with increased efficiency. Studies in this direction are currently in progress.

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Chromosomal studies of cross-sterile and cross-fertile sorghum, *Sorghum bicolor* (L.) Moench

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Abstract

Chromosome pairing and meiosis were studied in cross-fertile and cross-sterile sorghum lines and F_1 hybrids between one cross-sterile and several fertile lines. The cross-fertile parents exhibited regular meiosis, but the cross-sterile ones and the hybrids had abnomalities indicative of non-homologies, deficiencies and/or duplications. The significance of the chromosomal differentiation in cross-sterile sorghums in relation to the origin of cross-sterility and apomixis was discussed.

Introduction

Cross-sterility, the inability to set seed under cross pollination was reported first in maize (Demerec, 1929) and more recently in a sorghum line, R-473 (Murty & Rao, 1980). In maize, cross-sterility is controlled by several alleles of a gametophytic factor designated as *ga* (Ashman, 1975) and is brought about by a slowing down of the growth of the pollen tubes (House & Nelson, 1958). In R-473, under selfing, pollen tubes grow more or less normally; one of the synergids degenerates and pollen tubes enter the embryosac. Under cross pollination, growth of the pollen tubes is arrested; synergids remain intact so that pollen tubes cannot enter the embryosacs (Murty & Rao, 1980).

The cross-sterile line R-473 is a facultative apomict (Rao & Narayana, 1968; Rao & Murty, 1972; Murty & Rao, 1972 and Murty *et al.,* 1979a). Seed set under self pollination is 100%. But under cross pollination, with any other sorghum line, there will be practically no seed set. Only in some backcrosses a little seed set could be obtained. This seed results partly from apomixis, partly from sexual reproduction (Murty & Rao, 1979b). In advanced progenies, different types of individuals could be isolated; the chief types are normal sexual types, cross-sterile sexual types and cross-sterile facultative apomicts (Murty *et al.,* 1980). The line 102 is a cross-sterile line, but it does not have apomixis. Thus cross-sterility and apomixis are independent. Cross-sterile individuals have been isolated, but so far no cross-fertile apomictic individuals.

The present study was undertaken to find out if chromosomal differences exist between cross-fertile and cross-sterile lines.

Material and methods

The material for the study comprised three pure lines, R-473 (cross-sterile), White seed (normal) and 102 (a cross-sterile, true-breeding segregate from the cross White Seed × R-473) and 4 F_1 hybrids viz., White Seed × R-473; IS-84 × R-473; Kafir B × R-473 and Kafir B × *Aispuri.* All parents of these hybrids except R-473 are normal sorghum lines. The cross-sterile line 102 represents the F_6. It traces to a cross-sterile F_2 progeny in which cross-sterile plants were selected from F_2 to F_5. From F_5 on all the progeny individuals were found to be completely cross-sterile and breeding true.

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Standard propionic-carmine staining was used for cytological preparations. Data on pachytene chromosomes were obtained from camera-lucida drawings and photomicrographs of known magnification.

Results

Pachytene chromosomes

Parents

The morphology of the pachytene chromosomes of R-473 and White Seed conformed to that described in earlier reports. They were of the differentiated type as described by Garber (1950), Magoon & Shambhulingappa (1961) and Reddy (1963). Chromosomes could be identified on the basis of their total length, arm ratios and the extent of heterochromatic segments flanking the centromere (Table 1). The nucleolus-organizing chromosome was the longest of the complement. It had an almost median centromere. The nucleolus-organizing region was located in the short arm near the centromere. Chromosomes of R-473 appeared to be slightly shorter than those of White Seed. Chromosomes 1, 2, 6 and 7 could be identified very easily; chromosome 1 was the nucleolus organizer; chromosomes 2, 6 and 7 were asymmetric and chromosome 6 in particular had a short arm largely heterochromatic. The chromomeric pattern described by Reddy (1963) could not be observed consistently in the material used in the present study, but the arm ratios and general length pattern were almost identical to those reported by Reddy (1963).

Chromosome pairing was normal in White Seed, but in R-473 unpaired regions were observed. The number of such unpaired regions varied from 0 to 2 per PMC and 0 to 1 per bivalent. Similar unpaired regions were also encountered in the cross sterile line 102.

F_1 hybrids

Except for the F_1 Kafir B × Aispuri pachytene pairing was less regular than in the parents. They exhibited unpaired regions and also presented evidence for the occurrence of duplications and/or deletions. Heteromorphic bivalents were occasionally observed. The length differences observed in the parents seemed to be more or less adjusted in F_1s except for a few chromosomes. The members of a bivalent generally had similar morphology with

Table 1. Data on pachytene chromosomes in R-473 and White Seed (WS).

Chromosome No.	Line	Total length (μm)	Length (μm) of Short arm	Length (μm) of Long arm	Arm ratio (SA/LA)
1	R-473	60.4	26.7	30.7	0.89
	WS	69.3	33.4	35.0	0.95
2	R-473	49.7	16.4	33.0	0.47
	WS	55.7	19.2	35.4	0.54
3	R-473	47.7	20.4	25.4	0.80
	WS	53.0	24.4	29.0	0.84
4	R-473	39.0	17.0	20.3	0.84
	WS	41.3	18.2	22.6	0.80
5	R-473	36.7	16.4	19.4	0.84
	WS	37.3	15.2	19.9	0.76
6	R-473	33.0	9.4	22.3	0.42
	WS	35.4	9.5	24.7	0.39
7	R-473	30.7	10.7	19.0	0.56
	WS	31.3	12.1	17.8	0.67
8	R-473	27.0	11.4	14.7	0.77
	WS	30.2	12.5	16.8	0.74
9	R-473	25.7	11.7	13.4	0.87
	WS	27.6	11.5	15.4	0.75
10	R-473	23.7	10.3	12.0	0.86
	WS	24.2	10.2	12.9	0.79

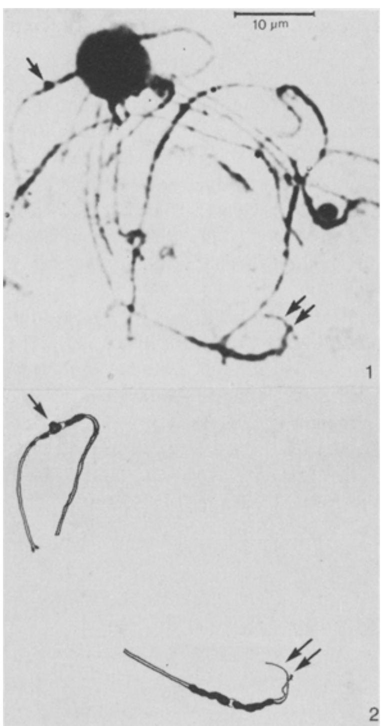
SA = Short arm; LA = Long arm

respect to arm ratios and the extent of heterochromatin.

Unpaired regions. Unpaired chromosome segments were observed in all the hybrids except Kafir B × Aispuri. Number and length of unpaired regions exceeded those in R-473 and 102. In several cases the unpaired regions were confined to the heterochromatic segments, for instance in the nucleolus-organizing bivalent in the F_1 Kafir B × R-473.

Duplications and/or deletions. There was evidence for the existence of microscopically detectable deletions and/or duplications in the hybrids, White Seed × R-473 and IS-84 × R-473. In both of them the abnormality was detected in the heterochromatic regions only. In the case of White Seed × R-473, it occurred in one of the shorter chromosomes in the short arm in the heterochromatic block near the centromere (Fig. 1). A similar small extra block of heterochromatin was observed in the hybrid IS-84 × R-473. This region was located in the short-arm heterochromatic block of the nucleolar bivalent and remained unpaired. In the case of hybrids, White Seed × R-473, IS-84 × R-473 and Kafir B × Aispuri, several hundred nuclei have been analysed. The abnormality could be detected wherever the chromosomes could be traced clearly. In the F_1 hybrid Kafir B × R-473, although unpaired regions could be detected, this particular type of extra chromatin could not be located.

No such abnormalities could be detected in the hybrid, Kafir B × Aispuri.



Figs. 1-2. Photomicrograph (1) and explanatory diagram (2) of pachytene in the hybrid White Seed × R-473, showing duplication/deletion (arrow) and a heteromorphic bivalent (double arrow).

Heteromorphic bivalents. Heteromorphic bivalents were observed in the F_1 White Seed × R-473. The short arm of one of the two chromosomes forming this bivalent was clearly smaller than that of its partner (Fig. 1).

Post-pachytene stages

Despite the presence of nonhomologies, chiasma frequencies were not affected. The number of half chiasmata at MI was more or less similar in all the parents and hybrids and ranged from 1.8 to 1.9 per bivalent.

Discussion

Of three lines in which pachytene chromosomes were studied, R-473 and 102 were cross-sterile and exhibited unpaired regions; White Seed had perfect chromosome pairing and was cross-fertile. Chromosome 'nonhomologies' therefore seem to be associated with cross-sterility. The cross-sterile line R-473 does not set seed normally under cross pollination. Occasionally some of its progeny lines give some seed set. It appears that in R-473 the cross-sterile character is accompanied or perhaps even caused by chromosomal imbalances. Occasionally this sterility may be rectified during sexual reproduction, resulting in the derivation of partially cross-fertile segregates.

The F_1 hybrids involving R-473 and normal lines clearly point to chromosomal differences between normal lines and R-473. Chromosomal differences generally result in sterility but in this case perhaps, the differences may be too small to result in total sterility, and only result in cross-sterility. These differences presumably are of the nature of minute deletions. The control F_1 (Kafir B × Aispuri) had normal chromosomal pairing.

Sexual reproduction in higher plants is a delicately balanced mechanism starting with the development of gametes and including the production of mature embryos (Mascarenhas, 1975). One principal effect of pollination is usually the degeneration of one of the synergids. This process has led several investigators to suggest that a stimulus passes from the pollen and initiates changes in the embryo sac. A difference in protein metabolism has been noted between unpollinated, cross-pollinated and self-pollinated lines of *Petunia* (Deurenberg, 1976). Even RNA (Tupy *et al.,* 1974) seems to be involved as well as phytohormones (Jensen *et al.,* 1977). These reports indicate some genetically controlled biochemical reactions that result in normal fertilization and triple fusion. The probable loss of some genetic material in R-473 presumably through deletions may have disturbed the course of the normal reproductive events. This disturbance is evident only under cross pollination, because under selfing there is normal seed set.

While the above hypothesis on cross-sterility in R-473 is purely tentative at present, a thorough knowledge of this phenomenon should have great practical possibilities. This is because R-473 is a facultative apomict in which the origin of cross-sterility seems to have preceded the origin of apomixis (Murty & Rao, 1980). It may, therefore, be possible to obtain obligate apomixis in R-473 through cytogenetic breeding manipulations.

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The Problems of Apomixis and its Prospects in the Eighties

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Apomixis results in and can be used for the fixation of heterozygosity and consequently heterosis. This possibility was discussed as early as the thirties by Navaschin and Karpechenko (cf Solentzeva 1978). Nearly 50 years have passed and during this period, the various attempts of breeders have resulted in some progress, most notable among them being the manipulation of obligate apomixis in the breeding of Buffel grass, *Cenchrus ciliaris* (Taliaferro and Bashaw 1966). Less spectacular achievements are those involving its application in citrus, berries, guayule, and numerous perennial forage grasses. Apomixis has been reported in grain sorghum and pearl millet and is believed to be present in several other important crops (Rao and Narayana 1968; Hanna et al. 1970; Bashaw 1980).

Among the cereals, the maximum amount of information has been obtained in sorghum. However, research work on apomixis in sorghum was hampered for a number of reasons. Most workers are either professional geneticists or breeders, who are handicapped by lack of a thorough knowledge of embryology, or orthodox embryologists, who have no knowledge of genetics. The support for apomixis research is also being received in the form of temporary and short-term grants. In addition, the phenomenon of apomixis in sorghum is the most complicated so far encountered in any flowering plant. All these reasons together with an inadequate understanding of the phenomenon (Rana et al. 1981; Narasa Reddy 1979) have resulted in limited success. However, a few devoted attempts made in recent years have produced a reasonably clear picture of the phenomenon and the procedures to be followed in this field of study (Murty et al. 1979; Murty and Rao 1979; Murty et al. 1981a). An account of the problems inherent in this field, the progress made so far, the program that can be profitably followed in the future, and the prospects accompanying such research are dealt with in this paper.

The Problems

The chief problems encountered in apomixis work are: (1) the confusion regarding the wide variety of terminology used in reference to this phenomenon; (2) the difficulties in the estimation of its frequency; (3) the low frequency with which it occurs in several sorghum lines; (4) the delicate balance between sexuality and apomixis influenced by the environment; and (5) the difficulties encountered in maintaining genetic stocks.

1, The Terminology

The term apomixis means only the production of offspring without the fusion of the male and female gametes. This phenomenon can occur in several ways, not all of which are useful as far as fixation of heterozygosity is concerned.

The theoretical details of such processes are discussed in a number of reviews (Gustafsson 1946, 1947 a and b; Fagerlind 1940; Maheshwari 1950; Stebbins 1950; Nygren 1954; Battaglia 1963; Khokhlov 1976; Asker 1980). There are two processes needed for fixation of heterozygosity: (a) production of unreduced female gametes and (b) development of such gametes into viable embryos.

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Production of Unreduced Female Gametes

Unreduced female gametes can be produced in several ways. Only two of the methods are useful, i.e., apospory (production of unreduced embryo sacs from nucellar cells) and diplospory (production of unreduced embryo sacs directly from the archesporial cell). These two phenomena may-lead to the production of diploid embryo sacs, the type of divisions through which they give rise to such sacs having a bearing on their usefulness. Conventionally, there are three types of divisions that lead to diploid cells. These are: (1) the formation of a restitution nucleus; (2) pseudo-homeotypic division, and (3) mitosis. Rosenberg (1927) described the phenomenon of meiotic nuclear restitution as the formation of a single nucleus with unreduced chromosome numbers owing to a failure of either the first or the second division referred to as the first division restitution (FDR) and the second division restitution (SDR), respectively. Cytologically, there are important differences between these two types. In the case of FDR the nucleus does not undergo the normally expected disjunctional separation of homologous chromosomes at anaphase I (AI). Instead, the entire diploid complement divides mitotically, giving rise to a diad with two unreduced spores. The two daughter nuclei are by and large similar. In SDR, the nucleus restitutes after anaphase I (AI). Each product of the normal disjunctional separation—a haploid set—divides mitotically but the sister chromatids do not separate to poles. Therefore, the doubled chromosomes of a haploid set constitute the second division restitution gamete. Since SDR is preceded by a disjunctional separation of homologous chromosomes which leads to genetic segregation, the SDR gametes may be quite dissimilar.

Thus FDR preserves heterozygosity and fixes heterosis. SDR leads to homozygosity and to dihaploid production. In addition to FDR and SDR, normal mitosis could also replace meiosis and is the ideal phenomenon for perpetuating heterozygosity.

There are other possible ways of producing diploid embryo sacs. One such mechanism, "synkaryogenesis" or "automixis", which occurs in sorghum, is dealt with in the next section.

Once a diploid embryo sac is formed, further development could be either autonomous (without the stimulation of pollen) or pseudogamous (with the stimulation of pollen).

2. Estimation of the Level of Apomixis

The frequency of apomixis has two components. One of them is the frequency of diploid embryo sacs. The other is the frequency of progeny obtained without the fusion of the male and female gametes. In fact, the latter can only be more correctly termed as the true apomictic frequency.

(1) Study of Serial Sections of Ovules

The classical procedure for the estimation of the frequency of diploid embryo sacs involves the cytological screening of sectioned ovules during megasporogenesis. This procedure provides a direct and accurate estimate of the relative frequencies of the normal (sexual) and the aposporous, and diplosporous types of embryo sacs, provided the investigator makes comparative studies of his material with normal sexual material. Overenthusiasm on the part of the observer results in erroneous observations. In several reports on apomixis in sorghum, the degenerating megaspores were interpreted as representing the degenerating megaspore mother cell and the sexual functional megaspore as a nucellar cell giving rise to aposporus embryo sacs (Narasa Reddy et al. 1979). To be accurate, this procedure involves sectioning of a large number of ovules since all sections do not contain the required stage of development. Also, estimation of the frequency of the different types of development from only the clearly discernible preparations is likely to introduce some bias. It should also be realized that the relative frequency of apomictic embryo sacs may not accurately reflect the relative apomictic seed, particularly when pollination is uncertain or there is marked zygotic competition (Barlow 1958). Not all the potential diploid sacs may develop into seed through apomixis and not all the sexual embryo sacs develop sexually. The frequency of apomixis depends on the relative efficiency of these two types of embryo sacs. In order to distinguish between the frequency of apomictic embryo sacs and the frequency of apomictically formed offspring we propose two terms, structrual apomixis and functional apomixis.

Structural apomixis is defined as the phenomenon by which an organism produces unreduced embryo sacs. Functional apomixis refers to the phenomenon by which an organism produces offspring without the fusion of gametes. Structural apomixis is purely under genetic control and has two components: genotype and genotype x environmental interaction. Functional apomixis may or may not be under genetic control. It has three components: genotype, environment, and genotype x environmental interaction. Functional apomixis can be induced easily through environmental factors like heat treatments, cold treatments, distant pollinations and delayed pollinations. Apomixis reported in maize, wheat and potato are all due to functional apomixis. Structural and functional apomixis are independent phenomena that can operate alone but when they occur together, they complement each other. Classical cytological techniques provide for the estimation of the former only. The latter can be estimated by progeny tests.

(2) Progeny Tests

The advantages of progeny tests have been known for several years. These methods allow for scoring of large numbers of individual plants (Tinney and Aamodt 1940). These procedures are also ideal to study the effect of environmental factors on the incidence of sexuality in facultative apomicts. Such studies have been previously restricted by limitations of cytological methods (Knox and Heslop-Harrisson 1963; Knox 1967; Evans and Knox 1969). Progeny tests, when used in conjunction with morphological marker loci, reduce the need for specialized equipment and expertise. These procedures are of special value for field stations and experiment farms, where both equipment and expertise are often lacking. Progeny tests provide a direct measure of the relative frequency of apomictic seed. Such an estimate is of greater populational significance than the prezygotic estimate afforded by cytological techniques (Marshall and Weir 1979).

Progeny tests also have some disadvantages. The frequency of apomixis could be biased upward due to accidental selfing and tight linkage of the marker genes. Also the possibility of autosegregation should be ruled out before definite conclusions are reached. Moreover, the frequency of apomixis is not constant and is subject to environmental effects.

Application of both these methods in sorghum is difficult. If we consider the classical microtome method, the difficulties faced are the absence of differences between the sexual and apomictic embryo sacs, and the great time and energy to be spent if careful analyses of large populations have to be made. Till recently, progeny tests could not be performed on R-473, because it is cross sterile. The phenomenon of cross sterility was first described in corn (Demerec 1929). Cross sterility refers to the inability of certain varieties of corn to set seed with foreign pollen and was shown to be controlled by a gametophytic locus (ga) located on the short arm of chromosome 4. Alleles of this locus prevent certain pollen genotypes from fertilizing the female gamete or give one pollen genotype a competitive advantage over the other. The same phenomenon occurs in sorghum. As of today, no single line of sorghum has been found that can induce seed set on emasculated spikelets of genuine R-473 earheads. Only recently did Murty and his colleagues find a procedure for performing progeny tests (Murty et al. 1979; Murty and Rao' 1979).

The difficulties in the detection and estimation of apomixis in R-473 has prompted development of some indirect methods (Marshall and Downes 1977; Reddy et al. 1980). The validity of these conclusions is discussed in item number eight in the section entitled Progress Made During the Seventies.

3. The Facultative Nature of Apomixis

Apomixis has so far been reported in five lines of sorghum. Details of the various materials are discussed in the next section. The most investigated line so far is. R-473 from India. Although it was initially believed that this line is an obligate apomict (Murty and Rao 1972; Rao and Murty 1972), under cross pollination at least, it does not behave as an obligate apomict. The frequency of apomictically produced offspring varies from 30 to 50% (Murty et al. 1981b). For apomixis to be useful in the fixation of heterozygosis, it has to be obligate or nearly so as in Buffel grass. The sexual potential in this line, whatever may be its extent, should be decreased to the minimum to achieve complete fixation of heterozygosity. Breeding of facultative apomicts is much more difficult than breeding of obligate apomicts, although some useful cultivars have been produced in forage grasses like Kentucky blue grass, guinea grass, blue stem, etc., (Bashaw 1980). The presence of some sexuality makes the progenies segregate in each generation. Also, the most important factor is to determine the stability of each line through several generations.

4. Environmental Effects on Apomixis

The frequency of apomixis,especially in facultative apomicts.is subject to environmental influences like locations, seasons and years. Day length has been found to have a significant effect on the frequency of apomixis in *Dichanthium aristatum* (Poir.) C. E. Hubb (Knox and Heslop-Harrison, 1963; Knox 1967). The line R-473 was investigated at one tropical (India) and one temperate location (Texas) and showed different frequencies of apomixis in the two environments. Similarly, even in the same location, the frequency of apomixis in field-grown and glasshouse-grown plants differs. The *kharif, rabi* and summer crops at Hyderabad have also given different results (Murty, unpublished). Generally, seed set on apomicts is greater in summer than in other seasons.

5. Maintenance of Pure Genetic Stocks

When N. G. P. Rao made his first observations at the time of the isolation of R-473, he noticed the absolute absence of seed set on emasculated heads of R-473 pollinated by alien pollen. However, later workers could find sporadic seed set under cross-pollination. In fact, J. Roy Quinby isolated two types of R-473 lines, one of them being completely cross sterile and the other giving up to 50% hybrids when crosses were made using the plastic bag method. We found that the frequency of multiple embryo sacs in the former line is much greater, the frequency of pollen penetration much lower and that no seed is set on cross-pollination in the former. Observations of chromosome morphology at pachytene indicated that R-473 carries structural heterozygosity for some chromosomal segments, especially the nucleolus organizing chromosome and a few others (Kirti et al.. In press). In such an individual carrying structural heterozygosity, sexually produced offspring may not reproduce the genotype. In such a case, it is possible to get offtypes even under selfing. Maintenance of delicately balanced, structurally heterozygous R-473, therefore, poses some problems. A practical method is to cross-pollinate a part of the earhead and collect only selfed seed from the plants that do not give any seed set. This is because all cross sterile plants maintain structural heterozygosity.

Progress Made During the Seventies

1. Source Materials for Apomixis

The first report of apomixis was in the line R-473 (Rao and Narayana 1968). This is an F_4 line from the cross of an Indian line Aispuri with a yellow endosperm kafir, IS 2942. The next report of apomixis was in the line 'Polygynaceous' by Hanna et al. (1970). A few more lines were tested in recent times and were found to have a low level of apomixis (Table 1). The other lines were tested at Hyderabad in progeny tests using hand crosses. All crosses yielded only hybrids and no maternals. This indicates that they may have

Table 1. The source material for apomixis.

Line	Origin	Frequency of apomixis	References
R-473	F, derivative of IS-2942 x Aispuri.	30-100%	MurtyandRao 1979; Murtyetal. 1979.
Polygynaceous	Multiple ovaried male sterile line derived in radiation experiments.	25.0	Hannaetal. 1970.
Polygynaceous (PGY)	A single ovaried selection from a cross of polygynaceous line x Colby	Very low	Tangetal. 1980
White Seed (WS)	A white seeded mutant of Experimental 3	" "	" "
South Dakota Mutant 3-58(SD)	A mutant of Experimental 3	" "	" "
Doubled Haploid (DH)	A doubled haploid line derived from Tx 403.		

some prezygotic apomictic potential, but none of this potential is realized in the progeny tests. White Seed, however, was observed to have a prefertilization embryological behavior similar to that of R-473. In addition, White Seed is the line that was helpful in the studies of apomixis in R-473. The extent of its usefulness in apomictic studies is given in the next section. The discussion in the following pages will be mainly about R-473.

2. Breakthrough in the Performance of Progeny Tests on R-473

The cross-sterility exhibited by R-473 was a great hindrance in the study of apomixis. In their attempts to overcome this hurdle at College Station, Texas, Murty et al. (1979) performed several bud pollinations with pollen from other lines including Dakota Amber, White Seed and Colby but with no success. The ovaries enlarged slightly and developed some green color when emasculated florets were pollinated with a mixture of live alien pollen of Colby and radiation killed pollen of R-473. But such ovaries did not continue to develop. These methods did not overcome the cross fertilization barrier of R-473.

In order to induce seed set on emasculated R-473, the methods adopted with self-incompatibility studies were followed. These included pollinating R-473 spikelets with pollen from individual plants of F_1, F_2 and BC F_1 of crosses in which R-473 was the male parent. Surprisingly, seed developed in two combinations. These involved the F,s (White Seed x R-473) and (Dakota Amber x R-473) and F_2s and BC F_1s of (White Seed x R-473). This induction of seed set provided an opportunity for the performance of progeny tests on R-473. The resulting progenies had two types of individuals—maternals and hybrids. Hybrids in these progenies could be distinguished from matemals (identical to R-473) by differences in height and panicle characters.

Subsequently, we have performed several progeny tests at Hyderabad. The procedure for performing a progeny test has been given in detail by Murty and Rao (1979). For accurate results, the female parents and the F, hybrid should be clearly identifiable morphologically. We found that in addition to White Seed, individual F_2 plants of the crosses (Kafir B x R-473) and (IS-84 x R-473) have also induced seed set. In fact, the seed set induced by these is much greater than that of White Seed x R-473 at Hyderabad (Table 2).

3. Frequency of Apomixis

By far, frequency of apomixis is the most important factor for the successful fixation of heterozygosity. The greater the frequency, the more advantageous it will be in breeding. The frequency of apomixis in facultative apomixis is, however, not only a function of the genetic potential but also of environmental factors. In sorghum, the frequency of apomixis is dependent upon four factors: (a) type of pollination, self or cross; (b) type of pollinator, cross sterile or cross fertile; (c) location; and (d) season.

The frequency of apomixis is greater under self-pollination than under cross-pollination. Under cross-pollination, the frequency is greater if a cross-sterile plant is used as the pollinator than if a cross-fertile plant is used. Apomixis was also found to occur in a greater frequency under the glass-house conditions of College Station, Texas than under the field conditions of Hyderabad (Tables 3, 4 and 5).

Table 2. Seed set on R-473 heads by individual F_2 plants from crosses of R-473 with IS-84. Kafir-B, and White Seed.

F_2 progeny		Number of plants		Seed set %	
		Giving seed set	Not giving seed set	Range	Mean
White Seed	x R-473	8	6	0-10.00	1.73
Kafir-B	x R-473	17	1	0-38.46	1400
IS-84	x R-473	11	4	0-43.90	13.25

The lower frequency of apomixis under cross pollination is probably due to defective endosperm formation. Endosperm in R-473 is derived in several ways and could, therefore, have different genetic constitutions. The relation genome: plasmon in the endosperm is normally 3:1 in sexual plants. In R-473, this relation instead could be either 2:2 or 2:5 in addition to 2:3; and this deviation from the normal ratio might cause degeneration of potential apomictic endosperms and embryo, and lower the frequency of apomixis realized. Under self-pollination, the relation might have existed in a perfectly balanced state.

4. Mechanism of Apomixis

There are at least three types of mechanisms for the production of diploid embryo sacs in R-473.

1. Apospory: A diploid embryo sac is formed from a nucellar cell.

Table 3. Frequency of apomixis—cross-pollination. Backcrosses at College Station, Texas (19751.

Male parent	Seed Set	Frequency of	
		Maternals	Hybrids
A Kafir x R-473	0	—	—
South Dakota x R-473	0	—	_
Polygynaceous derivative x R-473	0	—	—
Double haploid x R-473	1/300	0	1
R-473 x S. Colby	0	—	—
Dakota Amber x R-473	8/50	6 (75.00)	2
White Seed x R-473-1	16/480	2 (50.00)	2
White Seed x R-473-3	58/180	20 (39.21)	31
White Seed x R-473-5	23/170	10 (66.66)	5
White Seed x R-473-7	16/95	2 (50%)	2
White Seed x R-473-8	20/91	12 (75.00)	4
White Seed x R-473-9	8/50	4 (50.00)	4
Mean (%)		52.33	47.66

a. Numbers in parentheses are percentages.

Table 4. Frequency of apomixis—cross-pollination. Progeny tests on R-473 by F, and backcross plants at College Station, Texas (1975).

No. of seeds sown	No. germinated	No. of hybrids	No. of matemals	Percentage of matemals
21	15	10	2	16 66
12	3	1	2	66.66
8	4	1	3	75.00
7	6	2	4	66.66
6	3	3	0	0.00
9	3	1	2	66.66
17	13	7	6	46.15
24	8	0	8	100 00
33	12	3	9	75.00
24	11	1	10	90.99
29	3	2	1	33 33
46	13	5	8	61 54
20	16	16	0	0.00
Mean				53.74

Table S. Frequency of apomixis under cross-pollination. Progeny tests on R-473 at Hyderabad, *rabi* 1979.

Seed set range	0-100%
Mean	9.7%
Number of total seeds	886
Plants which survived	234
Percent apomixis	33.76

2. Diplospory: A diploid embryo sac is formed from an archesporial cell.
3. Synkaryogenesis or Automixis: These terms are used *sensu lato* in this publication. From haploid nuclei of the embryo sac, diploid nuclei are formed through fusion. This can involve fusion of sister nuclei of the egg apparatus (Murty et al. 1981b) or sister nuclei of the antipodals.

Normally, both apo- and diplosporous embryo sacs are identical to the sexual type sacs (Polygonum type). The synkaryotic sacs, however, are atypical. Even more atypical sacs with six nuclei were found in some derived apomicts.

Regarding the development of endosperm and embryo in aposporous embryo sacs, the endosperm in some ovules develops by the independent fusion of each of the polar nuclei with separate sperm nuclei (Murty et al. 1979). Sometimes endosperm arises from nuclei other than the polar (Murty et al. 1981a). The development of the embryo is autonomous. The stimulus of pollination, however, is necessary for the formation of the seed.

5. Isolation of True Breeding Lines

The objective of apomixis research is the production of uniform and vigorous lines that breed true. For this, single plant progenies from F_2 and BC F_1 plants that gave good seed set on R-473 and also those that were cross-sterile were grown on an extensive scale along with some untested plants. Three types of progenies were obtained: (a) those that were segregating freely, (b) those in which only two morphological types were found, and (c) those that were completely uniform.

The first type of progenies apparently indicated occurrence of normal sexual reproduction in the heterozygous parent. The second type apparently indicated the existence of facultative apospory.

Progenies of this type always have two types of individuals. A majority of them (up to 80%) are identical with their parent. A small frequency of offtypes are always encountered. The maternal types are presumably produced through apospory and the offtypes through sexual reproduction. Individual progenies from the maternals always behave in a similar manner. The cytological behavior of these plants was similar to R-473. All such plants were found to be cross sterile.

The third type of progenies was found to be 100% homozygotes, reproducing sexually.

6. The Concept of Vybrids—Definition, Production and Significance

Heterozygous individuals with facultative apomixis produce a population containing: (a) F_1 genotypes derived through apomixis, and (b) F_2 genotypes developed through sexual reproduction. The frequency of F, genotypes will be equal to the frequency of apomixis. If the next generation is derived through the F, genotype plants only, then the population mean will remain the same. If the procedure is repeated, it is possible to maintain heterozygotic vigor in subsequent generations and to keep the mean constant.

A peculiar type of population was produced using two derived facultative individuals. The F, was uniform and vigorous. The F_2 had two types of individuals—(a) those carrying the F, genotype, and (b) those carrying genotypes resulting from segregation. Individuals looking like the F, were selfed and carried over. The same type of behavior was noticed. These observations led to the concept of "vybrids". Vybrids are superior varieties in that their yield levels will be greater than those of conventional varieties although they may not be equal to those of their F,. Some more comments on vybrids are made later in the section entitled Program and Prospects of the Eighties.

7. The Concept of Dihaploids—Production and Significance

The possibility of parthenogenetic development of reduced egg cells followed by reduplication or fusion or development of embryos from secondary diploid cells of the embryo sac derived through fusions, is interesting from the breeder's point of view. It would give rise directly to homozygous diploids. The formation of such diploids has been presupposed by several authors. Automixis, fusion of two haploid nuclei in a meiotic embryo sac to give rise to diploid homozygous progeny, has been claimed to occur in *Rubus* (Thomas 1940). This possibility has now been realized in sorghum. These dihaploids. for all practical purposes, can be considered identical to those produced by anther culture techniques.

Several dihaploids were produced in our experiments. Some of them were cross-sterile and some were cross-fertile. The homozygosity of these lines was tested by crossing them to a pure line and observing the uniformity in the F, progeny.

8. The Interfering but Helpful Cross Sterility

Detection, estimation and manipulation of apomixis in R-473 has been much hampered because of cross sterility. We have made several attempts to isolate apomictic segregates without cross sterility. Such attempts were never successful. It was also noticed that in addition to R-473, White Seed also exhibited the formation of multiple embryo sacs, nucellar activity and antipodal differentiation. But White Seed never exhibited apomixis in progeny tests. In addition to this, we have also examined several other lines. Among them, 302 was found to have similar anomalies but no realizable apomixis.

The difference between these lines and R-473 is obligate cross sterility. Cross sterility in some way affects the reproductive system and promotes apomixis.

The different constituents of apomixis are known as the elements of apomixis (Petrov 1976). The elements of apomixis lie within the reproductive potentiality of sexual plants. They play a greater part only when the normal sexual process is impaired. Cross sterility is one such mechanism.

Long ago, Powers (1945) suggested the existence of three essential elements of apomixis: (a) failure of reduction of chromosome number; (b) failure of fertilization of egg cells, and (c) development of the egg cell to an embryo without its being fertilized. Production of diploid embryo sacs is one element of apomixis. The prevention of fertilization of unreduced embryo sacs leads to the stimulation of such embryo sacs to apomictic seed formation.

It appears, therefore, that apomixis in sorghum may not occur without cross sterility. In view of this, the conclusions reached by Reddy et al. (1980) need some modifications. They concluded that if mutation for male sterility caused a loss of apomixis, such a loss would have had to occur as five distinct events, once in each progenitor of the five M_2 progenies in which male steriles were derived. It was not realized that loss of cross-sterility makes a line reproduce sexually although it may have some potential for apomixis.

Program and Prospects of the Eighties

1. Rapid Methods for Estimating Prezygotic Potential of Apomixis

Estimation of the prezygotic potential of apomixis in a segregating population is almost impossible if one uses the serial section method. The ovule squash method used extensively by Murty et al. (1979) is the only method available for such a purpose. Estimation of the relative amount of DNA of Feulgen stained nuclei of embryo sacs using a microscope spectrometer (integrating densitometer; microphoto meter) should provide a rapid and easy alternative. If such an instrument is provided with a computerized recording device, large numbers of populations can be screened in a short time. A procedure for the estimation of apomixis based on the existing information and using the embryo sac squash method is given below:

1. Emasculate the spikelets of the suspected parent.
2. Pollinate abundantly with pollen from sister plants.
3. Fix material 4 hours after pollination.
4. Examine embryo sacs in ovule squashes.
5. Approximate apomictic potential = frequency of ovules with unfertilized embryo sacs (single) + frequency of ovules with multiple embryo sacs + frequency of ovules with degenerating embryo sacs and antipodal activity.

In recent years. Zein isoelectric phoretic patterns are being used for evaluation of genetic purity.in hybrid seeds (Motto and Salamini 1979). Similar techniques can also be easily perfected for apomictic studies in sorghum.

2. Rapid Methods for Performing Progeny Tests

Conventional progeny tests involve slow and tedious procedures of emasculation and pollination and visually observable morphological criteria. The utilization of grain characters (e.g., shrivelled vs plump endosperm or color of the endosperm) should help make for easy performance of progeny tests. The use of chemical dyes that can effectively distinguish between sexually and asexually produced seed should be an ideal method for apomictic research.

3. Utilization of Facultative Apomixis for the Production of Vybrids

The vybrids so far produced by us are agronomically inferior. They were synthesized only for testing the theoretical possibility. Future investigations should aim at exploiting the partial fixation of heterozygosity for yield advantage. The following steps are involved in the production of agronomically desirable vybrids.

1. Select adapted and desirable sorghum genotypes and cross with one or more facultative apomicts.
2. Produce and grow large BC F_1 progenies. Make individual selections.
3. Grow head to row progenies, keeping remnant

seed. Pick up uniform lines that have maintained vigor.
4. Sow the remnant seed of the uniform lines and make as many crosses as possible among themselves.
5. Select the good F_1s and carry over to the next generation.
6. Save the seed of only F_1-type plants for the next generation. Test the performance in yield trials.

Good hybrids will be those that have a high frequency of facultative apomixis, a high degree of yield heterosis, and a minimum of negative transgressive segregation.

Theoretically the performance of vybrids will be intermediate between those of F_1 hybrids and of the parental lines from which they have been synthesized.

4. Utilization of SDR, Automixis, and Synkaryogenesis

SDR, synkaryogenesis, and automixis could be profitably put to use for the production of dihaploids. The significance of dihaploids could be realized when one considers the tremendous opportunities for obtaining true breeding desirable lines in one step from heterozygous plants. Since the release of 'Maris Haplona' variety of rape, *Brassica napus* (cf Riley 1974), excellent commercial varieties like F-211 in tobacco (Nakamura et al. 1974), the Tanu and Huayu varieties of tobacco, and the Haupei and Lunghua varieties of wheat (Hu et al. 1978) have been produced using anther culture techniques. However, in sorghum, although several devoted research projects have been carried out in tissue culture (Brettell et al. 1980; Werinicke and Brettell 1980), anther culture techniques are yet to yield positive results. The present method of obtaining dihaploids, therefore, indicates a potential breeding tool in sorghum.

5. Achieving Obligate or Near Obligate Apomixis

By far, the real achievement of research on apomixis in sorghum, centers around attaining obligate apomixis. A perfectly operating gametophytic apomixis is usually not likely to arise in one single step. In nature, genes promoting effective apomictic reproduction are successively incorporated by mutation or recombination.

Apomixis obviously involves fixation of heterosis. It is not surprising, then, that induction of apomixis in sexual crops has been considered by breeders. According to Solentzeva (1978). this possibility was discussed by Navashin and Karpechenko as early as in the thirties. During later years, work of this type has been carried out in different materials (Asker 1980).

Several possibilities exist for increasing the frequency of apomixis through genetic means. The frequency of unreduced egg cells varies strongly among inbred lines of maize (Alexander and Beckett 1963). It is well known that in genera like *Saccharum* and *Citrus,* some clones or stocks produce unreduced female and male gametes to a much greater extent (Harlan and de Wet 1975).

The possibility of obtaining apomicts through means like wide crosses, mutations, etc., has been discussed by several authors. However, the following specific methods should prove fruitful in the case of sorghum.

(a) Selection Following Matings of Cross Sterile Facultative Apomicts

Several apomictic plants have been shown to have a simple genetic control. However, in many cases, it appears that there is certainly a polygenic control. The results in sorghum also indicate such a quantitative gene action. As such, it appears probable to increase the frequency of apomixis by mating facultative apomicts, selecting for increased apomictic frequency, and by repeating the process.

(b) Effect of Cytoplasms and the Search for Apomictic Restoration

In recent years, diverse cytoplasmic sources have been identified (Rao 1962; Nagur et al. 1965; Schertz 1978). On milo, R-473 is a restorer but it is nonrestoring on some of the new cytoplasms. If continuous backcrossing is involved, there are three possibilities:

1. Selection of spontaneous mutations that result in restoration due to mutation of the restorer genes.
2. Selection of spontaneous mutants that promote apomixis.
3. Selection of lines with altered frequency of apomixis due to gene-cytoplasm interactions (see J. R. Quinby, These Proceedings).

The second and third possibilities need to be tested during the eighties.

(c) Effect of Growth Regulators

Auxins and gibberellins are known to be involved in the postpollination reproductive events of plants. Various chemical treatments have been tried in order to induce parthenogenesis in plants but generally without success. However, parthenocarpy is easily induced by treatment with plant hormones. Deanon (1957) reported a significantly increased frequency of monoploids in maize after treatment with dimethyl sulphoxide (DMSO). The diploids were homozygous, resulting from haploid parthenogenesis followed by chromosome doubling (see J. R. Quinby, These Proceedings).

(d) Effect of Spontaneous and Induced Mutations

There exists the possibility of inducing apomixis by a combination of suitable spontaneous and artificial mutations with strong effects upon the reproductive system. Mutations are known that induce either FDR or SDR. Induction of mutations, screening for apomixis and selection of near obligate types is a possibility.

Summary

The progress of research work on apomixis is reviewed, the problems are stated and suggestions are made for the efficient utilization of the phenomenon in breeding. Maximum frequency of apomixis occurs in the Indian grain sorghum line R-473. Under self-pollination, apomixis occurs to the extent of 80%. Under cross pollination, it varies from 30 to 50%. Most apomictically produced offspring were heterozygotes resembling the female parent. However, a small frequency of individuals were obtained that are for all practical purposes dihaploids. These dihaploids arose from the phenomenon of second division restitution, automixis or synkaryogenesis.

Using facultative apomixis, it has been possible to obtain what are known as vybrids. Vybrids are the first and subsequent generation progenies of the F, hybrids of two facultative apomicts. In each generation, F, genotypes could be recovered and the mean of the population in any generation remains constant. Rapid techniques and procedures were outlined for the production and utilization of vybrids and dihaploids.

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The Nature of Apomixis and its Utilization in the Production of Hybrids ("Vybrids") in *Sorghum bicolor* (L.) Moench

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With one table and 16 figures

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Abstract

The reproductive behaviour of 4 facultatively apomictic sorghum lines (R473, 26, 32 and 35), F_1 hybrids among facultative apomicts, and F_1 hybrid of sexual line × facultative apomict, and individual plants from F_2 generation of a sexual line × facultative apomict was worked out by cytological method and/or by progeny tests. Pre-fertilization apomictic potential was indicated by the presence of a greater frequency of unfertilized embryo sacs and multiple embryo sacs. Fertilization is prevented in the facultative apomicts by the occurrence of cross sterility. Crosses of facultative apomicts yield some hybrids, some of which reproduce through facultative apomixis. Such facultative apomicts were termed as "Vybrids". Vybrids breed true to the same extent as their apomictic frequency and get perpetuated indefinitely if reproduced through "maternal" type plants only. Vybrids are super varieties with yield levels approaching that of the F_1 genotype. The procedural details for the production of Vybrids has been given.

Key words: *Sorghum bicolor* — apomixis — vybrids — progeny tests

Production of seed without the union of the female and male gametes is known as apomixis. This is an important phenomenon in studies on evolution, speciation and plant breeding. Apomixis makes heterozygotes breed true similarly to some of the balanced structural heterozygotes, like the Renner complexes in species of *Oenothera* (Stebbins 1950). This property of apomixis was realized during the early thirties notably by Karpeschenko and Navaschin (Solentzeva 1978). Since then, several studies were made on its mechanism, inheritance and utilization in plant breeding resulting in a vast amount of literature. Obligate apomixis, where all progeny individuals are produced

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only through apomixis, has been utilized at least in one instance in the breeding of buffel grass, *Cenchrus ciliaris* L. (TALIAFERRO and BASHAW 1966). One or the other type of apomixis occurs in important crop plants like sorghum (RAO and NARAYANA 1968), *Pennisetum*, cotton, potato and some forage grasses (cf. MURTY et al. 1981a). While it is easy to utilize obligate apomixis in breeding, the use of facultative apomixis is associated with some difficulties. Successful utilization of facultative apomixis has so far been made only in forage grasses (FUNK and HAN 1967, FUNK et al. 1973 and 1974). The present investigation forms part of a research project aimed at the practical application of apomixis in sorghum breeding and is concerned with the mechanism of apomixis and the concept of "Vybrids" which represent the products of facultative apomixis breeding in sorghum.

Materials and Methods

1. Material

The apomictic line originally reported from India, R473 along with 3 other facultative apomicts 26, 32 and 35; and a sexual commercial variety R16 (CSV-7R) were used. The lines 26, 32 and 35 are facultative apomicts derived and isolated in F_8 progenies of crosses of White seed × R473. White seed is a true breeding mutant obtained in the colchicine treatments of Franzke. Four F_1 plants of crosses of R473 as male parent with 4 lines of R16 in four different cytoplasms (*milo*, *G1*, *VZM-2* and *M35-1*) were used. One F_1 plant and 124 individual F_2 plants of the cross SPV232 × R473 were also studied for cross sterility reaction and pre-fertilization aposporous potential.

2. Crossing studies

All the facultative apomictic lines R473, 26, 32 and 35 are cross sterile i.e., they do not set seed if used as females in crosses to any other line. However, such lines do set a very little seed on emasculation and crossing with abundant pollen on 3 successive days. Such a seed gives rise to some hybrids in addition to some maternals. Cross sterility of individual plants from the F_2 (SPV232 × R473) was tested by crossing them to an unrelated line. Part of the ear head was selfed to get some seed and part was used for crossing (*Figs. 11, 12* and *13*).

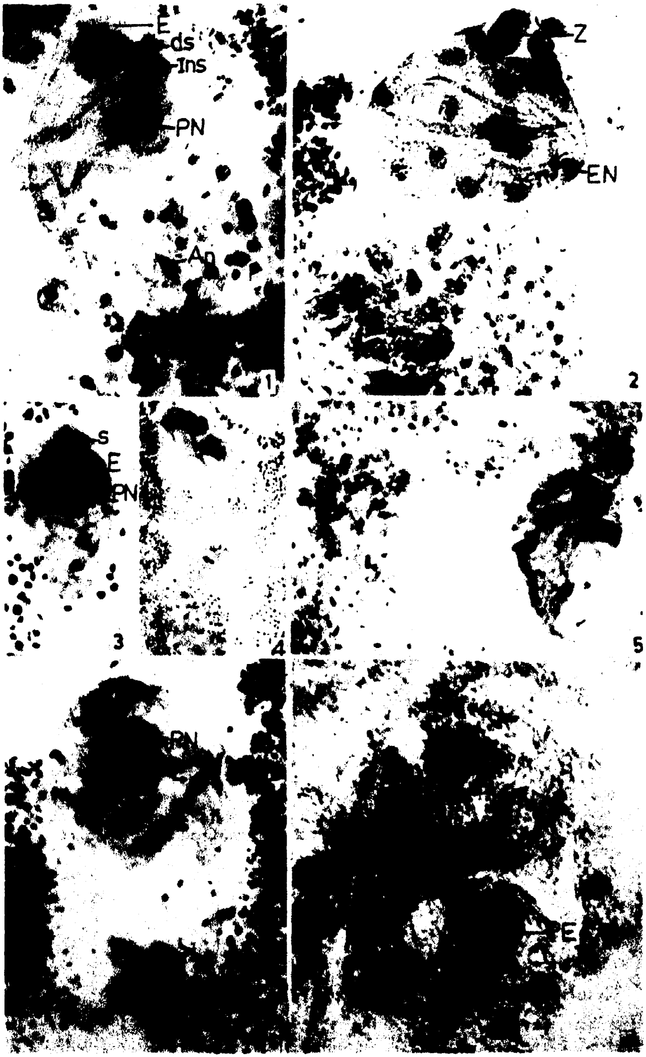
3. Cytological technique

For the study of embryo sacs, spikelets were emasculated a day before anthesis and either sibbed or crossed at the time of anthesis and fixed 6 h after pollination in a mixture of 1 : 3 : 4 glacial acetic acid, ethyl alcohol and chloroform. Ovules were squashed using the technique described by MURTY et al. (1979).

Results

1. Cytological studies

Cytological studies were made of sexual and apomictic lines to get information on the type of reproduction and the frequency of pre-fertilization apomictic potential. In the sexual material R16B, there is a single normal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Polygonum type of embryo sac in an ovule (*Fig. 1*). Either all the embryo sacs were fertilized, or some of the sacs were fertilized and some were unfertilized. The development of the endosperm was rapid. As many as 16 nuclei were present some times at 6 h after pollination (*Fig. 2*). The unfertilized sacs, however, revealed the presence of pollen tubes and other features like the degeneration of one of the synergids, or fusing polar nuclei characteristic of embryo sacs in which fertilization is taking place.

Several deviations occurred in the apomictic material. The frequency of fertilized sacs was low (*Table 1*). The unfertilized sacs did not show any signs of fertilization (*Fig. 6*). In addition, some ovules exhibited the presence of either small embryo sacs (*Fig. 3*) or multiple embryo sacs, the number ranging from 2—8 (*Fig. 4*). In most cases, the principal embryo sac, presumably the sexual sac, could be distinguished by its larger size and nuclei organized into the antipodals, central cell and egg apparatus. In most of the cases, it has the appearance of a degenerating organ, whereas the accessary sacs were well stained with prominent cytoplasm or with developing embryo and endosperm (*Fig. 5*). The accessary sacs were also smaller in size and the number of nuclei varied from 1—8. In some of the ovules examined 2 days after pollination, development of a proembryo or endosperm or both could be seen (*Fig. 7*). That these developments are apomictic was evident because there were no signs of pollen tubes and both the synergids were intact.

One hundred and twenty four individual plants from F_2 progenies (SPV 232 × R473) were examined for cross sterility. Out of these, 19 were cross sterile. An F_1 plant of this cross, 13 cross sterile F_2's, 9 cross fertile F_2s and 4 F_1s of crosses of R473 with an isosterile line in 4 different cytoplasms were examined in ovule squashes. Pre-fertilization aposporous potential was calculated as a percentage out of the total number of ovules, of the number of ovules with unfertilized embryo sacs with intact synergids, ovules with multiple embryo sacs and ovules with restituting antipodals. Normally the antipodals proliferate, but their nuclei appear granular. But in the aposporous materials these nuclei fuse to form only diploid nuclei which assume the appearance of nuclei of the embryo sac.

2. Progeny tests using quantitative characters

Large progenies of the 4 apomictic lines were grown for 8 generations. In most cases the progenies were uniform. Only occasionally offtypes could be seen. When crosses were made among these 4 lines, a very low seed set

Fig. 1. Normal unfertilized embryo sac showing an egg (E); a degenerating synergid (ds), an intact synergid (Ins) Polar Nuclei (PN) and antipodals (An) • *Fig. 2.* Normal fertilized embryo sac showing a zygote (Z) and a 16 nucleate endosperm (En) • *Fig. 3.* Small unfertilized embryo sac with intact synergids (S); egg (E) and Polar nuclei (PN) • *Fig. 4.* Two embryosacs; in one of the sac (Top) fertilization is taking place, the other one is unfertilized • *Fig. 5.* Two embryo sacs; sexual sac is seen degenerating, the other sac which is aposporous has several endosperm nuclei • *Fig. 6.* Unfertilized embryo sac with two intact synergids. • *Fig. 7.* Unfertilized embryo sac with four celled pro-embryo (PE). (All magnifications are Ca ×)

Tab. 1 Data on prefertilization aposporous potential in various sorghum material

S. No.	Pedigree	Total no. of ovules observed	Percentage of ovules with				Pre-fertilization aposporous potential (%)
			fertilized embryosacs	unfertilized embryo sacs with intact synergids	multiple embryo sacs	embryosacs with antipodal restitution	
1.	R-16B	35	100	0	0	0	0
2.	R473	30	40	10	30	20	60
3.	F_1 R-16A (VZM) × R473	85	73	5	2	20	27
4.	F_1 R-16A (G.) × R473	50	68	2	10	20	32
5.	F_1 R-16A (M-35-1) × R473	45	80	—	—	20	20
6.	F_1 R-16A (Milo) × R473	55	93	2	2	5	7
7.	F_1 SPV (232 × R473) — 30	50	90	5	—	5	10
	Mean of F_1's		80.8	2.8	2.8	13.6	19.2
		Cross steriles					
8.	F_2 SPV (232 × R473) — 19	30	60	20	10	10	40
9.	F_2 SPV (232 × R473) — 20	20	35	10	25	30	65
10.	F_2 SPV (232 × R473) — 18	30	50	30	10	10	50
11.	F_2 SPV (232 × R473) — 13	20	10	40	30	20	90
12.	F_2 SPV (232 × R473) — 14	30	60	20	10	10	40
13.	F_2 SPV (232 × R473) — 29	20	20	50	20	10	80
14.	F_2 SPV (232 × R473) — 99	20	80	10	—	10	20
15.	F_2 SPV (232 × R473) — 122	20	55	10	30	5	45
16.	F_2 SPV (232 × R473) — 117	40	70	20	5	5	30
17.	F_2 SPV (232 × R473) — 53	20	75	5	5	15	25
18.	F_2 SPV (232 × R473) — 116	20	50	10	25	5	50
19.	F_2 SPV (232 × R473) — 76	30	47	20	30	3	53
20.	F_2 SPV (232 × R473) — 15	50	76	10	8	6	24
	Mean of cross steriles		47.5	19.6	15.2	10.6	47.0
		Cross fertiles					
21.	F_2 SPV (232 × R473) — 11	30	60	10	20	10	40
22.	F_2 SPV (232 × R473) — 3	25	80	8	12	—	20
23.	F_2 SPV (232 × R473) — 10	15	82	12	—	6	18
24.	F_2 SPV (232 × R473) — 17	30	90	—	7	3	10
25.	F_2 SPV (232 × R473) — 22	25	92	4	4	—	8
26.	F_2 SPV (232 × R473) — 16	20	100	—	—	—	—
27.	F_2 SPV (232 × R473) — 1	30	94	6	—	—	6
28.	F_2 SPV (232 × R473) — 7	15	95	5	—	—	—
29.	F_2 SPV (232 × R473) — 28	10	70	20	10	—	30
	Mean of cross fertiles		84.7	7.2	5.8	2.1	15.2

resulted. Most of the grains were shrivelled and the germination was poor. The surviving plants were either maternals formed through apomixis or hybrids. The maternals could be distinguished visually based on similarity to the female parent in plant height, maturity, awn length and panicle shape.

The seed of the maternals and hybrids was harvested separately. Some of the hybrids were tested for their cross sterility reaction. All the tested plants were cross sterile. Their cytological behaviour was similar to those of their parents and hence concluded it was that facultative apomicts. Their progenies were grown in 2 different seasons (rainy season and post rainy season). For the most part they bred true. In each progeny, however, there was a varying number of "weak" plants. Progenies of the vigorous plants (maternals: these maternals actually represent the hybrids) were grown for another 2 seasons. They behaved in a similar manner. In each season, there were a few "weak" plants. These progenies reproducing through facultative apomixis were designated as "Vybrids". The Vybrids performed better than their parents.

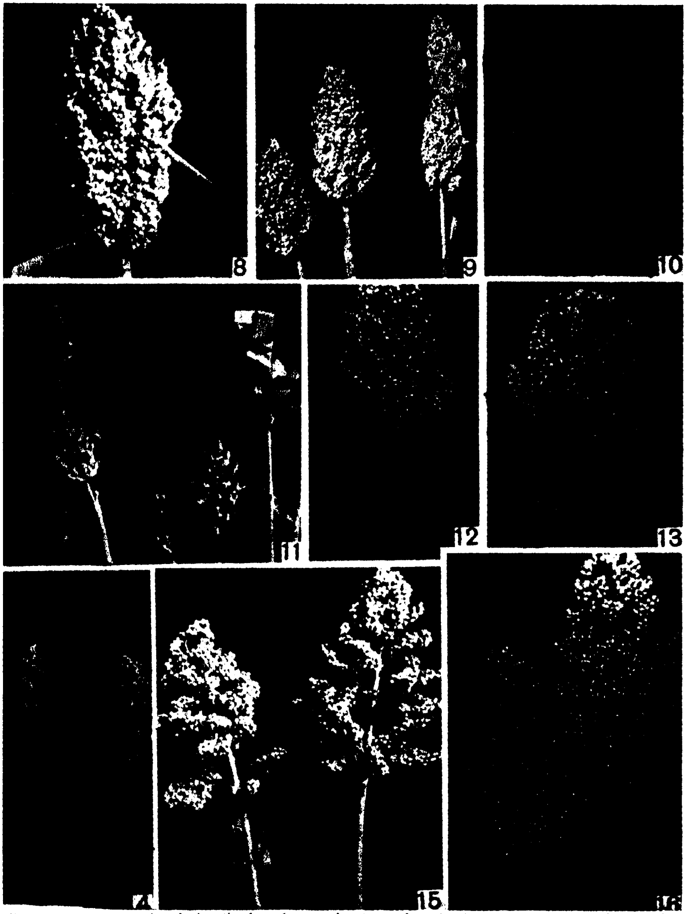
3. Progeny tests using a single dominant marker gene

The tan plant character in sorghum is recessive to the purple plant colour. The cross sterile F_2 individuals 8, 53 and 122 were tan. Progeny tests were conducted on these plants using R473 (purple) as a male. The progeny of such crosses had either only tan plants (in the case of 8 × R473 and 53 × R473) or a mixture of both tan and purple plants (122 × R473). The frequency of maternals varied from 88—100%.

Discussion

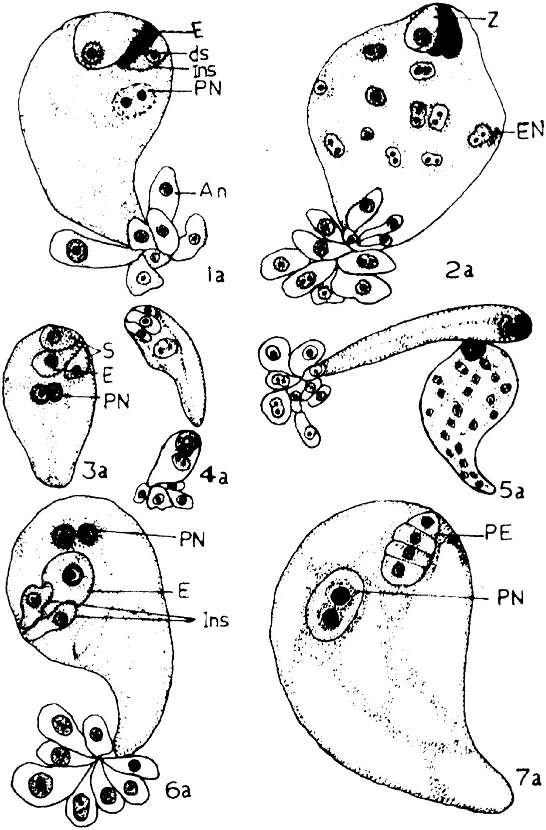
Since the discovery of apomixis in sorghum (Rao and Narayana 1968), several studies have established details on the nature, mechanism and frequency of the phenomenon (Murty and Rao 1972, Rao and Murty 1972, Murty and Rao 1978, Murty et al. 1981a and c). Apomixis in sorghum was thought to have 3 constituents known as the elements of apomixis (Asker 1980). These are: 1. production of diploid embryo sacs, 2. prevention of fertilization, and 3. development of viable seed from diploid embryo sacs without fertilization. Evidence for the existence of these 3 phenomena has been reported earlier.

Diploid embryo sacs were shown to develop in 3 different ways: 1. apospory, 2. diplospory (Murty et al. 1979), and 3. synkaryogenesis (Murty et al. 1981b). Of these, apospory and diplospory followed by first division restitution result in the fixation of heterozygosity. The genetics of this phenomenon is not known clearly. It is highly unlikely that a precise genetic analysis of apospory or diplospory in sorghum could be made at present. However, it is clear that it is linked with cross sterility. The recovery of plants having apospory in a high frequency in the F_1 of facultative × facultative apomicts and in the F_2 of sexual × facultative apomicts indicates genetic control. The third element of apomixis, the production of viable seed without fertilization represents the most important element. Its frequency is dependent upon the frequency of the first element. All 3 elements of apomixis have important implications in breeding. If the frequency of apomictically developed progeny



Figs. 8—16. Procedural details for the production of Vybrids • *Fig. 8.* Sexual desirable parent • *Fig. 9.* Facultative apomict • *Fig. 10.* F_1 • *Fig. 11.* Segregating F_2 • *Fig. 12.* Cross sterile plant simultaneously selfed and crossed • *Fig. 13.* Cross fertile plant simultaneously selfed and crossed • *Figs. 14* and *15.* Selected Cross sterile facultative apomicts • *Fig. 16.* Vybrid

can be made to be as high as possible, it can be employed with greater efficiency for the fixation of heterozygosity and consequently heterosis in heterotic crosses.



Using progeny tests, apomixis could be confirmed in the present study for the 4 plants (R473, 26, 32 and 35), for some of the cross sterile F_2's and the hybrids between the facultative apomicts. The F_1's of R16 lines in different cytoplasms by R473, although they were not apomictic (they segregate like normal sexual progenies), revealed some potential for apomictic reproduction in ovule squashes. This may be explained by assuming that they have only the first elements of apomixis i.e., production of diploid sex cells, but not the other two elements. A similar situation was described by POWERS (1945).

While obligate apomixis should be the ideal situation for the fixation of heterozygosity, the present study shows that, at present, facultative apomixis can also be exploited for the production of what are known as Vybrids. Vybrids represent the first and subsequent generation progenies of crosses of heterozygous facultative apomicts. In each generation, heterozygotes identical to the "hybrid" of the facultative apomicts occur in more or less equal frequency. If the Vybrid is perpetuated from the seed of these genotypes only, then the heterozygote gets perpetuated indefinitely.

The procedure for production of Vybrids has been illustrated in *Figures 8* to *16*. The method consists in making crosses between well adapted desirable sorghum varieties and one or more of the available facultative apomicts. There will be variation among the F_1's because the facultative apomict will be heterozygous. Desirable F_1's should be carried over to F_2. Desirable individual plants from F_2 should be tested for their cross sterility reaction. Cross sterile plants should be carried over and examined in ovule squashes. Cross sterile facultative apomicts isolated following this procedure can be mated. The progeny again has to be screened first for cross sterility and then for apomixis. Desirable plants can be tested in yield trials.

Since obligate apomixis does not exist in sorghum at present, the concept of Vybrids represents a useful and practical method for partial fixation of heterosis. This concept will have additional weightage in sorghum growing areas of India and Africa, where sorghums are grown under rain fed conditions and are frequently subjected to stress. It has been established that heterozygotes can withstand stress better than homozygotes (GRIFFING and LANGRIDGE 1963, PEDERSON 1968). Since cultivation of hybrids is associated with several difficulties in the developing countries, Vybrids provide an easy and in expensive seed material for stress environments.

Zusammenfassung

Die Natur der Apomixis und ihre Anwendung zur Erzeugung von „Vybriden" bei *Sorghum bicolor* (L). Moench

Das Fortpflanzungsverhalten von vier fakultativ apomiktischen *Sorghum*-Linien (R473, 26, 32 and 35), F_1-Hybriden von fakultativen Apomikten, einer F_1-Hybride aus der Kreuzung sexuelle Linie × fakultativer Apomikt, wie auch einiger Pflanzen aus der F_2-Generation einer solchen Kreuzung wurde zytologisch und/oder auf dem Wege der Nachkommenschaftsprüfung beurteilt.

Das apomiktische Vermögen wurde durch die größere Häufigkeit von unbefruchteten und von multiplen Embryosackmutterzellen vor der Befruchtung angezeigt. Die Befruchtung wird durch das Auftreten von Kreuzungssterilität bei den fakultativen Apomikten verhindert. Kreuzungen von fakultativen Apomikten ergeben einige Hybriden, die sich zum Teil wieder durch fakultative Apomixis fortpflanzen. Solche fakultative Apomikten werden

„Vybriden" genannt. Die Vybriden fallen entsprechend der Häufigkeit ihrer Apomixis echt und können unbegrenzt erhalten bleiben, wenn sie nur aus den muttergleichen Typen vermehrt werden. Die Vybriden sind Elitesorten, deren Ertragsleistung nahe der des F_1-Genotyps liegt. Die Details des Verfahrens für die Erzeugung der Vybriden werden erläutert.

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