GENETIC AND COMBINING ABILITY ANALYSIS OF SOME AGRONOMIC AND GRAIN QUALITY CHARACTERS IN SORGHUM

(*Sorghum bicolor* (L.) Moench)

A thesis submitted to the
Andhra Pradesh Agricultural University
in partial fulfilment of the requirements
for the award of the degree of

MASTER OF SCIENCE IN AGRICULTURE

By

JOSE GERALDO EUGENIO DE FRANCA

Department of Genetics and Plant Breeding
College of Agriculture
Andhra Pradesh Agricultural University
Rajendranagar
Hyderabad

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C E R T I F I C A T E

Mr. Jose Geraldo Eugenio de Franca has satisfactorily prosecuted the course of research, and the thesis entitled "GENETIC AND COMBINING ABILITY ANALYSIS OF SOME AGRONOMIC AND GRAIN QUALITY CHARACTERS IN SORGHUM (*Sorghum bicolor* (L.) Moench)" submitted is the result of original research work and is of sufficiently high standard to warrant its presentation to the examination. I also certify that the thesis or part thereof has not been previously submitted by him for a degree of any university.

Date: June 29, 1983

Chairman:

Dr. L.R. House
Principal Sorghum Breeder and Leader
Sorghum Improvement Program
International Crops Research Institute for the Semi-Arid Tropics
Patancheru P.O. 502 324
Andhra Pradesh
India.

C E R T I F I C A T E

This is to certify that the thesis entitled "GENETIC AND COMBINING ABILITY ANALYSIS OF SOME AGRONOMIC AND GRAIN QUALITY CHARACTERS IN SORGHUM (*Sorghum bicolor* (L.) Moench)" submitted in partial fulfillment of the requirements for the degree of Master of Science in Agriculture in the major subject of Genetics and Plant Breeding of the Andhra Pradesh Agricultural University, Hyderabad, is a record of the bonafide research work carried out by Mr. Jose Geraldo Eugenio de Franca under our guidance and supervision. The subject of the thesis has been approved by the Student's Advisory Committee.

No part of the thesis has been submitted for any other degree or diploma. All assistance and help received during the course of the investigations have been duly acknowledged by him.

Co-Chairman of the Advisory Committee

Chairman of the Advisory Committee

Thesis approved by the Student's Advisory Committee.

Chairman	(Dr. L.R. House)	
Co-Chairman	(Dr. S. Mahaboob Ali)	
Member	(Dr. D.S. Murty)	
Member	(Dr. G. Nageswara Rao)	

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JOSE GERALDO EUGENIO DE FRANCA

ABSTRACT

Title	:	Genetic and Combining Ability Analysis of some Agronomic and Grain Quality Characters in Sorghum (*Sorghum bicolor* (L.) Moench)
Name	:	Jose Geraldo Eugenio de Franca
Chairman	:	Dr. L.R. House Principal Sorghum Breeder and Leader of ICRISAT Sorghum Improvement Program.
Co-Chairman	:	Dr. S. Mahaboob Ali Professor & Head, Dept of Genetics & Plant Breeding APAU
Degree	:	Master of Science in Agriculture
Major field of study	:	Genetics and Plant Breeding

ANDHRA PRADESH AGRICULTURAL UNIVERSITY

1983

The objective of this study was to evaluate the combining ability, heterosis and variance components of a set of selected restorers and male sterile in sorghum for the following characters: days to 50% flowering, plant height, panicle length, grain yield per panicle, number of grains per panicle, thousand grain weight, grain breaking strength, % floaters, $ water absorption, flour particle size index, rolling quality of the dough and gel spreading.

Twenty parental lines - 11 male steriles and 9 restorers and their 99 hybrids formed the experimental material. Parents and hybrids were planted in adjacent trials in a RBD design with three replications each. The combining ability analysis followed a line x tester mating system.

The experiments were carried out under rainfed conditions during the rainy (Kharif) and post-rainy (Rabi) seasons of 1982 at ICRISAT Center, Patancheru, A.P., India.

Significant variation was observed in the genotypes studied for most of the characters analysed. Generally the restorers showed larger variation than the male sterile lines.

Significant levels of heterosis and heterobeltiosis were observed for plant height, grain yield per panicle, grain number per panicle and % floaters.

Dominance was in the direction of earliness, increased height, panicle length, grain number and yield, decreased seed weight, % floaters, flour particle size and gel spreading.

The results revealed that most of the agronomic and grain quality characters were highly influenced by additive gene action. However, grain yield per panicle and number of grains per panicle showed some evidence of non-additive gene action too.

Combining ability effects were significantly affected by the environment. Information on combining ability together with parental performance *per se* could help breeders in the evaluation of a large number of parents for hybrid performance.

Based on the performance of the hybrids and the GCA estimates, the following parents seemed to be useful for a hybrid breeding program: 623A, 296A, MA4, MA6, MR849 and MR867 for the *Kharif* and 623A, MA3, MR867 and MR864 for the *Rabi*.

Since the characters studied were mainly controlled by additive gene action, breeding methods which exploit this type of genetic variation should be rewarding.

CONTENTS

LIST OF TABLES AND FIGURES

APPENDICES

A.1. Means for days to 50% flowering of the hybrids and their parents in Kharif and Rabi experiments.

A.2. Means for plant height (cm) of the hybrids and their parents in Kharif and Rabi experiments.

A.3. Means for panicle length (cm) of the hybrids and their parents in Kharif and Rabi experiments.

A.4. Means for grain yield per panicle (g) of the hybrids and their parents in Kharif and Rabi experiments.

A.5. Means for number of grains per panicle of the hybrids and their parents in Kharif and Rabi experiments.

A.6. Means for 1000 grain weight (g) of the hybrids and their parents in Kharif and Rabi experiments.

A.7. Means for breaking strength (kg) of the hybrids and their parents in Kharif and Rabi experiments.

A.8. Means for floaters percentage of the hybrids and their parents in Kharif and Rabi experiments.

A.9. Means for lodging score (1 = 0%, 10 90% plants lodged) of the hybrids and their parents in Kharif and Rabi experiments.

A.10. Means for rust score (1 = 0%, 5 40% leaf area damaged) of the hybrids and their parents in Rabi experiment.

A.11. Means for percentage of water absorption of the hybrids and their parents in Kharif and Rabi experiments.

A.12. Means for particle size index of the hybrids and their parents in Kharif and Rabi experiments.

A.13. Means for rolling quality (cm) of the hybrids and their parents in Kharif and Rabi experiments.

A.14. Means for gel spreading (mm) of the hybrids and their parents in Kharif and Rabi experiments.

B.1. Estimates of heterosis % for days to 50% flowering compared to earlier parents in Kharif and Rabi experiments.

B.2. Estimates of heterosis % for plant height over the shorter parent in Kharif and Rabi experiments.

INTRODUCTION

Sorghum is grown as a staple food crop in the Semi-Arid Tropics (SAT) by millions of small farmers. However, the average yields of the crop in the SAT is far below the yields achieved in the developed nations where it is used as animal feed. Although 75% of the world sorghum acreage is represented in the Asian and African continents; their contribution to the total world sorghum production is only 41% (FAO, 1982) and grain yields average around 700 kg/ha.

In developing nations like India, commercial sorghum hybrids were released for cultivation. However, the area planted with these hybrids continues to be low in several regions (Pushpamma and Chitemma Rao, 1981). One of the reasons for the poor acceptance of the improved hybrids by the farmers has been their poor food quality.

Improvement of the consumer quality characters is limited due to the lack of reliable screening techniques and the poor knowledge of their inheritance (Doggett, 1977). On the other hand, commercial production of hybrid seed has generally been wrought with difficulties. Non-synchrony in the flowering of the male and female parents resulted in staggered plantings and restriction of the areas of seed production to a few districts where the flowering behaviour was predictable (Chopra, 1982).

Therefore the ICRISAT Sorghum Improvement Program has attempted to identify non-restorers in a diverse array of breeding stocks in an effort to develop an increased number of useful seed parents (Murty et al. 1983).

The objective of this study was to evaluate and compare the genetic potential of a group of restorers and male sterile parents recently developed at ICRISAT with hybrid parents currently being used in India. Therefore a line x tester experiment of 20 parents was evaluated in Kharif and Rabi seasons of 1982 so as to provide information on (I) combining ability parameters for a range of agronomic and grain quality traits, (II) extent of heterosis over superior parent and (III) type of gene action controlling agronomic and the grain quality traits studied.

Results of these experiments form the subject of this thesis. Informations obtained from this study should help breeders in choosing appropriate parents out of those evaluated for hybrid production and plan suitable breeding procedures.

II. REVIEW OF LITERATURE

II.1. GENETIC COMPONENTS

II.1.1. Testers and combining ability

The use of testcross to estimate the value of inbred lines in a breeding program started with Jenkins and Brunson (1932) in maize. According to Hallauer and Miranda (1981) the use of test crosses in maize breeding, which can be extended for any other crop species, has the following objectives:

(i) evaluation of combining ability of inbred lines in a breeding program; or

(ii) evaluation of breeding values of genotypes for population improvement.

Studies on combining ability are useful to understand the nature of genetic variance. They help the breeder to choose suitable parents for developing either hybrids or varieties. The concepts of general and specific combining ability were introduced by Sprague and Tatum (1942) who designated general combining ability (GCA) as the average performance of a line in hybrid combinations. The term specific combining ability (SCA) was applied to those cases where certain hybrid combinations did relatively better or worse than would be expected on the basis of the average performance of the lines involved.

Green (1948b) working with F_2 generations of maize drawn from crosses of high x high, high x low, and low x low combining inbred lines was able to show that combining ability is an inherited character.

Sprague and Tatum (1942) also emphasized that estimates of GCA and SCA are relative to and dependent on a particular set of inbred lines involved in the hybrids under test. GCA was relatively more important than SCA for unselected inbred lines while SCA was more important for previously selected lines of maize.

It is now generally recognized that the GCA effect is the result of additive gene action and that SCA is largely dependent on genes with dominance or epistatic effects.

Griffing (1956b) showed that for homozygous parents (inbreeding coefficient F=1), the genetic variance $\sigma^2 G$ (variance among hybrids) can be expressed in terms of combining ability variance as follows:

$$\sigma^2 G = 2\sigma^2 GCA + \sigma^2 SCA \qquad \text{.... Eq 1}$$

where $\sigma^2 GCA$ and $\sigma^2 SCA$ are the variances for general and specific combining ability effects respectively. $\sigma^2 GCA$ is an average effect and reflects the degree of resemblence among half sibs (HS), so that for F=1 we have:

$$\sigma^2 GCA = Cov(HS) = 1/2\ \sigma^2 A + 1/4\ \sigma^2 AA + \ \dots \qquad \text{Eq 2}$$

where Cov (HS) = Covariance among half sib progenies. The total genetic variance $\sigma^2 G$ in the population is reflected by the resemblence among full sib families (FS), so that for F=1, its equation is as follows:

$$\sigma^2 G = Cov(FS) = \sigma^2 A + \sigma^2 D + \sigma^2 AD + \sigma^2 AA + \sigma^2 DD \quad \ldots \text{Eq } 3$$

However, from Eq 1

$$\sigma^2 SCA = \sigma^2 G - 2\sigma^2 GCA \quad \ldots \text{Eq } 4$$

Replacing $\sigma^2 G$ and $\sigma^2 SCA$ from Eq 2 and Eq 3 respectively, we have

$$\sigma^2 SCA = Cov\ (FS) - 2\ Cov\ (HS)$$

$$\sigma^2 SCA = (\sigma^2 A + \ldots) - 2(1/2\sigma^2 A + 1/4\ \sigma^2 AA + \ldots)$$

$$\sigma^2 SCA = \sigma^2 D + 1/2\ \sigma^2 AA + \sigma^2 AD + \sigma^2 DD ++ \ldots$$

thus, combining ability variance components may reflect, additive effects and additive interactions, while specific combining ability variance components may reflect dominance and epistasis, plus components of additive epistasis (Rojas and Sprague, 1952).

The concept of a good test has been another question for most of the breeding programs. Matzinger (1953) defined a desirable tester as one that combinies the greatest simplicity in use with maximum information on the performance to be expected from the tested lines. Neverthless Allison and Curnow (1966) assessed that the best tester is the one that maximizes the expected mean yield of the variety produced by random mating the selected genotypes.

Green (1948a) comparing maize progenies from crosses using two testers pointed out that the average performance was a better estimate of combining ability than is the top cross performance of either tester alone.

Kempthorne and Curnow (1961) brought out that if common testers are to be used to estimate the yielding capacities of crosses between the inbred lines, it implies that we have to make the assumption that the general combining ability of each inbred line relative to the common testers is the same as its general combining ability relative to all the other inbred lines.

Regarding the selection of testers to heterogeneous population, Cress (1966) concluded that it can be done on the average performance of the test cross i.e., the tester with the highest average cross performance is chosen. He also assessed that if the selected genotypes are not to be used immediately in hybrid combination with the tester this emphasis on heterotic response is misplaced since it reveals little concerning the genetic potential and nothing concerning the expected rate of progress from selection.

On the stage of test,Hallauer and Miranda (1981) reported that some form of early generation testing is included in most breeding programs. However, this does not imply that a perfect relation exists between the initial and later generations of inbreeding, since early testing was designed to separate the population of lines into good and poor groups for combining ability. According to Sprague (1946), early testing is based on two assumptions: (i) there are marked differences in combining ability among open-pollinated plants and (ii) selected samples based on tests of combining ability of S0 (variety) or S1 (advanced generations of a hybrid) plants offer a larger proportion of superior lines upon inbreeding and then selection does a more nearly random sampling of combining abilities drawn from the same population than on the basis of visual selection alone.

Several are the procedures to estimate the combining ability. Hayman (1954a,b and 1958) proposed an analysis of diallel crosses to obtain genetic components of variation with the following assumptions:

1. Diploid segregation;
2. Only environment differences between reciprocal crosses;
3. Independent action of non-allelic genes;
   and in the parents;
4. No multiple allelism;
5. Homozygosity;
6. Genes independent distributed.

Griffing (1956a) presented a generalized evaluation of the use of the diallel crosses in quantitative inheritance studies and the term diallel was used to refer situations which P inbred lines are chosen to give maximum of P^2 progenies (crosses, including reciprocals and selfed progenies). Four experimental methods were described, depending on whether parents and reciprocals crosses were included or not. For each method the basis for sampling the experimental material gave rise to two models: I and II. In the model I the experimental lines used were referred as the population about which inferences were to be made. In the model II the parent population referred to was a random mating population in equilibrium, and the specific set of experimental lines used were considered a random sample from a population of inbred lines derived from the parent population by an inbreeding system free from situations which could change gene frequencies.

Sprague (1966) pointed out that the statiscal geneticists may argue that the parental lines should represent random derivatives from a random mating population. In this case the variances of GCA and SCA can be considered as estimates of population parameters. On the other hand, the breeder is less concerned with population characteristics and is more interested in gene action within a given set of selected inbred lines. In such situations the parental lines themselves are the reference population about which inferences can be made.

Kempthorne and Curnow (1961) proposed methods to analyse partial diallel crosses where only a random set of crosses in the PxP matrix are made.

Another popular method to study the combining ability of inbred lines is the line x tester, introduced by Comstock and Robinson (1948, 1952) and Kempthorne (1957). In this design a set of female parents (n) are crossed with a genetically different set of male parents (m) in all possible combinations resulting a total of mn progenies, presented by a MxN matrix as follows:

Table 1. Matrix M x N showing all possible combinations in a line x tester mating system with m males and n females.

Males	Females			
	1	2	...	n
1	11	12	...	1n
2	21	22	...	2n
m	1m	2m	...	mn

One of the main advantages of this method when compared to the others presented before is that it enables the breeder to test at one time a higher number of inbred lines.

Many studies were carried out to estimate the combining ability effects in several crop species like maize (Horner, 1963; Horner et al., 1963; Purdy et al., 1965; Widstrom, et al., 1972; Harville et al., 1978; El-Rouby et al., 1979; Nawas et al., 1981 and El-Itriby et al., 1981); wheat (Kronstad and Foote, 1964; Matuz et al., 1974; Bedair et al., 1979 and Abul-Nass et al., 1981a,b); barley (Upadhyaya and Rasmusson, 1967); cotton (Marani, 1963; Miller and Marani, 1963; Hawkins, et al., 1965; Marani, 1967; and Wilson et al., 1980); alfalfa (Kehr, 1961; Davis and Paton, 1962) and tobacco (Jones et al., 1972 and Aycock, 1972) and so on.

II.1.1.1. Combining ability in sorghum: Kambal and Webster (1965) worked on data collected over two years from a set of 190 hybrids obtained by crossing 10 male sterile lines and 19 restorers. They concluded that both σ^2GCA and σ^2SCA were important and stable over years for grain yield.

Niehaus and Pickett (1966) studied a diallel cross in two generations, F_1 and F_2 and pointed out that GCA effects were high in F_1 and F_2 while SCA effects were significant only during F_1 for grain yield and number of seeds per panicle.

Beil and Atkins (1967) studied the performance of 40 F_1 hybrids obtained by crossing 5 male sterile lines with 8 restorers at 3 locations over two years and found that GCA variances for grain yield, number of seeds per head, number of heads per plant, and 100 seed weight were much larger than SCA variances.

Liang (1967) worked with a 6 x 6 diallel cross and pointed out that with few exceptions GCA and SCA interacted with locations significantly for all the characters studied.

Malm (1968) studied a set of hybrids developed from crosses between American and African genotypes. It was concluded that for grain yield, seed size and protein content additive gene action was much more important than non-additive gene action.

Rao (1970) examined a series of crosses involving a wide range of parents of exotic and Indian origin. Combining ability effects for grain yield from crosses between Indian x exotic parents indicated that both GCA and SCA variances were of equal magnitude, thereby indicating the importance of non-allelic interactions in influencing yield. It was also stated that for days to flowering and plant height the gene action was essentially additive.

Studies carried out by Govil and Murthy (1973) Shinde and Sudewad (1980b),Srihari and Nagur (1980) and Dabholkar and Baghel (1980b) showed that both additive and non-additive gene action were involved in the inheritance at grain yield.

Govil and Murthy (1973) found that the best general combiners were also involved in the best specific combinations, indicating that predictions of yields of hybrids based on GCA effects of the parents should generally be valid.

Mattei (1974) working in Venezuela with a line x tester cross of 8 male sterile lines and 4 restorers evaluated over three locations observed that variance due to additive effects was several times larger than the variance due to non-additive effects for grain yield. He concluded also that the screening of parents based on their GCA should be effective.

Paisan (1975) analysed data from a set of single and three-way crosses and found that for both kind of hybrids, GCA effects of restorers lines accounted for the largest portion of variation expressed for grain yield, heads per plant, seeds per head and 100 seeds weight. Significant effects of GCA for females were expressed for all the characters studied in the single crosses. However, the variation attributable to specific combining ability effects made only slight contribution to the inheritance of all the traits in both types of hybrids.

Chavan and Nerkar (1978) studied a diallel cross of four varieties, two adapted for kharif and two adapted for rabi seasons and found that additive gene action was predominant for days to flowering, plant height and panicle length. For grain yield per head, the conclusion was that during kharif the character was mostly controlled by additive effects but in rabi, it was predominantly controlled by non-additive gene action.

On the other hand several studies showed the predominance of non-additive effects in the control of grain yield in sorghum. For example Nagur and Murthy (1970) and Nagur and Menon (1974) showed non-additive gene action for head weight, grain weight, volume of 100 grains and density during the winter season in India.

Shankaregouda et al. (1972) in a line x tester study pointed out that plant height and days to flowering were mostly controlled by additive gene effects, whereas, yield and number of grains per panicle were largely controlled by non-additive gene effects.

Similar results were also found by Goud et al. (1973), Shahane and Bapat (1981), Shinde and Sudewad (1981), and Rao et al. (1981).

To summarise, it can be concluded that several combining ability studies in grain sorghum indicated that most of the characters which form yield components are largely controlled by GCA effects while complex characters like grain yield and grain number are controlled by GCA as well SCA effects.

Regarding forage sorghum Chavda and Drolsom (1970) reported that plant height, node number, tiller number, leaf length and dry matter yield showed high specific combining ability values suggesting that the manifestation of the heterosis was specially due to this component of combining ability.

Boora and Lodhi (1981) studied crosses from 17 male sterile lines and 5 restorers were tested over two locations and concluded that variances for specific combining ability were higher for number of leaves per plant, leaf length, leaf breadth, leaf weight, green fodder yield per plant and dry fodder yield per plant. However, for days to flowering, plant height, stem thickness, and stem weight, the variance due to GCA was higher.

Neverthless other studies like Tripathi et al. (1977) and Dangi et al. (1980) concluded that additive genetic variance was predominant for number of leaves per plant, days to flowering, fodder yield and test weight.

Boora and Lodhi (1982) also found predominant non-additive genetic variance for tannin content and additive genetic variance for HCN content.

II.1.2. Heterosis:

The phenomenon of heterosis was observed more than two centuries ago, however the term heterosis was coined only in 1908 by Shull, (Duvick and Brown, 1981) to express the unusual vigour of the F_1 generation resulting from the hybridization of two inbred lines of maize. Mather and Jinks (1971) defined heterosis as the amount by which the mean of any F_1 family exceeds its better parent.

Heterosis has been observed in several crops like maize (Cress, 1966; El-Rouby et al. 1979; and Nawar et al. 1980); sorghum (Rao and Murthy, 1970; Goud and Sastry, 1974; Vasudeva Rao and Goud, 1975); wheat (Bedair et al., 1979) potato (Tarn and Tai, 1977); long bean (Mak and Yap, 1977); peas (Gritton, 1975); chili peppers (Lippert, 1975); sesame (Murty, 1975) and so on.

There are two important theories to explain the phenomenon of heterosis: (I) the dominance theory proposed by Bruce (1910) and

Keable and Pellow (1910) and (II) the overdominance theory as **establi-shed** by Shull (1908) and East (1908).

The first quantitative studies on heterosis tried to indicate the importance of overdominance as the cause of heterosis in maize. However, the estimates were biased due to the presence of linkage (Hallauer and Miranda, 1981).

Later, Gardner et al. (1953); Sprague et al. (1962); and Moll et al. (1964) were able to show that dominance is the principal cause of the heterosis.

Jinks and Jones (1958) reported that the presence or absence of heterosis is not by itself indicative of presence or not of any particular type of gene action or interaction. There is, however, a correlation between the presence or absence of non-allelic interactions and heterosis.

Mather and Jinks (1971) pointed out that linkage leads to an overestimation of epistasis. The summed effects of the individual linked genes, and the non-allelic interactions lead to apparent dominance.

The manifestation of heterosis depends also on the genetic divergence of the two parental varieties (Paterniani and Longuist, 1963; Moreno-Gonzales and Dudley, 1981). Hallauer and Miranda (1981) have shown that genetic divergenece among varieties is difficult to be predicted and the only way to determine its level is through varietal crosses. If the magnitude of heterosis manifested from the cross of two parental varieties is relatively large, it can be concluded that the two parental varieties are genetically more diverse than two varieties that manifest little or no heterosis in their F_1 hybrids.

Falconer (1981) defined heterosis as:

$$HF1 = dy^2$$

where HF1 is the magnitude of heterosis from the cross of two lines or populations; d is the amount of dominance effects contributed by the parental lines or varieties and y is the degree of dissimilarity between the relative gene frequency of the lines or populations involved.

Although superiority of the hybrids was known since a long time, it was only after the twenties when the development of the inbred line theory took place that the commercial exploitation of hybrids started (Hallauer and Miranda, 1981).

II.1.2.1. Heterosis in sorghum: Earlier studies showed the possibility of exploitation of heterosis in sorghum almost around the same time as in maize (Conner and Karper, 1927; Karper and Quinby, 1937; Bartel, 1949).

However, only during the fifties, with the discovery of a cytoplasmic-genetic male-sterile source in the Dwarf Yellow Milo variety, the sorghum hybrids started to be commercially exploited (Stephens and Holland, 1954).

In India, Argikar and Chavan (1957) found in sorghum that the magnitude of heterosis for panicle length was up to 59% over the superior parent.

Arnon and Blum (1962) studied the performance of seven hybrids and four commercial varieties and concluded that the most significant aspect of the hybrids was in the increased average of yield per head and a greater number of seeds per head. Similar results were obtained by Subramanian et al. (1962); Niehaus and Pickett (1966); and Blum (1970).

Quinby (1963) concluded that apart from the yield characters, heterosis is expressed in earlier blooming, increased tillering and height.

Arnon and Blum (1965) observed through a study with a hybrid (RS610) and well adapted varieties that a considerable initial advantage was acquired by the hybrid due to its earlier growth. They mentioned that during the seedling stage, the hybrid developed a much greater leaf surface per plant and per unit area and that the root production was also considerably higher than in the varieties. These observations were confirmed later by Kambal and Webster (1966) and Patanothai and Atkins (1971).

Rao and House (1966) found in India that contary to the expectations, the extent of heterosis obtained from exotic x Indian crosses was lower than exotic x exotic hybrids.

Chiang and Smith (1967a) studied a 7 x 7 diallel cross and suggested that the source of heterosis in plant height could be due to the accumulation of dominant genes from each parent in the heterozygote since there was no single cross showing non-allelic interactions when tested by Jinks' linear additive model.

Kirb and Atkins (1968) tested a set of 24 F_1 hybrids and their respective parents over two years and concluded that the greatest heterotic response was observed for grain yield. The hybrids averaged 22% over the mid parents. Similar results were also obtained by Liang et al. (1972); Iqbal et al. (1974); Kambal et al. (1976); Paisan and Atkins (1977), Sodani and Charturverdi (1978); Desai et al. (1980); Giriraj and Goud (1981) and Patel et al. (1982).

Quinby (1970) measured leaf blade width and length of parents and hybrids and was able to show that hybrids had smaller leaf blade area at maturity than female parents and that differences in leaf blade area did not seem to be an important difference between parents and hybrids. The results suggested also that sorghum hybrids have larger meristems than the parents and grow faster whenever growth is by cell division. Similar results were obtained by Blum (1977).

Collins and Pickett (1972) studied a diallel cross of nine parents and concluded that only few crosses revealed heterosis for protein content and none of them for lysine percentage.

Quinby (1973) showed that the processes which do not include rate of cell division, such as deposition of starch or the accumulation of protein in endosperm show little effect due to hybrid vigor.

II.1.3. Gene action:

II.1.3.1. Morphological characters:

a. Maturity - The expression of this character is largely influenced by the photoperiod and temperature as pointed out by Quinby and Shertz (1970).

Quinby and Karper (1945) observed that plant maturity of sorghum was controlled by three gene pairs. Later, Quinby (1966) demonstrated the presence of a fourth pair in a Hegari variety.

Miller et al. (1968) studied in Texas during the summer season (long day) a set of combinations of dominant and recessive alleles of the four maturity gene loci viz; Ma1, Ma2, Ma3, and Ma4 and obtained a range in days to flowering from 40 to 100 days, while in Puerto Rico during short days season of the winter the range was narrowed from 42 to 64, indicating that sorghum flowers at the same time in short days but not in long days.

Quinby (1973, 1974) reported that maturity genes control time of initiation of floral bud, flowering, as well as the leaf number.

In addition to the major genes, additive gene action was found to play a special role in the control of flowering (Chiang and Smith, 1967b; Liang et al., 1968; Nayakar, 1973; Dabholkar and Baghel, 1980a; Indi and Goud, 1981).

A study carried out by Ross and Kofoid (1978) with sorghum did not indicate any influence by epistatic gene action.

b. Plant height - Four loci are known to be important in the genetic control of height in sorghum, viz; DW1, DW2, DW3 and DW4 (Quinby and Karper, 1954). It was also found the recessive alleles are non-linked and brachytic i.e. the length of the internodes is reduced but not the peduncle length, panicle size, leaf number, and maturity.

Quinby and Karper (1954) also reported that there is instability in the DW3 allele, so that variation exists in height between varieties of the some genotype.

Quinby and Shertz (1970) assessed that each dwarf gene may reduced height by 50 cm or even more if there are recessive alleles at the four loci.

Quinby (1974) showed the importance of 3-gene dwarf genotypes in the production of 2-gene dwarf forage hybrids using short parents and revealed that 1-gene dwarf hybrid can be produced by using 3-gene dwarf females and the proper 2-gene dwarf males, mainly for countries like India where the importance of the stover cannot be neglected.

Ross and Kofoid (1979) were the first to identify homozygosity in the DW1 dominant allele in the cultivar SC 102-9.

The control of plant height by additive gene effects was reported by Chiang and Smith (1967b) and Indi & Goud (1981). However, Nayakar (1973) showed that non-additive gene action was more important.

c. Male sterility - Several factors controlling genetic male sterility in sorghum through a single recessive allele are known (Karper and Stephens, 1936; Stephens, 1937; Ayyangar and Ponnaya, 1937; Kajjari and Chavan, 1953; and Andrews and Webster, 1971). However, from the breeding point of view the cytoplasmic-genetic sterility is of interest in the production of commercial hybrids.

Stephens and Holland (1954) reported the discovery of the cytoplasmic-genetic male sterility in the variety Dwarf Yellow Milo restored by the genes of Kafir varieties nucleus.

Mital et al. (1958) found in India another cytoplasmic male sterility in the genotype IC2360.

Maunder and Pickett (1959) brought out that the inheritance of cytoplasmic male sterility is under monogenic control (MsMs) interacting with the sterile cytoplasm.

Rao (1962) reported male sterile plants in 9 Indian varieties viz. W.E.I, Bilichigan, Red Jonna, Indore Local, GJ103, BD8, Burma black, Norghum and C.10-2.

Miller and Pickett (1964) found partial male sterility in derived lines from the sorghum hybrids R610 and R650. It was suggested that partial male sterility was controlled by two major genes.

Ross and Hackerott (1972) registered seven genotypes with unknown cytoplasm derived from the crosses from cultivated and wild species.

A new cytoplasmic-genetic male sterility was reported by Schertz (1977) from an Ethiopian variety IS1266C and IS5322C as maintainer. Later Schertz and Ritchey (1978) tested three male steriles including IS1266C, which performed agronomically better.

The symbol A2 was given for this cytoplasmic-genetic male sterility and Schertz et al. (1981) released three pairs of A and B lines with A2 cytoplasm.

Quinby (1980) presented a hormonal theory to explain the cytoplasmic-genetic sterility and also pointed out that the Indian discovered cytoplasm "Maldandi", symbolized by A3 behaved similar to IS1112C.

Webster (1980) reported the development of some A lines from the cytoplasm of the variety 9E from Ghana.

Schertz (1982) and Quinby (1982) reviewed the cytoplasmic-genetic male sterility systems reported in sorghum. The risk of the use of only one cytoplasmic source, namely Milo has been emphasized.

II.1.3.2. Endosperm and grain quality characters:

a. Endosperm types - There are two main variants of the normal endosperm: waxy and sugary (Doggett, 1970). Waxy endosperm starch consists of 100% Amylopectin, while normal (non-waxy) ones show a ratio of 75% Amylopectin and 25% Amylose. Rooney and Miller (1982) pointed out that the term waxy referred to the glossy "Waxed floor like" appearence of the endosperm surface.

Waxy is a character controlled by the gene pair *wxwx*. Waxy is recessive to normal endosperm, and Xenia occurs when *wxwx* plants are pollinated with *Wx* pollen (Doggett, 1970).

Ellis et al. (1974) working with contrasting genotypes of endosperm types. viz; *WxWxWx*, *WxWxwx*, *Wxwxwx*, and *wxwxwx* concluded that protein and amino acid content were not significantly different for the four genotypes as well as *in vitro* protein digestibility of ground grain. However in vitro starch digestibility of purified starch from ground grains pretreated with pronase increased significantly with each additional dose of the waxy allele.

Regarding the sugary type, Karper and Quinby (1963) concluded that its inheritance was due to a recessive allele su and that no linkage was found between su and waxy or yellow seed control. The sugary grains showed dimpling of the endosperm.

b. Endosperm texture - Elis (1975) found out that corneous texture was simply inherited and partially dominant to floury and concluded that the variation in texture of sorghums classified as intermediate may be influenced by several modifying genes. It was assumed that most of the variation was genetically induced.

c. Endosperm color - Wayne (1971) concluded from results obtained due to crosses between normal and yellow endosperm that its inheritance is probably controlled by more than two genes and that a slight dominance seemed to be expressed in favour of non yellow type. Rooney and Miller (1982) reviewed the inheritance of pericarp color and thickness in sorghum grains and pointed out that in true yellow endosperm cultivars those genes affecting carotenoid content are homozygous. If the pericarp is thin or colorless (R-yy or rryy) and the testa is absent, the color of the grain appears yellow, but if the grain has a thick mesocarp (zz) the grain will appear white because the yellow endosperm color has been masked by a thick pericarp.

d. Protein and amino acid content: Liang et al. (1968) found that a partial dominance controlled the protein content and that two groups of genes were responsible for its inheritance.

Malm (1968) studied a line x tester system and concluded that the inheritance of protein content was due to additive effects. Similar results we obtained by Abifarin and Pickett (1970); and Collins and Pickett (1972). However, Crook and Casady (1974), Wilson et al. (1978) and Rao et al. (1982) reported that the non-additive gene action plays the most important role in protein inheritance.

Singh and Axtell (1973) identified two high lysine genotypes from Ethiopian orign, viz; IS11167 and IS11758.

Singh (1976) studied crosses from normal endosperm and high lysine Ethiopian lines (Shrunken) and concluded that F_1 modifiers arose with different proportions of opaque and translucent. It was also reported that the protein content of these modified selections were relatively lower than the normal and high lysine parents, neverthless the lysine values in protein were comparable to that of the high lysine ones.

Tripathi et al. (1971) reported that in grain sorghum the hardness of the grain had a positive and significant correlation with protein content.

Jambunathan and Subramanian (1983) assessed that the high lysine gene may not be stable in normal seed with a plump endosperm background.

II.1.3.3. Grain yield components:

a. Grain yield per plant: Liang and Walter (1968) studied a set of parental lines and their F_1, F_2 and B2 generations and concluded that additive gene action seemed to have a minor contribution to the inheritance of grain yield. In another work Liang et al. (1968) found out that at least four groups of genes are involved in controlling yield inheritance. Similar results were obtained by Liang et al. (1969); Shinde and Sudewad (1981); Indi and Goud (1981); and Nayarkar (1973).

However, it seems that additive as well as non-additive gene action control the inheritance of grain yield (Nagur and Murty, 1970; Nagur and Menon, 1974; Mattei, 1974; Raju et al. 1980; Finkner et al. (1981); and Dabholkar and Baghel, 1980b).

b. Panicle length: Whitehead (1962); Chiang and Smith (1967b) and Paisan (1975) showed that panicle length is controlled by additive gene action.

c. Panicle weight: Additive as well as non-additive gene actions was reported to control the inheritance of panicle weight (Chiang and

Smith, 1967; Liang and Walter, 1968; Nayarkar, 1973; and Srihari and Nagur, 1980).

d. Number of grains per panicle: Arnon and Blum (1961) and Niehaus and Pickett (1966) revealed that number of grains per head is the most important component of yield. Miller et al. (1976) evaluating parents, F_1, F_2 and back crosses found a very strong negative correlation between 1000 grains weight and number of seeds per head, and noted that yield per head of hybrids was higher when the female parent had smaller seed. It was also concluded that females should be selected for maximum number of grains per panicle without regard to seed size.

Nayakar (1973) and Dabholkar and Baghel (1980a,b) concluded that additive gene action was responsible for the inheritance of number of grains per panicle. However, Liang and Walter (1968) found out that this trait was basically controlled by non-additive effects.

e. 1000 grains weight: Miller et al. (1976) found that for each one gram increase in weight per 1000 grains there was a reduction of 77 grains per head.

Voigt et al. (1966) concluded that since the heritability of grain size was high (slightly higher than 60%) progress in changing seed size can be done through any method that exploits the additive gene action. These findings were confirmed by other authors like Dabholkar and Baghel (1980a,b), Shinde and Sudewad (1980a) and Patidar and Dabholkar (1981).

On the contrary, Liang and Walter (1968) and Nayakar (1973) found that additive gene action had a minor role in the inheritance of grain weight.

II.2. GRAIN QUALITY COMPONENTS

II.2.1. Grain structure:

The structure of the sorghum kernel plays a major role in determining the processing properties of the grain, its utilization and food preparation (Rooney and Miller, 1982).

The sorghum grain is a cariopsis in which the ovary wall dries and adheres strongly to the mature ovule and is composed of three main parts: the outer covering (pericarp), the storage tissue (endosperm) and the embryo (germ) (Ronney and Miller, 1982).

The pericarp is composed of three different parts, viz; the epicarp, the mesocarp and the endocarp.

The epicarp is the outermost portion of the grain and is often divided into the epidermis and hypodermis. The middle portion is the mesocarp, which may very in thickness from a set of a few remnent cells without starch with a thin, translucent appearance to several layers of cells containing starch granules, which gives a thick, chalky appearance. The innermmost layer of the pericarp is the endocarp consisting of the cross and tube cell layers, which are long and narrow with their long axis perpendicular to the long axis of the kernel (Rooney and Miller, 1982).

A cutin layer between the pericarp and endosperm is transformed into a seed coat (Sanders, 1955). It was also showed that the origin of the seed coat is traced from the integument. This subcoat is also known as the "testa" and its presence is controlled by the complementary genes B1 and B2 with the testa present when B1 and B2 genes are dominant (B1-B2-) (Rooney and Miller, 1982).

Rooney and Miller (1982) also pointed out that the testa thickness varies among sorghum genotypes and within individual kernels with the thickest part at the crown and the thinnest part area over the embryo. The testa color is controlled by the gene tp and it is brown for the Tp- genotypes and purple for tptp.

Freeman (1970) concluded that the nature of the sorghum grain endosperm consists of cells filled with starch and includes a single outside layer of cells called the aleurone layer which is a region or cells containing a dense protein matrix. It was also pointed out that endosperm cells which store starch are further divided into an outer horny or corneous region and an inner, floury or starch region. Hoseney et al. (1974) disclosed that hard or corneous endosperm is a result of strong adhesion between protein and starch so that, when hard endosperm is fractured many starch granules are broken rather than the starch-protein interface, while soft or floury endosperm is characterized by relatively large intergranular air spaces, where the starch granule is essentially round and covered with a thin sheet of protein. Embeded in this protein sheet there are large spherical protein bodies.

The embryo or germ is composed by two major parts: the embryonic axis and the scutellum (Rooney and Miller, 1982). The germ of some sorghum cultivars is more deeply embeded inside the endosperm and is extremely difficult to remove while some others protrude from the kernel.

Two other anatomical parts of the sorghum grain are the stylar area and the hilum. The stylar area is the point at which the style was attached during pollination. The hilum is the scar tissue resulting from detachment of the seed from the funiculus (Rooney and Miller, 1982).

II.2.2. Grain quality properties

a. Breaking strength - Kongseree and Juliano (1972) and Murty and House (1980) used a Kiya hardness tester (Kiya Seisakusho Ltd., Japan) to give the force required for individual grains to be crushed. However, Crosby (1982) pointed out that due to the number of grains required for a precise estimation, this technique even if useful is not a quick method to determine grain hardness.

b. Percent floaters - This is a convenient method to determine sorghum grain hardness (Hallgren and Murty 1983). Crosby (1982) described the use of a test solution of 1.327 s.g. (a mixture of tetrachloroethylene and odorless kerosene) which gave a good estimate of % floaters in a grain sample. The percent of floaters was highly correlated with hardness of the grain (Crosby, 1982).

Hallgren and Murty (1983) used a solution of sodium nitrate (1.31 s.g.) and reported the percent of floaters for 15 genotypes. They obtained a high correlation between percent floaters, required milling energy, flour particle size and other grain hardness parameters.

c. Water absorption - Stermer et al. (1977) reported the use of infrared spectroscopy as a rapid estimation of grain moisture. Abdelrahman and Farrel (1981) observed that the initial moisture content of the grain had some effect on the rate of water uptake in sorghum grain. However, after three hours of soaking the grain samples were not affected by the initial moisture.

Murty et al. (1981) used three samples of 100 grains each and soaked them for 5 hours in water to estimate the amount of water absorbed.

Percent of water absorption is correlated negatively with severity of grain molds (Rana et al., 1977) and roti quality (Murty et al., 1981).

d. Particle size index (PSI): It is a kernel hardness test based on the amount of flour that passes through a sieve or a nest of sieves. Corneous grains show a lower particle size index (Kirleis and Crosby, 1982). Estimates of PSI based on the percent of flour sample passed through one sieve were reported by Yamazaki and Danelson (1972) and Crosby (1982) and through a nest of sieves by Sullins et al. (1971) and Murty et al. (1981).

e. Gel consistency - Murty and House (1980) observed that gel spreading of the sorghum flour was negatively correlated with overall roti quality (r=-0.62). Murty et al. (1981) concluded that waxy endosperm produces runny gels while highly corneous grains showed thick gels.

Murty et al. (1982a) reviewed the usefulness of gel consistency tests in sorghum and assessed that this trait was correlated with kernel texture and flour particle size index. It was also observed that intermediate gel spreading values were associated with good roti texture while thick gels were associated with desirable ugali texture.

f. Rolling quality - This is one of the most reliable parameters to evaluate roti quality (Murty et al., 1981). Murty and Subramanian (1982) described a standard method to measure the rolling quality of sorghum <u>roti</u> dough.

Murty et al. (1982b) observed a great range of variation for rolling quality among white pericarp sorghums.

II.2.3. Utilization of sorghum for food

Several are the dishes prepared with sorghum flour or whole grain. An extensive list of recipes can be found in two pamphlets, viz. Sorghum Recipes by Home Economics Department, University of Nairobi (1975) and Sorghum and Millet - Food Production and Use by Vogel and Graham (1979).

A concise list was elaborated from Vogel and Graham (1979), Rooney and Murty (1982), Olantuji et al. (1982), Gebisa Ejeta (1982), Obilana (1982), Gebrekidan and Gebre Hiwot (1982), Subramanian and Jambunathan (1980), Guerrero (1979), Thakre (1981), Shanty and Neelakantan (1979).

1. Unleavened bread - Roti or chapati (India); rotti (Sri Lanka); waina (Nigeria), tortilla (Mexico); quitta (Ethiopia).

2. Leavened bread - Injera (Ethiopia); kisra (Sudan); dosai (India); thosai and hoppers (Sri Lanka) gahlet (Upper Volta); massa (Ghana and Nigeria); mugabi (Uganda).

3. Thick porridge - Ugali (Kenya, Tanzania and Uganda); to (Upper Volta and Mali); tuwo (Nigeria); bogobe (Botswana); lugma or aseda (Sudan); sankati and nuchu (India).

4. Thin porridge - Ugi (Nigeria and Ghana); eko (Nigeria); ambali and puttu (India); ugi (Kenya and Tanzania); edi and obshure (Uganda); nasha (Sudan).

5. Steamed products - Couscous (Mali and sub-Sahellian countries); noodles (China); burabrusko and acha (Nigeria); pitto (Sri Lanka).

6. Boiled products - Soru and bakri (India); daja-duka, dahuwa, ewa (Nigeria); kande (Tanzania); pearl dura (Sudan).

7. Alcoholic and non-alcoholic beverages Burukutu, yarebu, kuniu, pito (Nigeria); amarwa, busaa, warangi (Uganda); bogalwa (Botswana); Chimela, Chipumu (Zambia) embush, talla (Ethiopia); marisa, umbugug, abrey, huswa (Sudan).

8. Snack foods - Popped sorghum (India and Tanzania); puppet (Philippines); muruku, pakoda, vadai, hurda (India); adun (Nigeria).

The potential use of sorghum grain is significant for baked products, snacks, prepared breakfast foods and tortillas (Ronney, 1979).

Baking tests were carried out in different countries and the results suggest that composite flours with up to 10% of sorghum flour did not affect the bread quality (Semedo and Guerra, 1963; Desikachar, 1975; and Zhumabekova and Ostrovskaya, 1975). However, studies conducted in CFTRI, Mysore, India, brought out that the level of incorporation of sorghum flour could be increased further by adopting the following procedures: (i) increasing the quantity of water by 3% over that of farinograph water absorption; (ii) using 0.5% glyceril monostearate; (iii) adding 20 ppm of potassium bromate and (iv) adding 0.5% of sodium stearoyl lactylate (CPTRI, 1975).

II.2.4. Consumer acceptance

Farmers and their families are fully aware of the cooking qualities and flavor of the varieties available to them. Like gardners, farmers critically choose the varieties which they grow for food with regard to their yield per man-day of work, eating qualities, and storage losses (Morris, 1982).

Obviously, people will eat poor quality food under stress or hunger as pointed out by Doggett (1977), but they will only cultivate with enthusiasm grains which they want to eat themselves because they like them or because the market price is attractive.

Pushpamma and Chitemma Rao (1981) and Pushpamma and Vogel (1982) in more refined studies on varietal acceptance of sorghum assessed that success of any food grain or its products depends on acceptance by the consumers. They emphasized further the need for simple and practical methodology that enables the breeders to screen their high yielding selections with acceptable quality traits.

III. MATERIAL AND METHODS

The experiments involved evaluation of 20 parents (11 females and 9 restorers) and their 99 hybrids in the rainy (kharif) and post-rainy (rabi) seasons of 1982 at ICRISAT Center, Patancheru, A.P. India.

III.1. PARENTS

Eleven cytoplasmic-genetic male sterile lines and 9 restorers (Table 2) were chosen from a broad array of hybrid parental material available at ICRISAT. Among the parents, seven females and eight restorers were developed by the Sorghum Improvement Program of ICRISAT. Three female parents, namely, 2219A, 2077A, and 296A and the restorer CS3541 were developed by the All India Coordinated Sorghum Improvement Project (AICSIP). These are widely used in India for the production of the commercial hybrids CSH5, CSH6 and CSH9. The female parent 623A was developed at the Texas A & M University of USA, and is recognized as a tropically adapted line.

III.2. CROSSING PROGRAM

A line x tester crossing program was undertaken during the Rabi 1981 (Nov. 1981 - Feb. 1982) at the ICRISAT Center in irrigated nurseries.

In order to achieve good synchrony of the male and female parents, all the 20 parents were planted three times (at a 15 day interval) in 4 row plots of 4 m length.

Table 2. Pedigree or origin of parents used in the study

Parents		Pedigree/Origin	Height	Grain color
Females				
01	MA1	(2077 B x IS 9327) 9-1-6	Dwarf	Cream
02	MA2	(2077 B x IS 9327) 0-25	Medium	"
03	MA3	(2077 B x IS 9327) 9-3-9	"	"
04	MA4	(2077 B x IS 9327) 7-1-2-4-5	Dwarf	"
05	MA5	(IS 12645 x CS 3541) x IS 9327) 27-2-2-6-1	"	White
06	MA6	(IS 12645 x CS 3541) x IS 9327) 27-2-2-3-2	"	"
07	MA9	(Bulky x CS 3541) 25-1-1	Medium	Cream
08	2219A	AICSIP	Dwarf	"
09	2077A	AICSIP	Medium	Lt.yellow
10	623A	Texas A & M University	"	White
11	296A	AICSIP	"	Lt.yellow
Males				
01	MR 801	(SC-108-3 x CS 3541) 1-3-1	Medium	Cream
02	MR 861	(SC-108-3 x GPR 148) 12-5-3	"	"
03	MR 864	(SWARNA x CS 3687) 6-1-3	Dwarf	Lt.yellow
04	MR 803	(SC-108-3 x CS 3541) 30-3-3	Medium	Cream
05	MR 867	(SC-108-3 x E 35-1) 29-2-1	Tall	White
06	MR 824	(SC 108-3 x E 35-1) 25-1	Dwarf	"
07	MR 825	(SC-108-3 x CS 3541) 27-2-1	Medium	Cream
08	MR 849	(IS 12611 x SC-108-3) 1-1-3	"	White
09	CS 3541	AICSIP	"	Cream

The panicles of the restorers (males) were covered by paper bags before anthesis and the panicles of female lines were bagged before the stigmas were visible.

Hand pollinations were made onto the female panicles using bulk pollen from each of the male parent. For each cross combination, approximately 15 panicles were pollinated. The hybrid seeds of 99 crosses and self pollinated seeds of the 9 restorers and 11 maintainers of the female lines were obtained in sufficient quantities for planting the experiments in *kharif* and *rabi* seasons of 1982.

III.3. FIELD EXPERIMENTS

The experiments were repeated in the *kharif* season also known as monsoon or rainy season and usually begins in June and extends into September in the Hyderabad area and *rabi* season, known as post-rainy or winter season which is dry and cool with short days and lasts from October upto January (ICRISAT, 1981).

The parents and hybrids were randomized separately and planted using the randomized block design (RBD) but in adjacent trials in both the seasons as suggested by Arunachalam (1974).

The parents were evaluated along with the hybrids for comparative purposes although the line x tester study does not require the evaluation of parents in theory (Kempthorne, 1957).

There were three replications in each experiment. In all the four experiments the plot consisted of two rows of 4 m length separated by 75 cm. The space between plants within a row was about 12 cm (110,000 plants/ha) and was achieved by thining at one week after emergence.

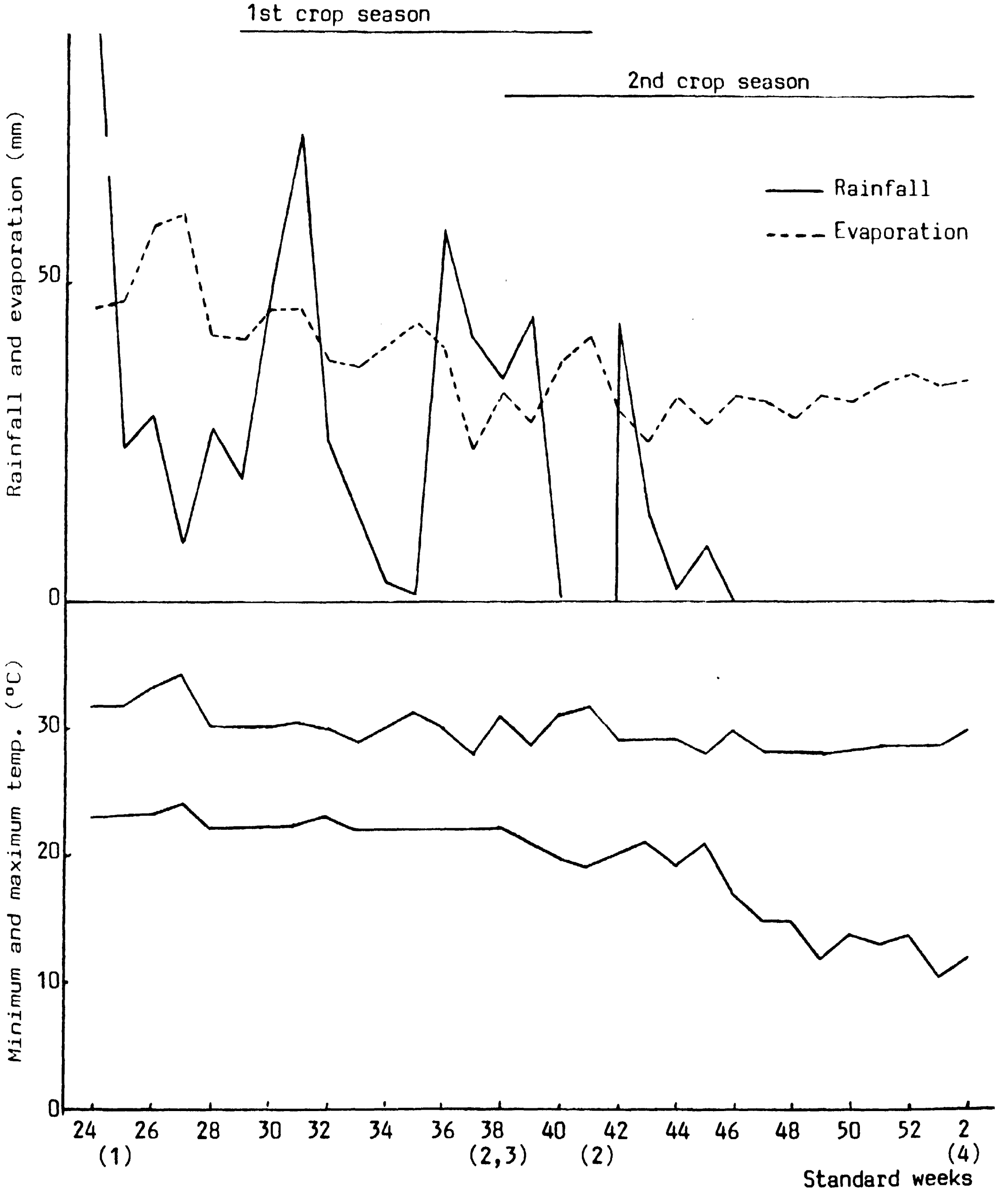
The *kharif* experiments were designated Lt-1 for the hybrids and Lt-2 for the parents, and the *rabi* trials designated as Lt-3 and Lt-4 for hybrids and parents, respectively.

The *kharif* and *rabi* experiments were conducted under rainfed conditions. The weather data is presented in Fig.1 and the amount of rainfall received during the *kharif* and *rabi* crop seasons was 456.7 mm and 150.9 mm respectively.

The fertilizers used provided N and P in the following ratio: 84 kg/ha of N and 84 kg/ha of P_2O_5 as basal dose and 46 kg/ha of N as topdress applied 30 days after emergence in both the seasons.

The *kharif* and *rabi* experiments were protected from attack by *Heliothis armigera* The *rabi* experiments received a basal application of Furadan (25 kg/ha) to help protection against shoot fly (*Atherigona* soccata) attack.

Fig. 1: Rainfall, evaporation, maximum and minimum temperature during the two crop seasons (Jun, 82 to Jan, 83)



1 - Sowing 1st season (kharif) - June 18, 82
2 - Harvest 1st season - Sept 20 to Oct 10, 82
3 - Sowing 2nd season (rabi) - Sept 20, 82
4 - Harvest 2nd season - Jan, 10, 83

III.4. CHARACTERS STUDIED

Observations were made on the following characters:

III.4.1. Plant characters:

1. Days to 50% flowering - Number of days from sowing upto 50% anthesis in the panicles of 50% plants in a plot (IBPGR, 1980).

The following characters were based on 5 randomly tagged plants at the flowering stage.

2. Plant height - Average length from ground to the top of the head in centimeters (IBPGR, 1980).

3. Panicle length - Average length in centimeters from the insertion of bottom to the top of the panicles (IBPGR, 1980).

4. Grain yield per panicle - Weight in grams of threshed, glumeless grains of 5 individual panicles ($\pm$ 12% moisture) taken with the help of an electronic balance (Mettler; P 5N).

5. Number of grains per panicle - Number of grains of 5 individual panicles were counted with the help of an electronic counter (Model 850-2, Sor.26, The Old Mill Company, Savage, MD, USA).

III.4.2. Grain characters

6. Thousand grain weight - Was obtained as follows:

$$1000 \text{ grain weight (g)} = \frac{\text{Grain yield/panicle (g)} \times 1000}{\text{No.of grains/panicle}}$$

7. Breaking strength - Kilograms of force required to crack a grain using a hardness tester (Kiya Seisakusho Ltd., Tokyo, Japan). Observations were taken on 5 grains per panicle in each of the 5 individual panicles (IBPGR, 1980).

8. Floaters percentage - Number of grains that floated in a sample of 100 grains in a 1.3 s.g. solution of $NaNO_3$ ($\pm$ 50% concentration). Data were taken on two random panicles per plot.

The following grain quality characters were studied on a small line x tester sample of 4 male steriles and 5 restorers (MA5, MA9, 2077A, 296A, MR861, MR864, MR824 , MR825 and CS3541).

9. Percentage of water absorption - Percent increase in the weight of a 100 grain sample after 5 hours soaking in distilled water. Data were recorded on two grain samples per plot from two individual panicles.

Thirty grams of grain from each five randomly selected heads were taken, bulked and ground in a carborundum stone mill (Domestic Mill Flour, Milcent D-2) at 1440 rpm and the following four characters were studied.

10. Particle size index: Percent of a 30 g flour sample that passed through a 75 μ sieve after sieving by hand for 10 minutes. Two samples were studied for each plot.

11. Rolling quality - Diameter in centimeters of a 'roti' dough made from 30 grams of flour and distilled water at room temperature after rolling it with a wooden rolling pin on a laminated board.

12. Gel spreading - Ten grams of flour was suspended in 70 ml of cold water and was added to 140 ml of boiling water with frequent stirring. The porridge was poured into a 20 x 52 mm petri dish (with a drop of oil smeared on the inner surface), and cooled in a refrigerator at 10^{o}C for 3 hours. Then the solidified porridge (gel) was put on a smooth glass sheet and the diameter of the gel was measured after 5 minutes in milimeters. Two observations were taken per plot.

III.5. STATISTICAL ANALYSIS

III.5.1. Analysis of the hybrids

The line x tester mating system was used to estimate the general and specific combining ability effects. Methods applied in this study followed Kempthorne (1957) and Arunachalam (1974).

The mathematical model to obtain estimates of general and specific combining ability are from (Beil, 1965) :

$$Y_{ijk} = \mu + g_i + g_j + s_{ij} + r_k + e_{ijk}$$

where: Y_{ijk} = mean of the k-th experimental unit of the progeny between i-th R (restorer) line and j-th A (female) line;

μ = general mean of the experiment;

g_i = effect of i-th R line;

g_j = effect of j-th A line;

s_{ij} = effect of the cross between i-th and j-th parent;

r_k = effect of k-th replication, and

e_{ijk} = random error associated with ijk-th experimental unit.

and: i = 1, 2, . . . 9

j = 1, 2, . . . 11

k = 1, 2, 3

The g_i and g_j terms are a measure of general combining ability of respective R and A lines while s_{ij} measures the deviation from the expected on the general or additive effect as pointed out by Sprague and Tatum (1942).

It was assumed for this study that the nine R lines and eleven A lines were a random sample of inbred lines of grain sorghum used at ICRISAT, then the estimates of the variance components were obtained from the expectation of the mean square.

The normal equations for the estimates of the general and specific combining ability are:

$$Y_{...} = 297\,\hat{\mu} + 33\sum_{i=1}^{9}\hat{g}_i + 27\sum_{j=1}^{11}\hat{g}_j + 3\sum_{i=1}^{9}\sum_{j=1}^{11}\hat{s}_{ij} + 99\sum_{k=1}^{3}\hat{r}_k$$

$$Y_{i..} = 33\,\hat{\mu} + 33\,\hat{g}_i + 3\sum_{j=1}^{11}\hat{g}_j + 3\sum_{i=1}^{9}\sum_{j=1}^{11}\hat{s}_{ij} + 11\sum_{k=1}^{3}\hat{r}_k$$

$$Y_{.j.} = 27\,\hat{\mu} + 3\sum_{i=1}^{9}\hat{g}_i + 27\,\hat{g}_j + 3\sum_{i=1}^{9}\sum_{j=1}^{11}\hat{s}_{ij} + 9\sum_{k=1}^{3}\hat{r}_k$$

$$Y_{ij.} = 3\,\mu + 3g_i + 3\hat{g}_i + 3\hat{s}_{ij} + \sum_{k=1}^{3}r_k$$

$$Y_{..k} = 99\,\hat{\mu} + 11\sum_{i=1}^{9}\hat{g}_j + 9\sum_{j=1}^{11}\hat{g}_j + \sum_{i=1}^{9}\sum_{j=1}^{11}s_{ij} + 99\hat{r}_k.$$

The following assumption is necessary for the normal equations to be applied:

$$\sum_{i=1}^{9}g_i = \sum_{j=1}^{11}g_j = \sum_{i=1}^{9}\sum_{j=1}^{11}s_{ij} = \sum_{k=1}^{3}r_k = 0.$$

The following solutions are then obtained:

$$\mu \qquad \frac{Y}{297}$$

$$\hat{g}_i = \frac{Y_{i..}}{33} - \hat{\mu}$$

$$\hat{g}_j = \frac{Y_{.j.}}{27} - \hat{\mu}$$

$$s_{ij} = \frac{Y_{ij.}}{3} - \hat{g}_i - \hat{g}_j + \hat{\mu}$$

$$r_k = \frac{Y_{..k}}{99} - \hat{\mu}$$

The sums of squares are obtained by multiplying the estimate for each parameters by the right-hand sides of the normal equations as discussed by Kempthorne (1952). They are:

$$M = \frac{Y^2_{...}}{297}$$

$$T = \Sigma Y^2_{ijk} - M$$

$$G_i = \frac{\Sigma Y^2_{i..}}{33} - M$$

$$G_j = \frac{\Sigma Y^2_{.j.}}{27} - M$$

$$S_{ij} = \frac{\Sigma Y^2_{ij.}}{3} - M - G_i - G_j$$

$$R = \frac{\Sigma Y^2_{..k}}{99} - M$$

where T = is the total sums of squares,

M = is the corrector factor,

G_i = the sums of squares for general combining ability effects of the R lines,

G_j = the sums of squares for general combining ability effects of the A lines,

S_{ij} = the sums of squares for specific combining ability effects

and R = the sums of squares for replicates.

The expectation of mean squares are obtained by finding the expected vàlues of the sums of squares on the original mathematical model and dividing by the appropriate degrees of freedom (Beil, 1965). So that they are:

$$E(G_i) = \Sigma(\frac{Y^2_{i..}}{33} - M) = (8) \quad (\sigma^2 + 2\sigma^2_s + 33\sigma^2_{g_i})$$

$$E(G_j) = \Sigma(\frac{Y^2_{.j.}}{27} - M) = (10) \quad (\sigma^2 + 2\sigma^2_s + 27\sigma^2_{g_j})$$

$$E(S_{ij}) = \Sigma(Y^2_{ij.} - M - G_i - G_j) = (10)(8) \quad (\sigma^2 + 2\sigma^2_s)$$

To make tests of hypothesis we must make the following assumptions:

μ is a constant,

g_i's are N.I.D. $(0;\sigma^2_{g_i})$, which is to say they are normally independently distributed with a mean of zero and have a constant variance designated $\sigma^2_{g_i}$,

g_j's are N.I.D. $(0;\sigma^2_{g_j})$,

s_{ij}'s are N.I.D. $(0;\sigma^2_{s_{ij}})$,

r_k's are constants,

e_{ijk}'s are N.I.D. $(0;\sigma^2)$

The development and descriptive information necessary for constructing an analysis of variance can be shown in Table 3 based on Kempthorne (1957) and Hallauer and Miranda (1981).

Table 3. Analysis of variance for data from hybrids

Source of variation	Degrees of freedom	S.S.	M.S.	Expectation of the mean squares: Components of variances	Covariances of relatives
Replicates	r-1	R			
g_i's	m-1	G_i	M_1	$\sigma^2 + r\sigma_s^2 + rf\sigma_{g_i}^2$	$\sigma^2 + r(Cov(FS)^a - 2\ Cov(HS)^b) + rfCov(HS)$
g_j's	f-1	G_j	M_2	$\sigma^2 + r\sigma_s^2 + rm\sigma_{g_j}^2$	$\sigma^2 + r(Cov(FS) - 2Cov(HS)) + rm\ Cov(HS)$
s_{ij}'s	(m-1(f-1)	S_{ij}	M_3	$\sigma^2 + r\sigma_s^2$	$\sigma^2 + r(Cov\ (FS) - 2Cov\ (HS))$
Error	(mf-1)(r-1)	E	M_4	σ^2	σ^2
Total	rmf-1	T			

where: r = number of replicates

m = number of R lines

f = number of A lines

[a] Cov (FS) = Covariance between full-sibs.

[b] Cov (HS) = Covariance between half-sibs.

Assuming no epistasis, the following equations may be written to describe covariance relationship and variance components as follows:

1. based on the components of variance:

$$\text{Cov (HS)} = (M1 - M3) + (M2 - M3) \quad /r(f+m) \quad = \sigma^2 GCA$$

$$\text{Cov (FS)} = (M1 - M4) + (M2 - M4) + M3 - M4) \quad /3r \quad +$$

$$6r \text{ Cov (HS)} - r(f+m) \text{ Cov (HS)} \quad /3r$$

$$\sigma^2 SCA = \frac{M3 - M4}{\text{--}}$$

and

2. based on genetic effects :

$$\text{Cov (HS)} = \left(\frac{1+F}{4}\right) \sigma_A^{2\,(1)} = \sigma^2 GCA$$

$$\text{Cov (FS)} = \left(\frac{1+F}{2}\right) \sigma_A^2 + \left(\frac{1+F}{2}\right)^2 \sigma_D^{2\,(2)}$$

Thus

$$\sigma_A^2 = \frac{4 \text{ Cov (HS)}}{1+F}$$

$$\sigma_D^2 = \frac{4 \text{ Cov (FS)} - 2 \text{ Cov (HS)}}{(1+F)}$$

$$\sigma_G^{2\,(3)} = \sigma_A^2 + \sigma_D^2$$

Since the A and R parental lines were assumed to be homozygous, the inbreeding coefficient (F) is equal to one.

(1) $\sigma^2 A$ = additive genetic variance

(2) $\sigma^2 D$ = dominance variance

(3) $\sigma^2 G$ = total genotypic variance

The standard errors for combining ability effects were calculated as follows (Singh and Chaudhary, 1979).

S.E. (gca for tester) = $(M4 / rf)^{1/2}$

S.E. (gca for line) = $(M4 / rm)^{1/2}$

S.E. (sca for all possible combinations) = $(2\ M4\ (mf - m-f)/mfr)^{1/2}$

where m = 1,2 9

f = 1,2 11

r = 1,2,3

III.5.2. Correlations between parents means and GCA effects

The correlation coefficients (r) between *per se* performance of the parents and their gca effects were calculated from the following formula (Bhola Nath, 1983):

$$\frac{\Sigma x'y' - \frac{(\Sigma x')(\Sigma y')}{n}}{\sqrt{\Sigma x'^2 - \frac{(\Sigma x')^2}{n} \quad \Sigma y'^2 - \frac{(\Sigma y')^2}{n}}}$$

where

x' = mean values

y' = the combining ability effects.

n = number of restorers or male sterile lines involved in the analysis.

III.5.3. RBD analysis of the parents

The experiments with the inbreds 9 R lines and 11 A lines were analysed through a two way classification ANOVA (RBD) using the following mathematical model:

$$Y_{ijk} = \mu + P_i + r_j + e_{ij}$$

where p = 1,2 ..., 20

r = 1,2,3

and μ = is the general mean allover treatments and replications,

p_i = the effect of i-th inbred,

r_j = effect of j-th replication and

e_{ij} = the error applied to each experimental unit in i-th treatment and j-th replication (Ostle and Mensing, 1963).

Thus, the ANOVA table for the inbred analysis was developed as follows (Table 4):

Table 4 . Analysis of variance of the parent experiments.

Source of variation	Degrees of freedom	Mean square	Expection of mean square
Replications	r-1	MR	$\sigma^2 + p\ \sigma^2 k$
Treatments	p-1	MT	$\sigma^2 + r\ \sigma^2 p$
Exp. error	(n-1)(p-1)	ME	σ^2

III.5.4. Heterosis:

Heterosis was calculated over the superior parent as suggested by Mather and Jinks (1971) using the formula:

$$H = \left[(\overline{F1} - \overline{P1}) / \overline{P1}\right] x\ 100$$

where H is the amount of heterosis in percentage

$\overline{F1}$ is the performance of a particular progeny over replications and

$\overline{P1}$ is the performance of the superior inbred involved in the cross over replications.

The test of significance for heterosis was done using the t test as follows:

$$t_{(h+l)} = (\overline{F1} - \overline{P1})/SE$$

where h and l are the degrees of freedom for the error in the ANOVA of hybrids and inbreds respectively and SE is the pooled standard error for the hybrid and parent experiments calculated as follows (Arunachalam, 1983 personal communication):

$$S.E. = ((M4 + ME)/r)^{\frac{1}{2}}$$

where M4 = is the error mean square for hybrids experiment,

ME = the error mean square for the parents experiment and

r = is the number of replications which are equal for both experiments.

IV. EXPERIMENTAL RESULTS

Experimental results obtained in the rainy (Kharif) and postrainy (Rabi) seasons of the parents and hybrids for the various agronomic and quality characters are presented in the following order: (1) Analysis of variance; (2) Average performance of hybrids and parents (3) general and specific combining ability and components of genetic variance.

IV.1. ANALYSIS OF VARIANCE

a. Hybrids: The analysis of variance of the hybrids for the 12 characters studied during the Kharif and Rabi seasons of 1982 are shown in Tables 5, 6 and 7.

The components of variance for hybrids, testers, lines and lines x testers were all highly significant for most of the characters studied. These results showed that statistically significant genetic variation was present among the hybrids and that general as well specific effects were involved in the performance of hybrids. The coefficient of variation of the experiments ranged from 1 to 24% for the various characters analysed and showed that experimental conditions were satisfactory.

In general, variances due to lines x testers were several times smaller than variances due to lines or testers. They were statistically non-significant for percentage of water absorption in

Table 5 *Mean squares of days to 50% flowering, plant height, panicle length and grain yield/panicle in hybrid experiments in Kharif and Rabi.*

Source	d.f.	Days to 50% flowering		Plant Height		Panicle Length		Grain Yield per panicle	
		Kharif	Rabi	Kharif	Rabi	Kharif	Rabi	Kharif	Rabi
Replications	2	1.52 NS	8.25**	122.56*	116.26NS	4.86*	3.81NS	224.19 NS	1829.61**
Hybrids	98	46.32**	2.39**	2800.96**	1996.83**	26.95**	17.85**	467.84**	613.43**
Testers(gi)	8	330.92**	3.03**	22938.80**	14686.20**	106.99**	78.20**	3822.86**	4573.26**
Lines (gj)	10	169.13**	12.35**	7723.14**	6515.81**	146.15**	80.66**	650.34**	1234.53**
T x L (sij)	80	2.51**	1.08**	234.40**	163.02**	4.05**	3.97**	109.53**	139.81**
Error	196	0.68	0.75	34.60	84.36	1.05	1.37	76.36	57.12
	S.E.	0.82	0.87	5.88	9.18	1.03	1.17	8.73	7.56
	C.V. %	1	2	3	5	3	4	15	14
	S.E(gi)	0.14	0.15	1.02	1.60	0.18	0.20	1.52	1.31
	S.E(gj)	0.16	0.17	1.13	1.77	0.20	0.23	1.68	1.45
	S.E(sij)	0.48	0.50	3.40	5.30	0.59	0.68	5.04	4.36

*significant (p=0.05) **significant (p=0.01)

Table. 6 Mean squares of number of grains per panicle, 1000 grain weight, breaking strength and floaters percentage in hybrid experiments in Kharif and Rabi.

Source	d.f.	No. of grains per panicle		1000 grain weight		Breaking Strength		Floaters percentage	
		Kharif	Rabi	Kharif	Rabi	Kharif	Rabi	Kharif	Rabi
Replications	2	1618000**	1270000**	14.13 NS	77.18**	8.10*	0.31 NS	1.11 NS	5.89**
Hybrids	98	414010**	405637**	36.40**	44.76**	3.95**	4.52**	8.25**	6.67**
Testers (gi)	8	1884000**	2509000**	263.56**	359.78**	18.95**	26.30**	20.42**	16.82**
Lines (gj)	10	968322**	1026000**	43.65**	65.35**	11.95*	17.06**	47.51**	36.47**
T x L (sij)	80	197730**	117672**	12.77**	10.68**	1.45**	0.78**	2.84**	1.93**
Error	196	120330	79189	7.43	4.72	0.60	0.26	0.88	1.00
	S.E.	346.89	281.41	2.73	2.17	0.77	0.51	0.94	1.00
	C.V. %	12	12	13	10	14	7	24	21
	S.E.(gi)	60.38	48.98	0.47	0.38	0.13	0.09	0.16	0.17
	S.E.(gj)	66.76	54.16	0.52	0.42	0.15	0.10	0.18	0.19
	S.E(sij)	200.27	162.47	1.57	1.25	0.45	0.29	0.54	0.58

*significant (p=0.05) **significant (p=0.01)

Table 7 Mean squares for grain quality characters studied in restricted set of hybrids during Kharif and Rabi

Source	d.f.	Water Absorption		Particle size index		Rolling Quality		Gel Spreading	
		Kharif	Rabi	Kharif	Rabi	Kharif	Rabi	Kharif	Rabi
Replications	2	2.67 NS	2.82NS	12.34NS	113.58*	4.99*	0.54NS	8.90 NS	7.11 NS
Hybrids	19	17.77**	27.96**	75.02**	35.57NS	3.47**	1.88NS	17.22**	9.51**
Testers (gi)	4	57.33**	102.65**	204.78**	55.78NS	2.98**	4.81**	37.82**	19.90**
Lines (gj)	3	12.07NS	19.38**	110.78**	78.38**	6.95**	1.69NS	30.73**	18.68**
T x L (sij)	12	6.01NS	5.21NS	22.82**	18.13NS	2.77**	0.95NS	6.98*	3.76NS
Error	38	4.71	3.90	5.90	24.41	0.77	0.88	3.43	3.50
	S.E.	2.17	1.97	2.43	4.94	0.88	0.94	1.86	1.87
	C.V.%	7	7	6	12	4	4	3	3
	S.E.(gi)	0.63	0.57	0.70	1.43	0.25	0.27	0.53	0.54
	S.E.(gj)	0.56	0.51	0.63	1.27	0.23	0.24	0.48	0.48
	S.E.(sij)	1.25	1.14	1.40	2.85	0.50	0.54	1.07	1.08

*significant (p=0.05) **significant (p=0.01)

the *Kharif* as well as *Rabi* seasons while for the characters particle size index, rolling quality and gel spreading they were non-significant in *Rabi* season.

The variances due to testers or the male parents were predominantly larger than the variation due to the lines or the female parents for the characters days to 50% flowering, plant height, grain yield/ panicle, number of grains/panicle, 1000 grain weight, breaking strength and percentage of water absorption.

The magnitude of variation due to the female effects was moderately high for the characters panicle length, particle size index, rolling quality and gel spreading.

Variance components were generally similar in the *Kharif* and *Rabi* seasons for all the characters except particle size index and rolling quality.

Finally, significant effects due to replications were observed for a few characters, particularly in the *Rabi* season.

The predominance of variances due to the male and female parents and low magnitude of variances due to male x female effects indicate the importance of general combining ability for most of the characters.

b. *Parents:* The analysis of variance for the observations made on the parents in experiments LT-2 and LT-4 of the *Kharif* and *Rabi* seasons respectively is presented in Tables 8, 9 and 10.

Variances due to parents were highly significant for all the characters studied and the average performance of the male and female parents was significantly different.

A critical examination of the genotypic variation between the parents showed that the variation among male parents was generally larger than the variation among the female parents. However, the female parents showed relatively more variation than the males for panicle length. Variation among the female parents for percent water absorption and rolling quality was statistically non-significant. The same was true for particle size index and gel spreading in the *Rabi* season.

Further analysis of the female parents indicated that the recently developed female parents and the commercial parents differed in their mean performance for all the characters. However, variation among the recently bred male sterile lines was insignificant in the *Kharif* season for grain yield, number of grains/panicle and 1000 grains weight.

IV.2. AVERAGE PERFORMANCE OF HYBRIDS AND PARENTS

The average performance of parents, hybrids and overall heterosis in the *Kharif* and *Rabi* seasons are presented in Table 11.

Table 8 Mean squares of days to flowering, plant height, panicle length and grain yield per panicle of parent experiments in Kharif and Rabi

Source	d.f.	Days to 50% flowering		Plant Height		Panicle Length		Grain Yield per panicle	
		Kharif	Rabi	Kharif	Rabi	Kharif	Rabi	Kharif	Rabi
Replications	2	0.80 NS	26.62**	66.35*	90.42*	2.87NS	4.02NS	119.92NS	73.58NS
Inbreds	19	73.88**	40.93**	1689.06**	1486.38**	36.16**	17.40**	488.02**	921.60**
Testers	8	60.08**	19.75**	1225.70**	1146.06**	16.08**	11.01**	316.77**	452.87**
Lines	10	41.85**	60.03**	553.88**	514.70**	43.09**	18.15**	189.12**	440.49**
New	6	17.49**	24.04**	259.52**	161.11**	20.94**	12.74**	31.08NS	260.51**
Old	3	95.64**	102.56**	1767.22**	1138.89**	16.56**	11.00**	434.95**	811.57**
New vs Old	1	56.68**	258.83**	872.71**	1080.31**	319.96**	104.70**	1453.83**	570.91**
T vs L	1	504.44**	19.35**	16747.59**	13925.76**	127.42**	61.01**	4846.93**	9472.53**
Error	38	0.96	3.48	13.02	19.80	1.73	1.56	44.13	35.45
	S.E	0.98	1.86	3.61	4.45	1.31	1.25	6.64	5.95
	C.V. %	2	3	2	3	5	5	13	17

*significant (P=0.05) **significant (P=0.01)

New - male sterile lines developed by ICRISAT Sorghum Improvement Program

Old - male sterile lines being used by AICSIP and Texas A & M University

Table 9 Mean squares of number of grains per panicle, 1000 grain weight, breaking strength and floaters percentage of parent experiments in Kharif & Rabi

Source	d.f.	No. of grains per panicle		1000 grains weight		Breaking strength		Floaters percentage	
		Kharif	Rabi	Kharif	Rabi	Kharif	Rabi	Kharif	Rabi
Replications	2	331396**	168913*	0.04 NS	1.53 NS	0.11 NS	1.29 NS	0.80 NS	0.60 NS
Inbreds	19	568869**	653597**	82.90**	176.80**	9.24**	23.25**	11.54**	14.11**
Testers	8	846409**	677759**	127.94**	128.31**	8.04**	11.78**	13.29**	4.68**
Lines	10	298201**	531751**	7.87**	48.47**	1.04**	5.29**	7.28**	8.99**
New	6	95993NS	539522**	4.57NS	27.93**	0.70**	2.84**	3.48*	2.05*
Old	3	707531**	597093**	16.02**	91.11**	1.43**	10.44**	10.69**	16.68**
New vs Old	1	1990173**	1603384**	63.22**	77.74**	5.69**	11.35**	16.99**	34.48**
T vs L	1	105527**	1678758**	472.90**	1848.07**	100.82**	294.58**	40.26**	175.19**
Error	38	54926	50519	2.14	3.78	0.16	0.42	0.85	0.62
	S.E.	234.40	224.80	1.46	1.94	0.40	0.65	0.92	0.79
	C.V. %	10	12	6	11	7	11	14	11

*significant (p=0.05) **significant (p=0.01)

New - male sterile lines developed by ICRISAT Sorghum Improvement Program

Old - male sterile lines being used by AICSIP and Texas A & M University

Table 10 Mean squares for grain quality characters studied in the restricted set of parents during Kharif and Rabi

Source	d.f.	Water Absorption		Particle size index		Rolling quality		Gel spreading	
		Kharif	Rabi	Kharif	Rabi	Kharif	Rabi	Kharif	Rabi
Replications	2	1.38 NS	0.25 NS	6.85 NS	16.89 NS	1.92 NS	0.23 NS	24.15 NS	8.04 NS
Inbreds	8	27.65**	154.79**	547.76**	520.06**	16.95**	27.60**	112.65**	93.48**
Testers	4	51.30**	292.66**	622.64**	477.34**	16.01**	40.19**	131.75**	148.50**
Lines	3	3.97 NS	1.48 NS	90.51**	9.97 NS	1.52 NS	0.73 NS	78.91**	9.56 NS
T x L	1	4.07 NS	63.24*	1619.97**	2221.23**	12.26**	57.89**	137.51**	31.79**
Error	16	2.50	9.89	8.84	9.24	1.35	1.14	10.75	3.91
	S.E.	1.58	3.14	2.97	3.04	1.16	1.17	3.28	1.98
	C.V. %	5	10	5	7	6	5	5	3

*significant (p=0.05) **significant (p=0.01)

Table 11 Average performance of parents and hybrids and heterosis over mid and superior parent in Kharif and Rabi experiments

Character	Parents						Hybrids		Overall heterosis on mid parent		Heterosis based on superior parent			
	Male sterile lines		Restorers		Overall mean						Range %		Overall %	
	K	R	K	R	K	R	K	R	K	R	Kharif	Rabi	Kharif	Rabi
1:														
Days to 50% flowering	64	65	65	57	62	57	59	54	- 4.8	5.3	- 9.0/ 17.7	-13.8/ 4.3	- 0.9	- 1.5
Plant height (cm)	131	119	164	149	146	132	202	183	38.4	38.6	9.2/126.6	5.3/114.3	55.8	56.6
Panicle length (cm)	27	28	25	26	26	27	30	30	15.4	11.1	-12.1/ 32.5	- 8.8/ 23.9	8.4	7.6
Grain yeild/panicle (g)	42.4	22.6	60.4	47.8	50.5	33.9	57.5	55.7	13.9	64.3	-43.7/108.8	-30.5/102.3	- 3.0	17.4
No. grains/panicle	2170	1721	2437	2057	2291	1872	2812	2427	22.7	29.6	-40.7/ 66.0	-21.9/ 66.6	12.7	14.1
1000 grains weight (g)	20.01	12.58	25.65	23.73	22.55	17.59	20.52	22.81	- 9.0	29.7	-46.4/ 39.4	-40.0/ 65.5	-19.0	- 0.6
Breaking strength (kg)	4.8	4.0	7.4	8.5	6.0	6.0	5.5	6.8	- 8.3	13.3	-51.1/ 28.9	-42.4/ 40.1	-23.7	-17.3
Floaters percentage	54	78	35	29	45	56	19	25	-57.7	-55.3	-89.7/238.9	-95.3/194.6	-24.7	- 6.7
2:														
% of water absorption	31.3	36.1	28.5	27.8	29.7	31.5	29.6	28.0	- 0.3	-11.1	- 8.4/ 15.1	-13.7/ 24.1	4.9	2.1
Particle size index	57.4	56.1	43.0	35.6	49.6	44.7	39.0	40.3	-21.4	- 9.8	-22.3/ 10.9	- 2.5/ 35.9	- 5.5	13.6
Rolling quality (cm)	18.0	20.3	20.9	24.2	19.6	22.4	20.6	23.9	5.1	6.7	-12.4/ 13.0	- 5.3/ 2.0	- 1.7	- 0.9
Gel spreading (mm)	69.0	68.0	63.3	61.5	65.8	64.4	61.3	62.8	- 6.8	- 3.4	-21.0/- 1.0	-16.1/ 3.4	-12.1	- 8.0

1 - Characters studied based on 20 parents and their 99 hybrids. 2 - Characters studied based on 9 parents and their 20 hybrids.

An examination of the overall means for parents and hybrids indicated that the hybrids generally flowered earlier, grew taller, had longer panicles, more number of grains per panicle and gave higher grain yield per panicle.

Thousand grain weight of majority of the hybrids was slightly lower than that of the parents while the grain breaking strength and percent water obsorption were about the same in parents as well as hybrids. Average percent floaters of hybrids was significant. Flour particle size of the hybrids was slightly larger compared to that of the parents. The rolling quality of the dough from hybrids was better and the gels prepared from flour of the hybrids were thicker.

The magnitude of heterosis was higher for plant height, number of grains and grain yield per panicle.

The best parents on the basis of hybrid performance and the GCA effects for each character studied are shown in Table 12.

a. Days to 50% flowering: The average number of days to 50% flowering of parents and hybrids are presented in Appendix A.1.

The range of average days to 50% flowering during the *Kharif* of the female parents was from 55 to 68 days compared to their array means from 54 to 62. The female parent 2219A produced earlier flowering hybrids while MA9 and 2077A produced later flowering hybrids. Similarly among the male parents the range of days to 50% flowering was

Table 12 — Selected parents based on their higher GCA Effects and superior performance of their hybrids in Kharif and Rabi experiments.

Character	Females				Males			
	GCA Effects		Hybrids performance		GCA Effects		Hybrids performance	
	Kharif	Rabi	Kharif	Rabi	Kharif	Rabi	Kharif	Rabi
(1)								
Days to 50% flowering	2219A,MA2,MA1	2219A	2219A,MA2	MA2,MA5,MA6	MR824,MR801	CS3541,MR861	MR801,MR824	All
Plant height	MA9,2219A	MA9,MA6	MA9,2219A	MA9,2219A	CS3541,MR801,MR824	CS3541,MR825	CS3541	CS3541
Panicle Length	2077A,623A	2077A	2077A,623A	2077A	MR825,MR801,MR864	MR864,MR825	MR825,MR801	MR825
Grain yield/ panicle	296A,623A,MA4	623A,MA3	623A,296A,MA4	623A,MA3,MA1	MR849,MR867	MR867,MR864	MR849,MR867	MR867,MR864,MR849
No. grains/ panicle	623A,296A,MA6	2077A,MA3,623A	623A,296A,MA6	2077A,MA3,623A	MR849,MR867	MR864,MR867	MR849,MR867	MR864,MR867,MR849
1000 grain weight	MA4	623A	MA4,296A,MA9	623A,MA3,296A	MR861,MR867	MR867,MR861	MR861,MR867,MR849	MR867,MR861,MR864
Breaking strength	623A	623A	623A,MA4,MA9	623A,2219A,MA1	MR867	MR867	MR867,MR824	MR867,MR824
% Floaters	2219A,MA2,MA1	2219A,MA1	MA2,2219A,MA1	2219A,MA1	MR867,MR824	MR867	MR824,MR867	MR867,MR824
(2)								
% Water absorption	2077A	296A	296A	2077A	MR861	MR861	MR861	MR861
Particle size Index	MA9	MA9	MA9	MA9	MR824,CS3541	MR824,CS3541	MR824,CS3541	MR824,CS3541
Rolling quality	MA5	MA5	MA9	MA5	MR861	MR864	MR861	MR864
Gel spreading	MA5,MA9	MA5,MA9	MA5	MA9	MR824	MR824	MR824	MR824

(1) Characters studied based on 99 hybrids. (2) Characters studied based on 20 hybrids.

from 63 to 77 days while the array means ranged from 57 to 67 days.

The results presented in Appendix B.1. Show that the overall heterosis of the 99 hybrids compared to the earlier parent was only -0.9% in the Kharif. Considering the female parents, the heterosis for earliness was expressed significantly in the Kharif by hybrids of 2077A, 296A, MA3 and MA9.

In the Rabi season means of days to 50% flowering of the parents as well as hybrids were low and the range was also narrowed.

Hybrids of MA3, MA4, MA9, 2219A and 296A exhibited significant heterosis for earliness. Among restorers a strikingly positive heterosis (for lateness) was observed in hybrids of MR849 in the Kharif season, however its hybrids showed significant negative heterosis in the Rabi season.

Hybrids of MR801, MR824 and CS3541 showed heterosis for earliness in the Kharif as well as Rabi seasons.

The frequency of crosses showing heterosis for earliness was much higher in the Kharif than in the Rabi, probably because the range for days to 50% flowering was narrow in the Rabi due to short day photoperiod effect. In the rabi season only four cross combinations viz; MA3 x MR849, MA4 x MR849, 2077A x MR849 and 296A x MR849 exhibited significant heterosis at 1% level of probability.

b. Plant height: Average plant height of parents and hybrids is presented in Appendix A.2. Almost all of the hybrids surpassed their parents in plant height. Hybrid array means were always higher than the parental means.

The height of the male parents ranged from 135 to 191 cm in the Kharif and 125 to 175 cm in the Rabi. MR867 and MR849 produced the tallest hybrids. Among the female parents MA9 and 2219A gave rise to the shortest hybrids.

In general the average plant height of the parents as well as hybrids were lower in the Rabi than in Kharif.

Estimates of heterosis for plant height were based on the shorter parent. (Appendix B.2)

The average heterosis was 55% and 56% in Kharif and Rabi seasons respectively. More than 25% of the crosses exhibited positive heterosis in the Kharif as well as in the Rabi seasons.

Comparing the average heterosis of the restorers, the range varied from 33% for CS3541 upto 100% for MR867 during the Kharif. Among the female parents, MA9 showed the lowest expression of heterosis, 23% in Kharif and 18% in the Rabi.

During the <u>Rabi</u> the hybrids of male MR 867 showed maximum heterosis for plant height (100%). Crosses with MR801 and MR825 exhibited significantly less heterosis and hence are more desirable if shorter hybrids are required.

c. <u>Panicle length</u>: Average panicle length of the 20 parents and 99 hybrids are presented in Appendix A.3.

The hybrids generally had longer panicles than their parents in both seasons, and the hybrid array means were significantly higher than parental means.

Hybrids of females MA4, 2077A and 296A showed longer panicles. Restorer parents MR864, MR803 and MR825 showed higher array means than those of the others.

The overall heterosis over the better parent for panicle length was 8.4% and 7.6% in the <u>Kharif</u> and <u>Rabi</u> seasons respectively (Appendix B.3.)

Hybrids with the male parents MR825, MR801, and MR803 exhibited significantly higher magnitude of heterosis. Among the 99 hybrids the cross MA1 x MR803 showed the maximum heterotic effect (32%) during <u>Kharif</u>, while 623A x MR825 showed the highest heterosis (24%) in the <u>Rabi</u> season. All crosses with MR825 exhibited a significant amount of heterosis (p=0.01).

Among the female parents, hybrids of MA1, MA2, MA3, 2219A and 296A expressed heterosis for increased panicle length. It is interesting to note that the crosses with 296A were heterotic mostly in the Rabi season.

d. Grain yield per panicle: The average performance of the parents and hybrids are presented in Appendix A.4. During Kharif grain yield/panicle of the male parents ranged from 40.7 to 77.9 g while those of the females ranged from 34.0 to 59.9 g.

On the average, hybrids of MR867 and MR849 showed higher yields. Among the female parents, hybrids of 623A and 296A were the highest yielders in the Kharif while hybrids of 623A, MA1 and MA3 were superior in the Rabi season. Crosses of MA4, MA5 and MA6 performed better in Kharif season, while crosses of MA1 and MA3 yielded better in the Rabi season.

The grain yield performance of the parents, particularly the females was very low in the Rabi season when compared to those of Kharif season.

Although heterosis for increased grain yield/panicle over mid-parent was pronounced in the Kharif as well as Rabi season (Table 11), average heterosis over the better parent was significant only in the Rabi season. During the Kharif significant positive and negative heterotic effects led to non-significant overall heterosis.

Array means of male parents (Appendix B.4) showed that hybrids with MR849 exhibited large amounts of positive heterosis in the *Kharif* season (70%). The combination MA6 x MR849 showed the highest amount of heterosis (108%).

Average heterosis over better parent in the *Rabi* season was around 17% and significant heterosis for increased yields were observed in crosses involving almost all the parents.

Crosses made using female parents MA1, MA2, MA3, 2077A, 296A and 623A showed relatively higher heterosis. Among the male parents, MR801, MR864 and CS3541 produced heterotic hybrids during *Rabi*.

The hybrids which showed the highest heterosis were MA1 x MR801 (102%) and 296A x CS3541 (101%). Interestingly MR849 hybrids were markedly less heterotic in the *Rabi* season.

e. *Number of grains per panicle*: Average number of grains per panicle exhibited by the parents and hybrids are presented in Appendix A.5. The male parents had significantly lower number of grains/panicle in the *Rabi* with the exception of MR849 which performed better in *Rabi*. Among the female parents MA1, MA3, MA9 and 623A performed equally better in *Kharif* and *Rabi* seasons. The overall hybrid mean for *Kharif* was higher than that of Rabi.

The hybrids of MR867, MR849 among the males and 623A, 296A, MA6 and MA5 among the females had higher number of grains per panicle in the Kharif while hybrids of male parents MR864, MR867, MR825 and MR849 and hybrids of female parents 623A, MA1, MA2 and MA3 had higher number of grains per panicle in Rabi season.

Average heterosis over superior parent for grain number per panicle was 12% in Kharif and 14% during Rabi season (Appendix B.5).

In the Kharif, the hybrids of the female parents 623A, MA1, MA2, MA5, MA6 and 2077A exhibited more heterosis than others. Considering the restorers, MR849 hybrids showed the highest heterosis (42%). MR803 and MR867 were other male parents which produced superior hybrids. In the Kharif between MA1 x MR849 showed maximum heterosis (66%) followed by that of MA1 x MR803 (65%) .

During the Rabi, 2077A crosses showed higher average heterosis (33%) followed by MA3, MA1 and 296A. Among male parents, MR867, MR861 MR864 and CS3541 produced hybrids with the highest grain number. Surprisingly MR849, the best heterotic restorer during the Kharif was inferior in Rabi and did not show positive heterosis in any cross combinations.

f. Thousand grain weight: Average 1000 grain weight of hybrids and their corresponding parents is presented in Appendix A.6.

The hybrids generally showed slightly lighter grains than the parents in the *Kharif* while the reverse was true in the *Rabi*. Among the male parents MR861 and MR803 had heavier grains while among the female parents MA6 and 623A had heavier grains.

Hybrids of MR861, MR867, MR849, MA4 and 296A had higher array means in the *Kharif* while hybrids of MA1, MA3, 623A, MR861, MR864, MR867 and MR849 had higher array means in the *Rabi*.

Negative heterosis (for decreased seed weight) was observed in most of the cross combinations (Appendix B.6). The majority of the parents produced hybrids whose average heterosis over the better parent was negative in both the seasons except MR849 which produced hybrids with increased seed weight in the *Kharif* (13%) and in the *Rabi* (17%) seasons. Similarly, hybrids of MR801 and MR864 showed significant positive heterosis in the *Rabi* season.

g. *Breaking strength*: Average grain breaking strength (kg) of the male parents was higher than that of the female parents (Appendix A.7). The hybrid array means of male parents were generally lower than those of the parents, however the array means of female parents were higher than their corresponding parental means.

Dominance was in the direction of harder grains. Array means of 623A, MA4, MA9, MR867 and MR824 were higher in the *Kharif* season while in the *Rabi* 623A hybrids exhibited higher grain breaking strength.

Overall, grains of the hybrids were less hard than the parents. Average heterosis was generally negative (Appendix B.7), however the crosses of the parents MR849 and 623A exhibited positive heterosis.

h. % floaters: Average % floaters for hybrids and parents with *Kharif* and *Rabi* seasons are shown in Appendix A.8.

The hybrids generally showed denser grains than the parents. During the *Kharif* the restorer MR824 exhibited the higher percentage of floaters as of the array mean of its hybrids whereas MR867 and CS3541 did not differ significantly from their respective array means. In the *Rabi* season the same trend was observe except for the restorer MR867 which showed denser grains than the array mean of its hybrids.

The male sterile lines in the *Rabi* showed very lighter grains and their floaters percentage was much higher than that in the *Kharif* and ranged from 38% (2219A) to 99% (MA5).

Among the hybrids MA3 x MR867, MA3,x MR824 and 623A x MR867 showed small values (2%) in the *Kharif* while in the *Rabi* the denser hybrids were 2219A x MR867 (4%), 2219A x MR824 (5%) and MA1 x MR824 (5%).

The overall heterosis during the *Kharif* was -24% while it was -6.7% (Appendix B.8) in the *Rabi* season. The range of magnitude of heterosis was larger during the *Kharif* since it varied from -89% up to 238% while during *Rabi* it varied from -95% to 194%.

In the Kharif 41 hybrids expressed significant (p=0.01 or p=0.05) heterosis while in Rabi season 31 cross combinations statistically significant (p=0.01 or p=0.05) heterosis either positive or negative.

i. Percentage of water absorption: Heterosis for this trait was expressed based on the parent which showed less water uptake (Appendix B.9). Average percent water absorption of 2077A and MR824 was higher than the other parents while grains of MR861 absorbed less water. Hybrids of 2077A and 296A absorbed less water than their parents. (Appendix A.9). The hybrids, although absorbed slightly more water than the better parent, the values were statistically non-significant.

Specific combinations with MA5 and MR861, showed significant positive heterosis only in Rabi.

j. Particle size index: The hybrid array mean of female parents were lower than those of the parents (Appendix A.10). In case of male parents, the hybrids showed lower averages in the Kharif than their corresponding parents while the reverse was true in the Rabi.

The heterosis was expressed on the parent which hadlless p.s.i. value. Average heterosis in the Kharif season was negative while it was significantly positive in the Rabi (Appendix B.10).

Hybrids of MA5 and 2077A had lower (negative) values in the *Kharif* and higher (positive) values in the *Rabi*. Among the male parents, hybrids of MR861 showed positive and high heterosis in the *Rabi*.

k. *Rolling quality*: The hybrids array means of females were generally higher than those of their parents in both seasons (Appendix A.11) 2077A and 296A showed poor rolling quality in both seasons.

The hybrid array means of males were slightly lower than their corresponding parents in *Kharif* and expressed almost equal values in *Rabi*.

Heterosis over better parent for rolling quality was either absent or the magnitudes were very low (Appendix B.11).

Among the hybrids 296A x MR861 and MA5 x MR824 showed highly significant positive and negative heterosis respectively.

l. *Gel spreading*: In the *Kharif* season gel spreading (mm) of male parents ranged from 58.7 to 70.3 mm (Appendix A.12), while their hybrid array means ranged from 58.6 to 63.4 mm. In the case of female parents, gel spreading range was from 61.7 to 75.7 mm and their hybrid array means ranged from 59.9 to 62.8 mm. Similar trends were observed in the Rabi season.

The parent showing more gel spreading was considered as the better for heterosis calculation. In general there was significant negative heterosis in both seasons (Appendix B.12).

The female parents 2077A and 296A produced heterotic hybrids with decreased gel spreading. All male parents produced hybrids with negative heterosis.

IV.3. GENERAL AND SPECIFIC COMBINING ABILITY AND COMPONENTS OF GENETIC VARIANCE

a. Days to 50% flowering: Variance estimates of combining ability for days to 50% flowering (Table 13) showed that variance due to GCA was predominant and several times larger in magnitude than variance due to SCA in the *Kharif*. However the GCA/SCA variance ratio was relatively low in the *Rabi* season. The GCA variance among males was larger than among females parents (Table 14).

In the *Kharif* male parents (Appendix C.1). MR801 and MR824 showed highly significant GCA effects for earliness, while MR849 showed highly positive GCA effect for lateness. Among the female parents MA1, MA2 and 2219A expressed highly significant GCA effects for lateness.

During the *Rabi* the male MR849 exhibited significant GCA effect for lateness while CS3541 showed a significant GCA effect for earliness. Among the females, MA2, MA6 and 2219A showed significant GCA effect for

Table 13 GCA/SCA Ratios for various agronomic and grain quality characters in Kharif and Rabi hybrid Experiments

Characters	σ^2GCA		σ^2SCA		σ^2GCA/σ^2SCA	
	K	R	K	R	K	R
(1)						
Days 50% flower	8.25	0.22	0.61	0.11	13.5	2.0
Plant height	494.88	347.93	66.60	26.22	7.4	13.3
Panicle length	4.08	2.51	1.00	0.86	4.1	2.9
Gr. yield/panicle	70.90	92.13	11.06	27.56	6.4	3.3
No. grains/head	40946	55006	25800	12827	1.6	4.3
1000 grains weight	4.69	6.73	1.78	1.99	2.6	3.4
Breaking strength	0.47	0.70	0.28	0.17	1.7	4.1
Floaters percentage	2.19	1.73	0.65	0.31	3.4	5.6
(2)						
Water absorption	2.12	4.13	0.43	0.44	4.9	9.4
Particle size index	19.00	3.62	5.64	0*	1.8	-
Rolling quality	0.16	0.17	0.67	0.02	0.2	8.5
Gel spreading	2.02	1.15	1.18	0.09	1.7	12.8

*assumed zero since SCA mean square was lower than error mean square.

1. Characters studied based on 99 hybrids.
2. Characters studied based on 20 hybrids.

Variance Components for General and Specific Combining Ability among the hybrids in Kharif and Rabi

Characters	$\sigma^2 g_i$		$\sigma^2 g_j$		$\sigma^2 s_{ij}$		$\sigma^2 g_i / \sigma^2 s_{ij}$		$\sigma^2 g_j / \sigma^2 s_{ij}$	
	K	R	K	R	K	R	K	R	K	R
Days to flowering (1)	9.95	0.06	6.17	0.42	0.61	0.11	16.31	0.54	10.12	3.79
Plant height	687.98	440.10	227.36	235.26	66.60	26.22	10.33	16.78	3.41	8.97
Panicle Length	3.12	2.25	5.26	2.84	1.00	0.87	3.12	2.59	5.26	3.28
Gr. yield/panicle	112.52	134.35	20.03	40.54	11.06	27.56	10.18	4.87	1.81	1.47
No. of Gr./panicle	51099.09	72464.48	28540.44	33641.78	25800.00	12827.53	1.98	5.65	1.11	2.62
1000 grains weight	7.60	10.58	1.14	2.02	1.78	1.99	4.27	5.32	0.64	1.02
Breaking strength	0.53	0.77	0.39	0.60	0.28	0.17	1.87	4.46	1.37	3.49
Floaters percentage	0.54	0.45	1.65	1.28	0.65	0.31	0.82	1.45	2.53	4.13
Water absorption (2)	4.28	8.12	0.40	0.94	0.43	0.44	9.87	18.59	0.93	2.16
Particle size index	13.00	3.14	5.96	4.02	5.64	0.00*	2.30	-	1.04	-
Rolling quality	0.32	0.32	0.28	0.05	0.67	0.02	0.03	16.00	0.42	2.50
Gel spreading	2.57	1.34	1.58	0.99	1.18	0.09	2.17	15.52	1.34	11.00

*assumed zero since SCA mean square was lower than error mean square.

(1) Characters studied based on 99 hybrids. (2) Characters studied based on 20 hybrids.

earliness. Among the females, MA2, MA6 and 2219A showed significant GCA effect for earliness while 2077A, 623A and 296A showed significant GCA effect for lateness.

About 15 hybrids exhibited highly significant SCA effects and about half of them had negative (for earliness) sign.

b. Plant height: GCA variances for plant height were larger in magnitude than SCA variance (Table 13) and GCA/SCA variance ratios were very high, particularly in Rabi season. The GCA variances of the male parents was larger than the GCA variances of the female parents indicating greater variation among the males compared to the females. The GCA and SCA variances showed similar trend in the Kharif as well as in the Rabi (Table 14).

An examination of GCA effects for the male parents revealed that MR801, MR824, MR825 and CS3541 showed negative effects. MR867 exhibited highly positive effects in both seasons, while MR849 showed positive effects only in the Kharif (Appendix C.2).

Among the female parents, MA1, MA9 and 2219A exhibited negative GCA effects while 296A, 2077A and 623A showed positive values during the Kharif. In the Rabi season MA6 showed highly significant GCA effects for shortness while MA2 and MA3 showed significant positive effects.

SCA effects were highly significant (p=0.01) for 31 crosses in the *Kharif* while only 7 crosses showed significant effects during the *Rabi*.

The frequency of positive and negative SCA effects was about the same in both the seasons.

c. Panicle length: GCA variances were three to four times larger than SCA variances (Table 13). In contrast to days to 50% flowering and plant height, the GCA variances of the females for panicle length were higher than those of male parents in both the seasons (Table 14). The magnitude of SCA variances were moderate although they were relatively less than GCA variances for each set of parents, viz; males and females.

Among the eleven female parents 2219A, 2077A, 296A and 623A showed positive GCA effects for panicle length while almost all the others showed negative effects in both the seasons (Appendix C.3). Among the male parents MR801, MR864 and MR824 exhibited significantly desirable GCA effects in both the seasons while MR861, MR867 and CS3541 showed significantly negative GCA effects. It seems necessary to note that although 623A showed significant (p=0.01) positive GCA effects, several of its crosses expressed significant (p=0.01) negative SCA effects.

The crosses MA1 x MR803, MA1 x MR849, 2077A x MR801, 2077A x MR825 and 623A x MR825 showed desirable SCA effects in the *Kharif* while 2077A x MR801 and 296A x CS3541 were the best during *Rabi*.

d. Grain yield per panicle: As in the case of the other characters discussed, GCA variances for grain yield/panicle were three to six times larger than SCA variances (Table 13). The GCA variances of male parents were several times larger than that of females (Table 14). Consequently the GCA/SCA variances ratios of female parents were much lower than that of the male parents.

A study of the GCA effects of the male parents showed that MR867 and MR849 exhibited strong positive effects in the Kharif as well as in the Rabi (Appendix C.4). On the other hand MR801, MR825 and CS3541 showed significant (p=0.01) negative GCA effects. Among the females 623A was the best in the Kharif as well as in Rabi.

Parent 2219A showed significant (p=0.01) negative GCA effects. Among the newly developed female parents MA4 showed significant (p=0.05) positive effects in the Kharif while MA1 and MA3 exhibited significant (p=0.01) effects during the Rabi. Significant SCA effects were observed in some of the hybrids of 296A.

e. Number of grains per panicle: The magnitude of GCA and SCA variances was considerably high although the GCA variances were larger (Table 13). The GCA/SCA variance ratio for grain number per panicle was smaller compared to that of the other characters in the Kharif season. However, the proportion of GCA variance was much more than SCA variance in the Rabi season.

The GCA variances of the males were higher than that of the females (Table 14). The GCA/SCA variance ratios were relatively lower in the Kharif than in the Rabi. They were however, more than one in both the seasons.

An examination of the GCA effects of the testers revealed that MR867 and MR849 exhibited strong positive effects while CS3541, MR801 and MR802 exhibited significant (p=0.01) negative effects. Among the female parents 296A and 623A showed significant (p=0.05 and p=0.01) respectively) and positive GCA effects during Kharif. Female parents MA3, 2077A and 623A showed positive and significant (p=0.01) GCA effect in Rabi season while MA4 and MA6 showed negative GCA effects in the Rabi (p=0.01) (Appendix C.5).

Crosses 296A x CS3541 and 296A x MR867 showed highly significant (p=0.01) and large SCA effects in the Rabi. There were 16 crosses exhibiting significant SCA effects either in Kharif or in the Rabi.

f. Thousand grain weight: The GCA variances were predominant and the GCA/SCA variance ratios were high, particularly in the Rabi (Table 13). GCA variances of the males were very high compared to females (Table 14).

The male parents MR861, MR867 and MR849 showed significant positive GCA effects (Appendix C.6) while MR801, MR825 and CS3541 showed significant negative GCA effects. None of the female parents showed consistently positive GCA effects in both seasons. MA4 exhibited desirable GCA effects in the Kharif while 623A showed positive GCA in the Rabi.

g. Breaking strength: GCA variances were larger than SCA variances. However, the GCA/SCA variance ratio was much lower in the Kharif season (Table 13) than in the Rabi. The GCA variances were larger for the male parents than for female parents (Table 14).

Significant positive GCA effects were exhibited only by 623A and MR867 (Appendix C.7). All the other parents exhibited non-significant effects. MA4 and MA9 showed positive GCA effects in the Kharif season only.

There were 8 and 18 hybrids showing significant SCA effects in the Kharif and Rabi seasons respectively. The crosses 296A x MR861 and 623A MR867 showed the highest SCA effects.

h. Percent floaters: Variances for general and specific combining ability are shown in Table 13. The variances of GCA were higher than SCA variances and the GCA/SCA variance ratios varied from 3.4 in the Kharif to 5.6 in the Rabi.

Among the female parents MA1, MA2, MA3, MA4, 2219A and 623A exhibited negative and significant (p=0.01) effects in the Kharif while only two restorers showed significant (p=0.01) negative GCA effects viz. MR867 and MR824. In the Rabi season, the same parents exhibited negative and significant effect (p=0.01) except MA4 whose effect was non-significant negative.

i. Percent water absorption: Significant GCA variances were observed (Table 13). The magnitude of SCA variance was non-significant. Similarly GCA variances of the testers was significant while those of female parents were very low (Table 14).

Among the 5 male parents studied, MR861 exhibited significant negative GCA effects while MR824 and MR825 showed significant positive effects (Appendix C.9).

j. Particle size index: GCA variances were relatively large compared to the SCA variances (Table 13). GCA variances among the male parents were much higher than those of female parents (Table 14).

The male parents MR861 and MR864 showed significant (p=0.01) positive GCA effects while MR824 showed strongly negative effects (p=0.01) (Appendix C.10).

Among the female parents MA9 exhibited negative GCA effects while 296A showed significant (p=0.05 and p=0.01) respectively) positive GCA effects in the Rabi season.

Only three crosses exhibited significant (p=0.05) SCA effects, viz; MA5 x MR824, 2077A x MR825 and 296A x MR824 in Rabi season.

k. Rolling quality: GCA variance was higher than the SCA in the Rabi season (Table 13). On the contrary the reverse was true in the

Kharif season. Variances among the male and female parents were of the same order in the *Kharif* season while only the male parents exhibited significant GCA variance in the *Rabi* season (Table 14).

Negative GCA effects were exhibited by 2077A and MR825 (Appendix C.11). Positive SCA effects were shown in the crosses MA5 x MR825 and MA9 x MR864.

1. Gel spreading: GCA variances were larger than SCA variances in both seasons (Table 13). Male and female parents exhibited almost equal GCA variances (Table 14).

Among the male parents MR864 and MR825 showed positive GCA effects while MR824 showed strong negative effects (Appendix C.12). Parent 296A showed significantly positive GCA effects while MA5 and MA9 showed negative but not significant GCA effects.

The crosses MA9 x MA825 and 296A x MR825 showed significant positive and negative SCA effects respectively in the *Kharif*.

IV.4. CORRELATION BETWEEN PARENTAL PERFORMANCE AND THEIR GCA EFFECTS

The correlation coefficients (r) between the performance of parents and their corresponing GCA effects are shown in Table 15 for the various characters.

Table 15: Correlation coefficients (r) between parental performance per se and their general combining ability effects in Kharif and Rabi experiments.

Characters	Male sterile lines		Restorers	
	K	R	K	R
Days to 50% flowering	0.99**	0.80**	0.84**	0.63
Plant height	0.70*	0.38	0.47	0.71*
Panicle length	0.82**	0.92**	0.92**	0.36
Grain yield/panicle	-0.20	0.60*	0.60	0.77*
No. grains/panicle	0.17	0.67*	0.83**	0.83**
1000 grains weight	0.69*	0.64*	-0.10	0.70*
Breaking strength	0.77**	0.82**	0.33	0.89**
Floaters percentage	0.88**	0.65*	0.50	0.57

*significant (p=0.05) **significant (p=0.01)

Among the traits analyzed days to flowering and panicle length showed the highest correlation coefficients. On the case of grain yield per panicle and 1000 grain weight only the restorers exhibited significant (p=0.05) coefficients in both the seasons.

The two grain quality parameters involved i.e. breaking strength and floaters percentage showed significant (p=0.05 or p=0.01) coefficients in the *Kharif*, however, only the males had significant (p=0.01) coefficient during the *Rabi* season.

IV.5. GENETIC VARIANCES

Estimates of the components of genetic variances for the various characters studied are presented in Table 16.

The proportion of additive genetic variance ($\sigma^2 A$) to the total genetic variance ($\sigma^2 G$) was more than 0.8 for several characters, namely; days to 50% flowering, plant height, panicle length, grain yield per panicle and percent of water absorption, indicating that additive gene action is the predominant kind of gene action governing these characters.

The characters which showed significant proportion of non-additive gene action include number of grains per panicle, 1000 grain weight, breaking strength, particle size index, rolling quality and gel spreading, However, non-additive gene action was not of much importance in the *Rabi* season and even during *Kharif* the magnitude of $\sigma^2 D$ was much lower than $\sigma^2 A$. Thus for almost all the characters studied, additive gene action is probably the most important mode of inheritance.

Table 16: Estimates of components of genotypic variance for the characters studied in hybrids experiments in Kharif and Rabi

Characters	σ^2_A		σ^2_D		σ^2_G		σ^2_D/σ^2_G		σ^2_A/σ^2_G	
	Kharif	Rabi	Kharif	Rabi	Kharif	Rabi	Kharif	Rabi	Kharif	Rabi
Days to 50% (1) flowering	16.50	0.44	0.61	0.11	17.11	0.55	0.04	0.20	0.96	0.80
Plant height	987.77	695.86	66.60	26.22	1054.37	722.08	0.06	0.04	0.94	0.96
Panicle length	8.17	5.03	1.00	0.86	9.17	5.89	0.11	0.15	0.89	0.85
Grain yield per panicle	141.80	184.27	11.06	27.56	152.86	211.83	0.07	0.13	0.93	0.87
Number of grains per panicle	81892	110013	25800	12827	107692.	122840	0.24	0.10	0.76	0.90
1000 grain weight	9.39	13.46	1.78	1.99	11.17	15.45	0.16	0,13	0.84	0.87
Breaking strength	0.93	1.40	0.28	0.17	1.21	1.57	0.23	0.11	0.77	0.89
Floatersm%	2.12	1.65	0.43	0.31	2.55	1.96	0.17	0.16	0.83	0.84
Water (2) absorption	4.25	8.27	0.43	0.44	4.68	8.70	0.09	0.05	0.91	0.95
Particle size index	19.99	7.25	5.64	0.00*	25.64	-	0.22	-	0.78	-
Rolling quality	0.32	0.34	0.67	0.22	0.99	0.36	0.67	0.06	0.33	0.94
Gel spreading	4.04	2.30	1.18	0.09	5.22	2.39	0.23	0.04	0.77	0.96

1 (1) Characters studied based on 99 hybrids (2) Characters studied based on 20 hybrids

* assumed zero since SCA mean square was lower than the error mean square

V. DISCUSSIONS AND CONCLUSIONS

Results from the analysis of variance of the hybrid experiments carried out in Kharif and Rabi enable one to evaluate the extent of genetic variation present in the material under study. In both the seasons, the results followed the same trend i.e. genetic variation due to the testers was higher than that for the male sterile lines for all the characters except days to 50% flowering in the Rabi. It indicates that greater genetic variability was present among the males. These results were predictable since the testers selected were a sample from a large population of diverse restorers while the male sterile lines were either commercial lines currently being used in India or newly developed lines but with a narrow genetic background (Table 2). Relatively low variability among the female parents might be due to their selection for reduced height which is known to affect other characters in sorghum (Campbell et al., 1975; and Goud and Vasudeva Rao, 1977). Similar results were reported by Kambal (1962) and Paisan (1975). However, Beil (1965) observed contradictory results.

In general, the magnitude of genetic variability was relatively low in restricted L x T set (20 hybrids) studied for the quality parameters. This is obviously due to the small sample size.

The estimates of the magnitude of general and specific combining ability are based on several assumptions. For the interpretation of the present results it was assumed that the differences in general combining ability are mainly based on differences in additive effects and differences in specific combining ability are due to the difference in non-additive effects (Sprague and Tatum, 1942). However, Kempthorne (1956) has pointed out that the non consideration of epistatic effects in the interpretation of genotypic components places severe restrictions on the validity of the estimates. It was also assumed that all the parents involved in the study had an inbreeding coefficient (F) equal to one. However, Hallauer and Miranda (1981) have shown that in practice this assumption is frequently not correct. It was assumed that the inbreds represent a random sample from a broad based random mating population which in real sense is not true; only a sample of parents among the lines developed by the ICRISAT Sorghum Improvement Program was used. Thus, it seems necessary to emphasize that the parents in this study did not represent a random sample of the available genetic and morphological variation in grain sorghums and were presumably somewhat narrow based genetically.

For days to 50% flowering the females MA2, MA6 and 2219A showed a desirable GCA effect for earliness. The results obtained with 2219A were similar to those reported by Rao et al. (1968). Among the restorers five of them revealed high GCA effects for earliness. However, MR849 had a strikingly positive (lateness) effect during Kharif. The performance of the two extreme parents 2219A and MR849 repeated in the Rabi also (Appendix A.1).

The variance ratios of GCA/SCA for days to 50% flowering brought out an interesting feature since during the Kharif, the ratio was 13.5 while during the Rabi it was reduced to 2.0. This discrepancy could probably be attributed to the restricted variability for days to flowering during short days (Miller et al., 1968). It is also known that plant maturity and height in sorghum are controlled by four major genes (Quinby, 1974). Therefore, the control of flowering is partially due to some additive gene action, although during Rabi both additive and non-additive gene action were significant. These results confirm the findings of Chiang and Smith (1967) Liang and Walter (1968); Nayarkar (1973); Dabholkar and Baghel (1981a) and Indi and Goud (1981).

Plant height data revealed that crosses with MA1, MA9 and 2219A led to short hybrids while 2077A and 623A resulted in tall hybrids. All the restorers showed negative GCA effects except MR849. The GCA/SCA variance ratios (7.4 for Kharif and 13.3 during Rabi) disclosed that a strong additive gene action was responsible for plant height. Similar results were obtained by Chiang and Smith (1967) and Indi and Goud (1981), while Nayarkar (1973) reported that non-additive gene action played the principal role in plant height inheritance. As mentioned earlier, four major dwarfing genes are also known to control inheritance of height in sorghum (Quinby 1974).

For panicle length it was observed that 2077A and MR849 showed the highest GCA effects during Kharif while 2077A and MR864 had the highest GCA effects during Rabi. The GCA/SCA variance ratios revealed that although additive gene action was the most important, the non-additive effects also influenced significantly the genetic control of this character. This observation is in agreement with the results obtained by Whitehead (1962), Chiang and Smith (1967) and Paisan (1975).

Regarding grain yield per panicle, during the Kharif season only three male steriles showed significant positive effects: MA4, 623A and 296A. On the other hand, among the restorers MR849 and MR867 were superior general combiners. During Rabi the female 623A repeated its good performance followed by the newly developed lines MA3 and MA1. Among the males, the highest GCA effects were due to MR867, MR864 and MR849. The GCA/SCA variance ratios showed that during Kharif the GCA variance was six times higher than the SCA while in Rabi the value was depressed to three times. Thus, it could be concluded that additive gene action plays the most important role in the inheritance of grain yield. This was observed by many authors (Liang and Walter, 1968; Liang et al., 1968; Mattei 1974; Shinde and Sudewad, 1980a). However, the importance of the non-additive gene action can not be ruled out, as pointed out by Kambal and Webster (1965), Rao (1970), Govil and Murty (1973) and Srihari and Nagur (1980).

Concerning number of grains per panicle, two male sterile lines exhibited significant positive GCA effects viz. 623A and 296A in the Kharif season. Two restorers, namely MR849 and MR867 were better combiners. In Rabi, 2077A showed higher GCA effect followed by MA3 and 623A and among the males the highest values were shown by MR864, MR867 and MR849. The GCA/SCA variance ratio revealed that additive and non-additive gene action are almost of equal importance since during the Kharif season the value was only 1.6, although during Rabi it was increased to 4.3. These results confirmed the findings of Nayarkar (1973) and Dabholkar and Baghel (1970a, b). However, Webster (1980), reported that this trait was primarily controlled by non-additive effects.

Thousand grain weight data showed that during the Kharif only MA4 among the female parents had positive and significant GCA effect. Three restorers, MR861, MR867 and MR849 showed positive general effects. During the Rabi, 623A was the best general combiner followed by MA1 and MA3. Concerning the male parents, MR867 and MR861 showed significant values of GCA effects. Since a predominance of additive gene action was observed, the GCA/SCA variance ratios confirmed the results obtained by Voigt et al. (1968), Dabholkar and Baghel (1980a, b) and Patidar and Dabholkar (1981). Nevertheless, Nayarkar (1973) and Liang and Walter (1968) found out that additive gene action had a minor role in the inheritance of the character.

General combining ability effects for grain breaking strength showed that 623A, MA4 and MA9 exhibited positive GCA effects (towards hard grains) during *Kharif*. One restorer, MR867 has shown significant positive effects in both the seasons. In *Rabi* only 623A among the male steriles repeated its *Kharif* performance. The GCA/SCA variance ratios showed a predominance of additive effect in *Kharif* as well as in *Rabi*, although during the latter season the ratio was higher. Srivastava and Ram (1974) obtained similar results for breaking strength in wheat.

Regarding general combining ability for % floaters (Appendix C.8), six female parents: MA1, MA2, MA3, MA4, 2219A and 623A and two restorers MR867 and MR824 have shown significant negative effects (denser grains) during *Kharif* while in the *Rabi* there was a consistent result for the same parents except MA4. The GCA/SCA variance ratios showed that this character is controlled mainly by additive gene action.

Percentage of water absorption data for *Kharif* and *Rabi* revealed only one parent, MR861 with significant negative (p=0.01) GCA effect. GCA/SCA variance ratios revealed a predominant role of additive gene action in both the seasons.

Regarding the character flour particle size index, in the *Kharif* season, two restorers, viz. MR824 and CS3541 have shown significant (p=0.01 and p=0.05) negative GCA effects while MR861 and MR864 showed significant positive effects. Among the female parents MA9 showed a significant negative effect while 296A exhibited significant positive effect. Among the hybrids MA5 x MR824 and 2077A x MR825 revealed significant negative SCA (hard grains) effect. During Rabi there were no significant effects either for parents or hybrids. The GCA/SCA variance ratio revealed almost equal magnitude for additive and non-additive gene action during Kharif while in Rabi there was no significance for the SCA mean square and then the variance component was assumed zero. Results reported by Aamodt et al. (1935) in wheat brought out that soft texture (soft grains) was dominant to vitreous texture (hard grains). Symes (1965) studied the grain hardness inheritance in wheat through particle size analysis and showed that it was controlled by a single major gene, although the existance of minor genes as modifiers was also demonstrated.

For rolling quality during the Kharif season, two hybrids MA5 x MR825 and MA9 x MR864 during Kharif have shown positive and significant SCA effects. The GCA/SCA variance ratios brought out opposite results for the two seasons since in Kharif there was a predominance of non-additive gene action while during the Rabi additive gene action was more important. Probably, the inheritance of particle size index is highly influenced by the environment, confirming results obtained by Murty et al. (1981).

Combining ability effects for gel spreading disclosed that only two restorers in Kharif season had significant GCA effects, viz. MR864 (positive) and MR824 (negative). Among the females only 296A showed significant positive effect during the Kharif. Two cross combinations viz. MA9 x MR825 (positive) and 296A x MR825 (negative) exhibited significant SCA effects. Nevertheless, in Rabi only the restorer MR825 showed significant (p=0.05) GCA effect among all the parents. None of the hybrids has shown significant specific combining ability effect. The discrepancy on the GCA/SCA variance ratios (1.7 in Kharif and 12.8 in the Rabi) revealed the strong environmental effect on the genetic control of this character.

Although additive gene action was the predominant mode of inheritance for most of the characters, significant amounts of heterosis over mid-parent and/or superior parent for several of the characters indicate the presence of non-additive gene action. The overall means of the hybrids when compared with those of parents indicate that dominance is generally in the direction of earliness, tall plants, increased panicle length and grain number and decreased seedweight. In general, the performance of the hybrids with respect to grain breaking strength, % floaters, flour particle size, gel spreading, and rolling quality indicated dominance towards denser and harder grains.

The texture or hardness of the endosperm suitable for various traditional products were discussed by Rooney and Murty (1982). The parameter % floaters measures hardness of the grain (Hallgren and Murty, 1983). The average % floaters of the parents and hybrids were

45 and 19 in the Kharif and 56 and 25 in the Rabi respectively. Less number of floaters indicate higher density, harder texture, large particle size, thick gels and better rolling quality. The present results are in conformity with those of Hallgren and Murty (1983).

In this study, heterosis over mid or superior parents lead to earlier bloom, taller plants and higher yield confirming results reported by Arnon and Blum (1962), Quinby (1963), Arnon and Blum (1965), Kambal and Webster (1966) and Patanothai and Atkins (1971).

The magnitude of overall heterosis compared to superior parents was not significant during Kharif for grain yield per panicle. However, heterosis of individual hybrids ranged from -44% to 108.8%. Hybrids made with the restorer MR849 had the highest effect (71%). On perusal of the data from Rabi trials, it can be observed that the magnitude of heterosis was relatively higher than in the Kharif. This was not due to any increment in the yield of the hybrids but was due to a marked reduction of the yield of parents, probably due to the premature lodging (Appendix A.9) and the high incidence of rust (Puccinia purpurea Cooke) (Appendix A.10) in the Rabi.

The hybrids of MR849 showed highest heterosis for grain yield during Kharif, probably because of their late maturity and consequent avoidance of the dry spell during August 1982. This dry spell, on the other hand affected markedly the hybrids that matured earlier (Fig.1).

For thousand grain weight heterosis was negative and led to lighter grains particularly in Kharif. Heterosis was negative for breaking strength also during both the seasons. However, some hybrids exhibited high and positive heterotic effects since the ranges varied from -51% to 29% in Kharif and -42% to 40% in Rabi season.

The magnitude of heterosis for the characters percentage of water absorption, particle size index, rolling quality and gel spreading was small, probably due to the low level of genetic variability among the parents since only four male steriles and five restorers were used.

As pointed out earlier, the inconsistency of some of the combining ability and heterosis estimates over the two seasons, particularly for grain yield and quality characters, was partly due to the effect of severe damage caused by leaf rust (Puccinia purpurea Cooke) in the Rabi experiments. The occurance of this disease led to poor grain filling and consequently to poor textural properties of the grain and ultimately to the biased estimates of flour particle size, percentage of water absorption, dough rolling quality and gel spreading.

Premature lodging of many entries in the Rabi season also led to similar effects. A cursory examination of the average visual scores of lodging and rust (Appendics A.9 and A.10) indicates limited genetic variation. None of the parents showed lodging during the Kharif season while most of the hybrids lodged. However, it is important to note that the hybrids of MA9, MA6 and 296A exhibited the lowest scores. Among the restorers, hybrids of MR861 and MR849 showed less lodging.

In the Rabi season, however, the results were confounded due to the severity of rust which probably hastened lodging. Specific combinations of 623A, MA9, MA3 and MA4 and MR867, MR861 and MR849 showed the least lodging scores. The rust scores showed that MR864 was almost free from rust and its hybrids were the least affected.

Among the 99 hybrids, the specific crosses MA5 x MR864 and MA6 x MR864 exhibited the lowest rust damage. Inheritance of rust is reported to be controlled by major genes (Coleman and Dean, 1961 and Rana et al., 1976).

Estimates of the components of genotypic variance have shown higher levels of additive effects than the GCA/SCA variance ratios, probably because it was assumed that the parents involved in this study were purely homozygous (inbreeding coefficient, F=1) which led to an inflation in the additive effects in detriment of the non-additive, in which epistasis should be included.

Correlation coefficients between parental performance and their GCA effects were frequently high and mostly significant in both the seasons (Table 16). However, performance *per se* does not seem to enable the breeders to select parents for the production of the best hybrids because, several productive hybrids could not be predicted on the basis of parental performance. Moreover, many of the correlations were not stable over seasons. These observations are in agreement with the findings of Niehaus and Pickett (1966), Rao (1972), Mattei (1974) and Bhola Nath (1983). Kirkby and Atkins (1968), Collins and Pickett (1972) and Singhania and Rao (1975) observed that even though superior parents general produced higher yielding hybrids it does not mean that the best hybrids originate from the best superior combiners or higher yielding parents. Probably, the selection of parents based on the parental performance per se together with the GCA effects should help the breeders in the first stages of a breeding program.

From the results obtained in this study the following inferences can be made:

1. Characters controlled by quantitative inheritance such as grain yield per panicle and grain number although revealed strong additive gene action, they were also to some extent affected by non-additive gene action.

2. Additive action of minor genes also plays significant role in the inheritance of characters known to be governed by major genes as in the case of plant height and days to 50% flowering.

3. The frequent inconsistency of combining ability effects over seasons for several of the characters indicated that caution must be exercised in the generalization of results and extrapolating interpretations. The results on combining ability analysis can be applied only to the specific environments in which they were obtained and the specific parents used. Relatively more environmental effects were observed for percent water absorption, flour particle size and rolling quality.

4. Comparison of parental performance per se and general combining ability effects showed that neither of them can individually always predict the most productive hybrids. However, information on both of these parameters can probably help the breeders in the initial stages of a hybrid breeding program to choose parents for extensive use.

5. The heterosis and combining ability results showed that the breeders should pay more attention for further evaluations to the following parents: 623A, 296A, MA4, MR849 and MR867 for the Kharif season and 623A, MA3, MR867 and MR864 for the Rabi season.

6. Based on the height and nicking of flowering of the parents, hybrid MA1 x MR864 appeared to be the best in Rabi for production, since it was the sixth in order among the highest yielding hybrids in Rabi and had the most desirable agronomic characters.

VI. SUMMARY

The objectives of this study was to evaluate the combining ability, performance and variance components of selected sorghum genotypes for the following 12 characters: days to 50% flowering, plant height, panicle length, grain yield per panicle, number of grains per panicle, thousand grain weight, breaking strength, % floaters, % water absorption, particle size index, rolling quality of the dough and gel spreading.

A set of 20 parental lines: 11 male steriles and 9 restorers, and their 99 hybrids formed the material for the experiments. Fifteen of the parents were recently bred at ICRISAT while the remaining five are in commercial use in India.

Parents and hybrids were planted separately but in adjacent trials with 3 replications each in a RBD design in two different seasons: rainy (*Kharif*) and post-rainy (*Rabi*) of 1982 at ICRISAT Center, Patancheru, A.P., India. The combining ability analysis for the observations made on the 12 characters followed a line x tester mating system as proposed by Kempthorne (1957).

Significant variation among the parents and hybrids was observed. In general, variability due to testers was higher than due to the male steriles.

Significant levels of heterosis were observed for almost all the characters. However, overall heterosis was pronouced for plant height, grain yield per panicle, grain number per panicle, % floaters and breaking strength only. Average dominance was in the direction of earliness, increased height, panicle length, grain number, yield and decreased seed weight, % floaters, flour particle size and gel spreading.

The results have shown that most of the agronomic characters studied are highly influenced by additive gene action, although for characters known to be as controlled by quantitative inheritance such as grain yield per panicle and number of grains per panicle there was some evidence of non-additive gene action.

The grain quality characters: 1000 grain weight, breaking strength, % floaters, flour particle size, rolling quality and gel spreading were governed predominantly by additive gene action but significant levels of non-additive gene action was also observed.

Based on the performance of the hybrids and the GCA estimates, the following parents appear to be more useful and productive in crossing programs: 623A, 296A, MA4, MA6, MR849 and MR867 for the Kharif and 623A, MA3, MR867 and MR864 for the Rabi.

Parent 2219A would be useful in breeding for earliness and reduced height. Parent 623A was a good combiner for grain yield, grain number and panicle length. Specific cross combinations which appear to be worthy testing in regional programs were identified.

Since the various characters studied are mainly controlled by additive gene action, breeding methods which exploit effectively this kind of genetic variation should be rewarding.

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Appendix A.1 : Means for days to 50% flowering of hybrids and their parents in Kharif and Rabi Experiments

Males		Females											Array mean of male parents	Mean of male parents
		MA 1	MA 2	MA 3	MA 4	MA 5	MA 6	MA 9	2219 A	2077 A	623 A	296 A		
MR 801	K	54	54	54	58	58	58	62	52	64	57	59	57	63
	R	54	54	54	55	54	54	54	53	54	55	55	54	57
MR 861	K	56	57	58	60	60	60	61	54	62	59	60	59	65
	R	54	54	57	55	54	54	54	53	56	54	56	55	57
MR 864	K	55	56	57	58	59	59	60	54	61	58	60	58	65
	R	55	54	55	54	54	54	55	53	56	55	54	54	55
MR 803	K	56	55	56	58	60	60	60	53	61	59	59	58	64
	R	54	54	54	55	56	54	55	53	56	56	55	55	56
MR 867	K	56	55	56	58	59	60	61	53	61	60	60	58	64
	R	54	54	54	54	54	54	54	53	56	57	56	55	56
MR 824	K	54	54	55	58	58	58	60	51	59	58	57	57	63
	R	54	53	54	55	55	54	54	52	57	55	55	54	56
MR 825	K	56	55	56	59	60	60	61	53	61	60	60	58	65
	R	54	54	55	54	53	53	54	53	56	56	55	54	54
MR 849	K	66	64	66	67	68	68	69	64	67	69	70	67	77
	R	54	55	56	55	55	54	54	54	55	56	54	55	63
CS 3541	K	56	55	57	57	58	59	62	53	61	57	59	58	63
	R	54	54	54	54	53	53	54	52	55	54	55	54	55
Array mean of female parents	K	57	56	57	59	60	60	62	54	62	60	60	59a	
	R	54	54	55	55	54	54	54	53	56	55	55	54	
Mean of female parents	K	56	56	59	60	59	59	63	55	68	58	63		62b
	R	55	54	60	60	54	54	56	54	67	57	64		57

a = hybrids' means b = parents' means

S.E. hybrids = K (0.82) R (0.87) C.V. hybrids = K (1) R (2)

S.E. parents = K (0.98) R (1.86) C.V. parents = K (2) R (3)

LSD .05 hybrids = K (1.32) R (1.39) LSD .05 parents = K (1.61) R (3.08)

Appendix A.2 : Means for plant height (cm) of hybrids and their parents in Kharif and Rabi Experiments

Males		Females											Array mean of male parents	Mean of male parents
		MA 1	MA 2	MA 3	MA 4	MA 5	MA 6	MA 9	2219A	2077A	623A	296A		
MR 801	K	174	182	178	183	185	188	159	170	228	214	191	187	141
	R	173	173	178	162	177	162	138	163	180	197	182	171	132
MR 861	K	195	204	195	194	201	192	157	170	225	204	189	193	158
	R	190	193	198	185	183	173	152	168	205	195	183	184	148
MR 864	K	193	204	202	194	198	188	161	179	226	236	208	199	172
	R	185	207	195	183	178	172	148	173	202	208	188	185	153
MR 803	K	211	199	199	199	198	200	160	171	233	226	206	200	175
	R	180	193	192	182	177	168	147	170	202	200	197	183	163
MR 867	K	248	241	252	257	272	279	230	230	296	277	281	260	191
	R	232	233	243	233	227	227	197	225	260	247	265	235	175
MR 824	K	175	187	188	191	188	201	163	167	202	211	180	187	135
	R	172	178	178	180	173	172	148	172	187	192	172	175	125
MR 825	K	181	190	191	193	189	193	164	168	207	212	198	190	185
	R	168	180	180	162	160	162	133	163	195	197	175	170	153
MR 849	K	235	247	236	229	229	233	180	218	245	226	216	227	177
	R	152	203	197	187	188	183	145	182	207	207	185	185	172
CS 3541	K	165	171	176	172	167	164	151	159	198	194	186	173	146
	R	158	175	170	167	140	142	128	152	182	180	185	162	122
Array mean of female parents	K	197	203	202	201	203	204	169	181	229	222	206	202	
	R	179	193	192	182	178	173	148	174	202	203	192	183a	
Mean of female parents	K	120	140	131	115	128	123	138	110	140	157	136		146b
	R	110	118	122	110	112	107	127	105	123	152	120		132

a = hybrids' means b = parents' means

S.E. hybrids = K (5.88) R (9.18) C.V. hybrids = K (3) R (5)
S.E. parents = K (3.61) R (4.45) C.V. parents = K (2) R (3)
LSD .05 hybrids= K (9.41) R (14.70) LSD .05 parents = K (5.96) R (7.35)

Appendix A.3 : Means for panicle length (cm) of the hybrids and their parents in Kharif and Rabi Experiments

Males		Females: MA 1	MA 2	MA 3	MA 4	MA 5	MA 6	MA 9	2219 A	2077 A	623 A	296 A	Array mean of male parents	Mean of male parents
MR 801	K	29	30	30	34	29	30	31	32	39	35	33	32	26
	R	28	30	30	31	30	30	28	31	39	32	32	31	26
MR 861	K	26	26	27	29	27	27	27	29	32	31	31	28	25
	R	27	25	28	29	28	27	26	29	32	31	29	28	25
MR 864	K	29	29	29	31	31	30	31	33	36	37	33	32	28
	R	30	29	31	33	32	31	30	32	35	35	33	32	28
MR 803	K	32	29	30	32	28	27	29	30	35	34	34	31	24
	R	29	29	30	31	29	29	30	31	34	34	32	31	26
MR 867	K	27	27	27	27	26	26	28	27	31	28	29	28	20
	R	26	27	27	28	27	27	28	28	31	27	29	28	22
MR 824	K	28	27	29	30	30	28	31	31	36	31	31	30	24
	R	28	29	30	30	29	28	29	30	33	30	30	30	24
MR 825	K	30	30	31	34	31	30	31	33	40	37	35	33	27
	R	30	28	30	33	31	30	31	33	34	36	33	32	28
MR 849	K	29	29	29	29	28	28	28	31	33	29	30	29	23
	R	29	30	30	33	30	31	29	33	32	30	33	31	26
CS 3541	K	27	27	28	30	26	27	27	30	34	32	32	29	24
	R	26	26	28	29	28	27	27	31	32	30	32	29	25
Array mean of female parents	K	29	28	29	31	28	28	29	31	35	33	32	30a	
	R	28	28	29	31	29	29	29	31	34	29	31	30	
Mean of female parents	K	23	23	23	30	26	26	26	28	34	31	32		26b
	R	24	25	26	30	27	27	26	29	32	29	28		27

a = hybrids' means b = parents' means

S.E. hybrids = (K (1.03) R (1.17) C.V. hybrids = K (3) R (4)
S.E. parents = k (1.31) R (1.25 C.V. parents = K (5) R (5)
LSD 0.05 hybrids= K (1.64) R (1.87) LSD .05 parents = K (2.12) R (1.86)

Appendix A.4 : Means for grain yield per panicle (g) of the hybrids and their parents in Kharif and Rabi Experiments

Males		Females											Array mean of male parents	Mean of male parents
		MA 1	MA 2	MA 3	MA 4	MA 5	MA 6	MA 9	2219 A	2077 A	623 A	296 A		
MR 801	K	46.6	52.7	37.0	54.3	46.6	54.1	42.0	41.2	59.7	63.7	61.3	50.8	57.2
	R	48.4	46.5	46.0	32.3	35.3	34.6	41.6	35.3	41.1	52.0	43.6	41.5	23.9
MR 861	K	57.3	65.4	56.0	71.9	67.5	71.1	61.8	49.6	63.6	60.9	68.0	63.0	63.7
	R	64.9	58.4	74.5	48.7	50.1	46.0	58.7	41.8	60.8	69.7	49.7	56.6	51.8
MR 864	K	44.6	51.5	51.1	61.3	51.6	50.6	45.6	39.6	45.0	70.6	61.3	52.0	58.6
	R	78.0	64.0	75.6	69.8	65.0	63.6	59.3	58.9	71.0	73.3	69.4	68.0	48.2
MR 803	K	63.1	52.6	53.2	68.9	67.7	54.4	53.2	54.2	60.8	67.9	66.2	60.2	60.6
	R	50.7	53.3	61.3	48.8	52.1	40.4	47.9	46.1	47.7	75.1	53.6	52.5	58.1
MR 867	K	58.3	65.6	56.5	72.1	81.4	92.4	77.8	60.7	80.5	71,3	77.5	72.2	77.9
	R	75.0	73.1	84.2	70.2	62.7	65.4	65.4	66.0	84.7	80.3	99.4	75.1	60.0
MR 824	K	48.5	47.3	54.4	60.9	51.6	57.7	52.8	57.7	46.6	63.9	64.5	55.1	64.1
	R	64.8	58.00	69.7	51.4	45.8	49.1	55.9	45.2	55.5	70.6	43.2	55.4	50.0
MR 825	K	43.2	44.7	49.1	46.4	53.3	44.4	49.2	38.2	35.9	54.0	46.5	45.9	67.9
	R	51.0	45.2	44.0	34.3	39.2	44.6	47.9	43.7	45.3	63.5	34.3	44.8	42.3
MR 849	K	77.6	70.0	70.5	75.6	79.3	85.0	70.0	67.4	69.2	81.5	70.3	74.2	40.7
	R	72.7	74.4	66.3	61.3	59.2	57.8	51.1	67.4	65.3	82.9	53.2	64.7	61.0
CS 3541	K	41.7	42.8	41.0	48.5	41.0	41.0	53.2	34.6	46.8	45.1	49.6	44.1	52.7
	R	42.8	46.4	46.5	34.1	28.8	29.9	38.0	35.9	48.3	48.3	70.9	42.7	35.2
Array mean of **female** parents	K	53.4	54.7	52.1	62.2	60.0	61.2	56.2	49.2	56.4	64.3	62.8	57.5	
	R	60.9	57.7	63.1	50.1	48.7	47.9	51.8	48.9	57.7	68.4	57.5	55.7a	
Mean of female parents	K	34.0	41.6	39.0	38.2	42.6	39.6	43.5	36.2	37.4	54.6	59.9		50.5b
	R	23.0	23.3	20.1	9.2	13.4	13.3	37.2	20.3	12.6	50.6	25.5		33.9

a = hybrids' means

S.E. hybrids = K (8.73) R (7.56)

S.E. parents = K (6.64) R (5.95)

LSD .05 hybrids = K(13.98) R (12.09)

b = parents' means

C.V. hybrids = K (15) R (14)

C.V. parents = K (13) R (17)

LSD .05 parents= K(10.98) R(9.84)

Appendix A.5 : Means for number of grains per head of the hybrids and their parents in Kharif and Rabi Experiments

Males		Females											Array mean of male parents	Mean of male parents
		MA 1	MA 2	MA 3	MA 4	MA 5	MA 6	MA 9	2219 A	2077-A	623 A	296 A		
MR 801	K	2631	3059	2134	2683	2703	2947	2235	2209	3191	3257	2728	2707	2611
	R	2155	2399	2458	1912	2028	1946	2086	1721	2590	2206	2091	2145	1744
MR 861	K	2360	2630	2358	2520	2572	2597	2588	2164	2533	2999	2722	2549	1689
	R	2290	2113	2511	2053	1876	1817	2149	1746	2484	2181	1908	2103	1506
MR 864	K	2752	3028	2812	2982	2731	3235	2733	1997	2542	3669	3118	2873	2654
	R	3118	2850	3062	2710	2622	2494	2607	2372	3267	2862	2673	2785	2351
MR 803	K	3153	2736	2643	2718	2947	2422	2360	2706	2691	3218	2734	2757	1909
	R	2222	2260	2362	2071	2222	2107	2290	2007	2410	2472	2268	2245	1894
MR 867	K	2980	3123	2789	2768	2921	3625	3134	2847	3593	2795	3009	3053	2472
	R	2688	2815	2803	2410	2445	2332	2618	2528	3183	2720	3471	2728	2084
MR 824	K	2584	2342	2873	2880	2896	3071	2982	2782	2732	3237	3462	2894	2651
	R	2626	2450	2841	2203	2211	2354	2688	1795	2696	2844	2431	2467	2198
MR 825	K	2530	2754	2831	2914	3158	2736	2544	2092	2607	3282	3004	2768	3529
	R	2608	2479	2657	2318	2445	2721	2731	2194	2498	2945	2108	2519	2305
MR 849	K	3658	3263	3046	2999	3314	3303	3003	3258	3327	3344	3146	3242	2204
	R	2785	3041	2606	2325	2702	2657	2549	2773	2799	3057	2500	2709	2978
CS 3541	K	2445	2435	2274	2509	2411	2601	2535	1840	2626	2511	2962	2468	2217
	R	2118	2221	2278	1832	1999	1689	1907	1942	2614	2232	2724	2141	1456
Array mean of female parents	K	2788	2819	2640	2775	2850	2949	2679	2433	2871	3146	2987	2812a	
	R	2512	2514	2620	2204	2284	2235	2403	2120	2727	2613	2463	2427	
Mean of female parents	K	1827	2171	1875	2137	2201	2306	2187	1657	2216	2504	2796		2291b
	R	1758	2162	1801	1008	1475	1263	2085	1390	1656	2439	1893		1872

a = hybrids' means b = parents' means

S.E. hybrids = K (346.89) R (281.41) C.V. hybrids = K (12) R (12)

S.E. parents = K (234.40) R (224.80) C.V. parents = K (10) R (12)

LSD .05 hybrids= K (555) R (450) LSD .05 parents=K (387) R (371)

Appendix A.6 : Means for 1000 grain weight (g) of the hybrids and their parents in Kharif and Rabi Experiments

Males		Females											Array mean of male parents	Mean of male parents
		MA 1	MA 2	MA 3	MA 4	MA 5	MA 6	MA 9	2219 A	2977 A	623 A	296 A		
MR 801	K	17.60	17.23	17.27	20.22	17.22	18.36	18.75	18.60	18.37	19.70	22.61	18.72	22.18
	R	22.52	19.52	18.74	16.64	17.87	17.86	20.00	20.64	15.88	23.58	21.04	19.48	13.61
MR 861	K	24.10	24.40	24.00	28.72	26.24	27.67	23.86	22.75	24.96	20.14	24.89	24.70	37,60
	R	28.32	27.61	29.60	23.72	26.77	25.28	27.28	23.54	24.49	32.04	26.20	26.80	34.44
MR 864	K	16.21	17.00	18.30	20.45	19.11	15.70	16.74	20.08	18.51	19.15	19.56	18.26	22.72
	R	25.07	22.51	24.67	25.76	24.70	25.41	22.76	24.77	21.74	25.62	25.68	24.43	20.65
MR 803	K	20.11	19.25	20.12	25.26	22.64	23.60	22.46	19.81	22.41	20.54	23.79	21.82	31.69
	R	22.77	23.52	25.91	23.53	23.72	18.96	20.86	22.95	19.93	30.61	23.63	23.31	30.58
MR 867	K	19.55	21.12	20.24	26.24	28.11	25.43	25.04	21.13	22.43	25.26	25.79	23.67	31.56
	R	27.89	26.03	29.98	29.22	25.66	28.07	24.99	26.11	26.53	29.50	28.68	27.51	28.86
MR 824	K	18.88	20.22	18.85	32.54	18.20	18.84	17.57	20.75	17.00	19.78	18.37	20.09	24.13
	R	24.55	23.52	24.50	23.16	20.71	20.75	20.85	25.18	20.31	24.71	17.80	22.37	22.68
MR 825	K	17.75	16.28	17.61	16.01	16.75	16.37	19.17	18.27	14.11	16.35	15.50	16.74	19.23
	R	19.63	18.32	16.52	14.82	15.59	16.40	17.58	19.96	18.71	21.77	16.80	17.83	18.38
MR 849	K	20.84	21.33	23.27	25.05	23.60	25.55	23.38	20.41	20.31	24.44	22.28	22.77	17.92
	R	26.08	24.47	25.42	26.13	22.00	21.37	20.14	24.27	23.32	27.13	21.51	23.80	20.20
CS 3541	K	17.14	17.64	18.07	19.30	16.72	15.64	21.17	18.96	17.65	17.91	16.48	17.88	23.85
	R	20.30	20.85	20.57	18.25	14.53	18.26	19.97	18.44	18.91	21.50	26.03	19.78	24.16
Array mean of female parents	K	19.13	19.39	19.75	23.75	20.95	20.80	20.90	20.08	19.53	20.36	21.03	20.52a	
	R	24.13	22.93	23.99	22.36	21.28	21.37	21.60	22.87	21.09	26.27	23.04	22.81	
Mean of female parents	K	18.87	19.39	20.78	18.00	19.58	21.72	20.10	21.70	17.00	21.72	21.31		22.55b
	R	13.22	10.80	11.29	9.06	9.14	10.59	17.85	14.49	7.50	20.95	13.45		17.59

a = hybrids' means   b = parents' means

S.E. hybrids = K (2.73) R (3.17)   C.V. hybrids = K 9(13) R (10)

S.E. parents = K (1.46) R (1.94)   C.V. parents = K (6) R (11)

LSD .05 hybrids = K (4.36) R (3.48)   LSD .05 parents = K (2.42) R (3.21)

Appendix A.7 : Means for breaking strength (kg) of the hybrids and their parents in Kharif and Rabi Experiments

Males		Females											Array mean of male parents	Mean of male parents
		MA 1	MA 2	MA 3	MA 4	MA 5	MA 6	MA 9	2219 A	2077 A	623 A	296 A		
MR 801	K	4.6	4.2	4.3	5.7	5.1	4.7	5.3	4.8	5.5	5.6	4.8	5.0	6.3
	R	5.9	5.8	5.4	5.5	5.3	5.3	6.2	6.4	5.2	7.7	6.3	5.9	6.2
MR 861	K	5.5	5.6	5.8	6.3	5.5	5.8	5.7	5.1	6.0	5.1	7.4	5.8	7.2
	R	6.6	6.7	7.1	6.0	7.0	6.6	6.9	6.4	6.3	8.5	6.8	6.8	7.7
MR 864	K	4.3	4.5	4.7	5.2	5.0	4.1	5.5	4.9	4.8	6.9	4.1	4.9	6.4
	R	7.2	6.6	6.4	6.9	6.9	6.8	6.7	7.4	6.8	8.0	5.9	6.9	7.6
MR 803	K	4.8	4.6	5.5	5.8	5.2	5.3	6.4	4.9	6.3	7.0	4.6	5.1	7.1
	R	7.1	6.7	7.0	6.5	6.2	5.5	6.9	7.3	6.0	9.1	6.9	6.8	8.7
MR 867	K	6.2	7.0	6.9	8.1	5.2	7.1	7.3	7.2	6.7	11.9	4.8	7.2	10.7
	R	8.7	8.0	8.9	8.3	8.2	9.0	9.0	8.3	8.1	12.4	7.3	8.7	12.7
MR 824	K	5.2	5.1	5.1	7.4	4.7	5.9	6.8	5.5	5.7	8.8	5.3	6.0	9.2
	R	7.4	7.3	7.6	7.8	6.5	6.9	7.5	7.4	7.2	11.0	6.4	7.5	10.4
MR 825	K	4.7	4.4	4.8	5.2	5.7	5.0	5.8	4.6	4.9	7.1	4.4	5.1	8.0
	R	6.2	6.1	5.6	5.3	5.8	5.5	7.0	6.6	5.4	8.0	6.1	6.1	8.5
MR 849	K	5.5	4.9	5.3	6.8	5.7	6.4	5.7	5.2	5.8	7.3	5.4	5.8	5.7
	R	7.0	6.9	6.9	7.0	5.8	6.0	6.0	7.5	6.7	9.7	5.6	6.8	6.9
CS 3541	K	4.7	4.5	5.1	5.1	4.7	4.3	5.7	4.7	4.3	5.1	4.4	4.8	6.4
	R	5.6	6.0	5.4	5.8	5.2	5.1	6.0	6.2	5.5	7.7	6.6	5.9	7.5
Array mean of female parents	K	5.1	5.0	5.3	6.2	5.3	5.4	6.0	5.2	5.6	7.2	5.0	5.5a	
	R	6.9	6.7	6.7	6.6	6.3	6.3	6.9	7.1	6.4	9.1	6.4	6.8	
Mean of female parents	K	4.9	4.7	4.9	4.9	4.9	4.7	6.1	5.0	3.6	5.1	4.4		6.0b
	R	4.2	3.7	3.2	3.3	2.8	3.3	5.7	5.4	2.4	6.6	3.6		6.0

a = hybrids' means b = parents means

S.E. hybrids = K (0.67) R (0.51) C.V. hybrids = K(14) R (7)

S.E. parents = K (0.40) R (0.65) C.V. parents = K(7) R (11)

LSD .05 parents= K (1.24) R (0.82) LSD .05 [illegible]

Appendix A.8 : Means for floaters percentage of hybrids and their parents in Kharif and Rabi Experiments

Males		Females											Array mean of male parents	Mean of male parents
		MA 1	MA 2	MA 3	MA 4	MA 5	MA 6	MA 9	2219 A	2077 A	623 A	296 A		
MR 801	K	3	9	8	14	13	25	17	5	27	13	60	18	29
	R	22	21	20	41	60	33	36	15	54	17	25	31	63
MR 861	K	10	8	19	21	28	26	15	5	15	11	51	19	47
	R	8	6	9	23	34	40	34	17	33	9	22	21	20
MR 864	K	7	10	13	13	44	38	29	16	30	15	62	25	52
	R	16	16	11	14	34	37	28	2	28	11	29	21	36
MR 803	K	28	8	14	6	40	30	14	13	14	6	47	20	27
	R	14	21	15	17	47	42	34	11	24	13	41	25	25
MR 867	K	7	9	2	5	19	8	8	7	8	2	41	11	12
	R	9	6	9	8	12	15	17	4	19	14	36	14	12
MR 824	K	5	4	2	8	22	23	5	4	12	5	33	11	11
	R	5	17	10	19	33	22	20	5	23	10	38	18	20
MR 825	K	7	11	8	8	36	30	25	7	21	11	30	18	18
	R	15	30	44	44	37	54	31	12	41	26	69	37	26
MR 849	K	13	7	42	22	21	30	33	22	62	40	67	33	95
	R	7	12	17	16	37	40	32	14	42	19	37	25	27
CS 3541	K	11	15	7	9	43	32	18	5	23	9	44	20	21
	R	10	20	15	22	72	71	25	17	27	18	35	30	36
Array mean of female parents	K	10	9	13	12	30	27	18	9	21	12	48	19a	
	R	12	17	17	23	41	39	29	11	32	15	37	25	
Mean of female parents	K	43	34	49	62	37	52	38	23	95	71	86		45b
	R	58	74	96	96	99	85	55	38	98	57	97		60

a = Overall means of hybrids b = Overall means of parents

S.E. (hybrids) = K (0.94) R (1.00) C.V. hybrids = K (24) R (21)
S.E. (parents) = K (0.92) R (0.79) C.V. parents = K (14) R (11)
LSD .05 hybrids = K (1.50) R (1.60) LSD .05 parents=K (1.52) R (1.31)

Appendix A.9 : Means for lodging score (1 = 0%, 10 > 90% plants lodged) of hybrids and their parents in Kharif and Rabi Experiments

Males		Females											Array means of male parents	Means of male parents
		MA 1	MA 2	MA 3	MA 4	MA 5	MA 6	MA 9	2219 A	2077 A	623 A	296 A		
MR 801	K	6	6	7	3	3	4	1	7	2	5	1	4	-*
	R	5	6	7	5	5	6	6	5	7	4	4	6	2
MR 861	K	1	1	2	1	1	1	1	4	1	2	1	1	-
	R	2	3	2	3	3	4	3	5	5	2	3	3	1
MR 864	K	6	7	4	4	2	5	1	4	6	2	1	4	-
	R	3	3	3	3	3	3	2	3	4	4	3	3	1
MR 803	K	3	4	5	1	1	3	1	4	3	2	1	3	-
	R	4	5	4	5	3	6	4	4	5	3	4	4	1
MR 867	K	3	4	5	1	2	2	3	5	5	3	1	3	-
	R	3	1	3	2	3	3	4	3	4	2	2	3	1
MR 824	K	3	4	4	3	5	2	1	3	5	6	1	3	-
	R	3	4	4	4	5	6	5	6	5	4	5	5	2
MR 825	K	2	4	4	3	4	2	1	8	4	3	1	3	-
	R	6	6	6	6	6	6	5	6	6	6	5	6	3
MR 849	K	1	2	1	1	1	1	1	1	2	1	1	1	-
	R	3	3	4	4	6	5	5	4	4	2	5	4	1
CS 3541	K	6	5	4	2	3	2	1	7	3	4	1	3	-
	R	5	5	4	6	7	7	4	7	5	7	4	6	1
Array means of female parents	K	3	4	4	2	3	2	1	5	3	3	1	3a	
	R	4	4	4	4	5	5	4	5	5	4	4	4	
Means of female parents	K	-	-	-	-	-	-	-	-	-	-	-		-b
	R	1	2	1	2	3	3	2	1	1	2	1		2

* - In Kharif, the parents did not lodge

a = Overall means of hybrids b - overall means of parents

Appendix A.10 : Means for rust score (1=0%, 5 > 40% leaf area damaged) of hybrids and their parents in Rabi Experiments

Males	Females											Array mean of male parents	Mean c male parents
	MA 1	MA 2	MA 3	MA 4	MA 5	MA 6	MA 9	2219 A	2077 A	623 A	296 A		
MR 801	3.0	3.7	4.0	3.7	3.7	3.7	3.0	4.0	4.3	3.3	3.3	3.6	3.7
MR 861	3.0	4.0	4.0	4.0	3.7	3.7	3.3	4.0	4.3	4.0	4.0	3.8	3.0
MR 864	2.0	2.3	2.7	3.0	1.7	1.7	2.3	2.0	2.3	3.0	2.3	2.3	1.0
MR 803	3.7	3.7	4.0	4.3	4.0	4.0	2.7	3.3	4.0	3.7	3.3	3.7	3.3
MR 867	3.7	3.7	3.0	3.7	3.3	4.0	3.7	3.3	3.3	4.0	3.3	3.5	3.3
MR 824	3.3	3.3	3.7	4.3	4.0	3.7	3.3	3.7	4.0	3.3	3.7	3.7	3.0
MR 825	3.3	3.7	3.0	4.0	3.7	3.7	3.7	3.7	4.0	3.7	3.7	3.7	3.3
MR 849	3.3	3.7	4.0	4.0	4.0	4.0	3.7	3.7	4.0	3.7	3.3	3.8	2.3
CS 3541	3.7	4.0	3.3	4.0	4.0	4.0	2.7	3.3	4.0	4.0	3.0	3.6	3.3
Array mean of female parents	3.2	3.6	3.5	3.9	3.6	3.6	3,2	3.4	3.8	3.6	3.3	3.5a	
Means of female parents	4.0	4.0	4.0	4.0	3.7	3.7	3.3	3.7	4.0	4.0	4.0		3.4b

a = Overall means of hybrids S.E. (hybrids) = 0.16 C.V. (hybrids) = 9
b = Overall means of parents S.E. (parents) = 0.28 C.V. (parents) = 15

Appendix A.11: Means for percentage of Water Absorption of Hybrids and their parents in Kharif and Rabi Experiments.

Males		Females: MA 5	MA 9	2077 A	296 A	Array mean of male parents	Mean of male parents
MR 861	K	26.2	27.2	23.0	27.9	26.1	25.1
	R	24.7	23.6	23.4	22.3	23.5	19.9
MR 864	K	30.8	29.9	27.2	29.0	29.2	28.6
	R	26.5	28.4	28.0	25.2	27.0	29.2
MR 824	K	32.7	30.0	30.9	33.0	31.6	30.9
	R	31.9	30.0	30.9	30.0	30.7	30.8
MR 825	K	31.3	29.7	32.7	30.9	31.1	29.3
	R	31.8	28.4	31.2	30.4	30.4	29.8
CS 3541	K	30.6	29.7	28.6	30.8	29.9	28.4
	R	32.0	27.4	27.9	25.6	28.2	29.4
Array mean of female parents	K	30.3	29.3	28.5	30.3	29.6[a]	
	R	29.4	27.6	28.3	26.7	28.0	
Mean of female parents	K	28.4	29.7	36.4	30.7		29.7[b]
	R	45.1	29.5	40.1	29.8		31.5

S.E. hybrids = K(2.17) R(1.97) C.V. hybrids = K(7) R (7)

S.E. parents = K(1.58) R(3.14) C.V. parents = K(5) R(10)

LSD .05 hybrids=K(4.39) R(3.99) LSD .05 parents=K(3.35) R(6.66)

a = hybrids means b = parent means

Appendix A.12: Means for Particle Size Index of Hybrids and their Parents in Kharif and Rabi Experiments.

Males		Females				Array mean of male parents	Mean of male parents
		MA 5	MA 9	2077 A	296 A		
MR 861	K	42.7	38.7	42.7	48.8	43.2	50.8
	R	39.7	40.9	44.1	40.4	41.3	39.6
MR 864	K	45.5	40.1	43.9	44.6	43.5	48.7
	R	40.9	38.0	46.6	40.1	41.4	34.3
MR 824	K	30.2	29.2	35.6	41.7	23.2	37.6
	R	36.1	35.6	37.8	40.2	37.4	36.5
MR 825	K	38.8	37.1	33.8	39.1	37.2	42.1
	R	47.2	36.1	44.0	43.0	42.6	35.3
CS 3541	K	34.3	37.0	37.1	40.1	37.1	36.6
	R	39.1	34.8	40.3	40.1	38.6	32.2
Array mean of female parents	K	38.3	36.4	38.6	42.9	39.0[a]	
	R	40.6	37.1	42.6	40.8	40.3	
Mean of female parents	K	49.3	37.6	74.6	68.3		49.6[b]
	R	55.3	40.0	67.1	62.2		44.7

[a]Hybrid means [b]Parent means

S.E. hybrids = K(2.43) R (4.94) C.V. hybrids = K (6) R (12)

S.E. parents = K(2.97) R (3.04) C.V. parents = K (6) R (7)

LSD .05 hybrids= K(4.92) R (10.00) LSD .05 parents =K(6.30) R(6.44)

Appendix A.13: Means for Rolling Quality (cm) of Hybrids and their Parents in Kharif and Rabi Experiments.

Males		Females				Array mean of male parents	Mean of male parents
		MA 5	MA 9	2077 A	296 A		
MR 861	K	22.3	20.8	20.5	21.7	21.3	19.2
	R	25.0	24.9	23.3	24.6	24.4	24.6
MR 864	K	20.0	22.3	20.3	20.4	20.7	22.2
	R	24.5	23.9	24.8	25.1	24.6	24.6
MR 824	K	19.0	20.9	19.6	20.7	20.0	21.7
	R	23.7	23.2	23.6	23.1	23.4	23.8
MR 825	K	21.7	20.2	18.3	20.9	20.3	20.5
	R	23.8	22.7	23.4	22.6	23.1	23.5
CS 3541	K	22.1	21.2	19.4	20.4	20.8	21.1
	R	24.8	23.2	23.6	24.6	24.0	24.3
Array mean of female parents	K	21.0	21.1	19.6	20.8	20.6[a]	
	R	24.4	23.6	23.7	24.0	23.9	
Mean of female parents	K	20.3	19.9	14.9	16.8		19.6[b]
	R	23.2	23.2	18.0	16.4		22.4

[a] Hybrid means

[b] Parent means

S.E. hybrids = K(0.88) R(0.94) C.V. hybrids = K(4) R(4)

S.E. parents = K(1.16) R(1.17) C.V. parents = K(6) R(5)

LSD .05 hybrids=K(1.78) R(1.90) LSD .05 parents =K(2.45) R(2.48)

Appendix A.14 : Mean of Gel Spreading (mm) of Hybrids and their parents in Kharif and Rabi Experiments

Males		Females				Array mean of male parents	Mean of male parents
		MA 5	MA 9	2077 A	296 A		
MR 861	K	59.5	59.3	61.3	62.7	60.7	63.2
	R	62.0	61.3	62.3	61.7	61.8	59.3
MR 864	K	62.7	61.7	63.8	65.3	63.4	70.3
	R	62.7	61.7	64.7	64.3	63.3	64.3
MR 824	K	56.7	56.8	58.7	62.2	58.6	58.7
	R	62.7	59.7	62.3	61.0	61.4	60.0
MR 825	K	61.3	63.0	61.5	61.0	61.7	63.7
	R	62.7	63.7	66.7	65.7	64.7	62.0
CS 3541	K	59.1	60.5	62.2	63.0	61.9	60.5
	R	64.0	60.7	64.7	61.3	62.7	61.7
Array mean of female parents	K	59.9	60.3	62.1	62.8	61.3[a]	
	R	62.8	61.4	64.1	62.8	62.8	
Mean of female parents	K	64.3	61.7	74.3	75.7		65.8[b]
	R	66.3	59.3	74.3	72.3		64.4

[a]Hybrid means

S.E. Hybrids = K(1.85) R(1.87)

S.E. Parents = K(3.28) R(1.98)

LSD .05 hybrids= K(3.76) R(6.95)

[b]Parent means

C.V. Hybrids=K(3) R(3)

C.V. Parents=K(5) R(3)

LSD .05 parents=K([illegible].95) R(4.20)

Appendix B.1. Estimates of heterosis % for days to 50% flowering compared to earlier parents in Kharif and Rabi experiments

Males		Females											Average heterosis of male parents
		MA 1	MA 2	MA 3	MA 4	MA 5	MA 6	MA 9	2219A	2077A	623 A	296 A	
MR 801	K	-4.7**	-4.7**	-7.9**	-4.4**	-2.2	-2.3	-2.1	-4.9**	1.0	-1.7	-6.9**	-3.7
	R	-1.2	-0.6	-5.3*	-2.9	1.2	0.6	-3.5	-1.8	-4.7*	-3.5	-2.3	-2.2
MR 861	K	0.0	1.2	-1.1	0.0	1.2	1.7	-4.2**	-0.6	-4.1**	0.6	-4.2**	-0.9
	R	-1.2	0.0	-0.6	-4.1*	1.2	1.2	-4.1*	-1.8	-1.7	-4.7*	-2.3	-1.6
MR 864	K	-1.8	-1.2	-2.8	-3.9**	-0.6	-0.6	-4.7**	-1.8	-5.7**	0.0	-4.8**	-2.5
	R	-0.6	0.0	-0.6	-1.2	0.6	0.0	0.0	2.4	1.2	0.6	1.2	-0.3
MR 803	K	0.0	-2.4	-4.0**	-3.3**	1.1	1.1	-4.7**	-3.0*	-4.2**	1.7	-5.8**	-2.1
	R	-1.8	0.0	-2.4	-1.2	4.3*	0.6	-1.8	-3.1	0.0	0.0	-1.2	-0.6
MR 867	K	0.0	-3.0*	-5.1	-3.3**	0.0	1.1	-3.7**	-2.4	-5.7**	2.9*	-4.2**	-2.1
	R	-1.8	-0.6	-4.7*	-3.5	0.6	1.2	-4.1*	-2.4	-0.6	-3.0	-1.2	-1.8
MR 824	K	-3.5**	-4.7**	-5.7**	-3.9**	-2.2	-1.1	-5.3**	-6.1**	-6.8**	-1.1	-9.0**	-4.5
	R	-2.4	-1.2	-4.2*	-1.8	1.9	0.0	-3.0	-4.3*	1.2	-1.8	-2.4	-1.6
MR 825	K	-1.2	-2.4	-4.5**	-2.8*	0.6	1.7	-3.2**	-3.7**	-6.6**	2.9*	-5.3**	-2.2
	R	-0.6	0.0	0.6	-1.2	-0.6	-0.6	-1.2	-3.1	2.4	2.4	0.6	-0.1
MR 849	K	16.6**	13.6**	13.1**	11.6**	14.0**	15.2**	8.4**	17.7**	-0.5	18.9**	11.1**	12.7
	R	-1.8	1.8	-6.1**	-8.8**	1.9	1.2	-4.7*	0.0	-12.2**	-2.3	-13.8**	-4.1
CS 3541	K	-1.2	-1.8	-3.4**	-5.0**	-1.7	0.6	-1.6	-2.4	-3.2**	-1.7	-5.8**	-2.5
	R	-2.4	0.0	-1.8	-1.2	-1.2	-0.6	-1.2	-3.7	-0.6	-2.4	-0.6	-1.4
Average heterosis of male parents	K	0.5	-0.6	-2.4	-1.7	1.1	1.9	-2.3	-0.8	-4.0	2.5	-3.9	-0.9a
	R	-1.5	-0.1	-2.8	-2.9	1.1	0.4	-2.6	-2.5	-1.7	-1.6	-2.7	-1.5

*significant (p=0.05) **significant (p=0.01)

a = overall heterosis

Appendix B.2. Estimates of heterosis % for plant height over the shorter parent in Kharif and Rabi experiments

Males		Females											Average heterosis of male parents
		MA 1	MA 2	MA 3	MA 4	MA 5	MA 6	MA 9	2219A	2077A	623A	296A	
MR 801	K	45.0**	30.0**	35.9**	59.1**	44.3**	53.1**	15.2**	55.3**	62.5**	52.0**	40.4**	44.8
	R	57.6**	46.5**	46.6**	47.0**	58.2**	51.6**	9.2**	55.6**	45.9**	49.4**	51.4**	47.2
MR 861	K	62.2**	45.4**	49.1**	68.7**	56.8**	55.8**	13.8**	55.3**	60.3**	29.7**	39.2**	48.8
	R	72.7**	63.4**	63.0**	68.2**	64.2**	62.5**	19.7**	60.3**	66.2**	31.5**	52.8**	56.8
MR 864	K	60.8**	45.6**	54.4**	69.0**	54.9**	52.8**	16.9**	63.2**	61.0**	50.2**	52.9**	52.9
	R	68.2**	74.6**	60.3**	66.7**	59.7**	60.9**	17.1**	65.1**	63.5**	37.4**	56.9**	57.3
MR 803	K	75.8**	41.8**	52.2**	72.7**	54.4**	62.3**	15.7**	55.9**	66.3**	43.4**	51.2**	53.8
	R	63.6**	63.4**	57.5**	66.1**	58.2**	57.8**	15.8**	61.9**	63.5**	31.9**	63.9**	54.9
MR 867	K	106.7**	71.5**	92.6**	123.5**	112.8**	126.6**	66.4**	109.7**	111.2**	76.3**	106.6**	100.4
	R	110.6**	97.2**	100.0**	112.1**	103.0**	112.5**	55.3**	114.3**	110.8**	62.6**	120.8**	99.9
MR 824	K	45.8**	39.1**	43.5**	66.1**	46.6**	63.1**	20.8**	52.3**	50.2**	56.4**	33.9**	47.1
	R	56.1**	50.7**	46.6**	63.6**	55.2**	60.9**	18.7**	63.5**	51.3**	53.3**	43.1**	51.2
MR 825	K	50.8**	35.4**	46.1**	67.8**	47.9**	56.9**	19.1**	53.2**	47.7**	35.2**	45.3**	45.9
	R	53.0**	52.1**	47.9**	47.0**	43.3**	51.6**	5.3	55.6**	58.1**	29.7**	45.8**	44.5
MR 849	K	96.1**	75.8**	80.1**	98.8**	79.2**	89.1**	30.2**	98.8**	74.3**	43.6**	58.8**	75.0
	R	37.9**	71.8**	61.6**	69.7**	68.7**	71.9**	14.5**	73.0**	67.6**	36.3**	54.2**	57.0
CS 3541	K	37.2**	22.1**	34.6**	49.6**	30.2**	33.1**	9.2**	45.0**	40.9**	32.9**	37.0**	33.8
	R	43.9**	47.9**	39.7**	51.5**	25.4**	32.8**	5.5	44.4**	49.3**	47.9**	54.2**	40.2
Average heterosis of female parents	K	64.5	45.2	54.3	75.0	58.7	65.9	23.0	65.4	63.8	46.6	51.7	55.8[a]
	R	62.6	63.1	58.1	65.8	59.5	62.5	17.9	66.0	64.0	42.2	60.3	56.6

** significant (p = 0.01)   a = overall heterosis

Appendix B.3. Estimates of heterosis % for panicle length over superior parent in Kharif and Rabi experiments

Males		Females											Average heterosis of male parents
		MA 1	MA 2	MA 3	MA 4	MA 5	MA 6	MA 9	2219A	2077A	623A	296A	
MR 801	K	12.3**	14.1**	14.1**	11.3*	11.1**	15.4**	18.6**	16.0**	17.5**	10.0**	2.7	13.0
	R	9.0*	14.1**	16.7**	2.2	9.8**	12.5**	7.7**	4.5	22.9**	7.9**	17.1**	11.3
MR 861	K	4.1	5.2	11.1**	-3.3	5.2	2.1	3.8	4.1	-4.8*	-1.5	-2.3	2.2
	R	9.5*	0.0	6.4	-5.5	1.2	0.0	0.0	0.0	-1.0	4.5	7.3*	2.0
MR 864	K	3.1	2.8	2.8	3.3	10.4**	7.1*	10.6**	16.0**	8.4**	17.8**	4.6	7.9
	R	7.1*	2.4	9.5**	7.7*	13.1**	10.7**	5.9	9.1**	8.3**	20.4**	16.7**	10.1
MR 803	K	32.5**	20.5**	25.8**	4.9	11.0**	5.1	12.2**	9.3**	4.2	8.3**	5.9*	12.7
	R	11.5**	12.8**	15.4**	0.0	4.9	7.5*	14.1**	7.9*	8.3**	17.0**	15.8**	10.5
MR 867	K	17.7**	17.2**	13.7**	-9.3**	0.8	1.3	6.6*	-2.9	-6.4**	-12.1**	-8.6**	1.6
	R	9.7*	10.8**	2.6	-8.8**	-2.4	0.0	6.4	-5.7	-.31	-6.8*	6.1	1.1
MR 824	K	16.5**	13.7**	22.7**	0.2	9.4**	9.5**	16.5**	11.0**	8.6**	-0.4	-1.5	9.7
	R	19.4**	16.2**	15.4**	-1.1	4.9	6.2	11.5**	1.1	3.1	1.1	11.0**	8.1
MR 825	K	12.1**	11.4**	13.8**	12.6**	15.6**	11.4**	13.6**	17.9**	19.1**	18.2**	9.0**	14.1
	R	4.7	-1.2	7.1*	9.9**	8.2*	7.1*	10.6**	12.5**	7.3**	23.9**	14.1**	9.5
MR 849	K	25.4**	25.4**	24.2**	-2.7	10.4**	5.9*	6.9*	12.4**	-2.4	-7.6*	-7.3**	8.2
	R	11.5**	15.4**	14.1**	8.8**	8.5*	17.5**	11.5**	12.5**	-1.0	4.5	19.5**	11.2
CS 3541	K	12.4**	14.4**	18.6**	-1.3	1.0	3.3	4.1	7.2*	2.6	2.5	1.7	6.0
	R	8.2*	2.7	10.3**	-3.3	2.4	2.5	2.6	4.5	-1.0	3.4	17.1	4.5
Average heterosis of female parents	K	15.1	13.9	16.3	1.7	8.3	6.8	10.3	10.1	5.2	3.9	0.5	8.4a
	R	10.1	8.1	10.8	1.1	5.6	7.1	7.8	5.8	4.9	8.4	13.9	7.6

*significant (p=0.05) **significant (p=0.01)

a = overall heterosis

Appendix B.4. Estimates of heterosis % for grain yield per panicle compared to superior parent in Kharif and Rabi experiments

Males		Females											Average heterosis of male parents
		MA 1	MA 2	MA 3	MA 4	MA 5	MA 6	MA 9	2219A	2077A	623A	296A	
MR 801	K	-18.5	-7.9	-35.3**	-5.1	-18.4	-5.4	-26.5*	-27.9*	4.4	11.4	2.3	-11.5
	R	102.3**	94.4**	92.3**	35.2	47.5*	44.9	11.8	47.8*	71.9**	2.9	71.4**	56.6
MR 861	K	-10.1	2.7	-12.1	12.8	6.0	11.6	-2.9	-22.1*	-0.1	-4.5	6.8	-1.1
	R	25.4*	12.9	43.9**	-5.8	-3.2	-11.2	13.5	-19.2	17.5	34.7**	-4.0	9.5
MR 864	K	-25.2*	-13.5	-14.2	2.8	-13.3	-15.1	-23.5*	-33.5**	-24.5*	18.5	2.2	-12.7
	R	62.0**	32.8**	56.9**	44.9**	34.8**	31.9**	23.1*	22.2	47.3**	44.9**	44.1**	40.4
MR 803	K	4.2	-13.3	-12.2	13.7	11.7	-10.3	-12.2	-10.5	0.3	12.1	9.3	-0.6
	R	-12.6	-8.3	5.6	-16.0	-10.2	-30.5**	-17.4	-20.5*	-17.8	29.4**	-7.7	-9.6
MR 867	K	-25.2**	-15.8	-27.4**	-7.4	4.5	18.7*	-0.1	-22.0*	3.3	-8.4	-0.5	-7.3
	R	25.0**	21.9**	40.3**	-17.1	4.5	9.1	9.0	10.0	41.2**	33.9**	65.6**	22.1
MR 824	K	-24.4*	-26.2**	-15.2	-5.0	-19.6*	-10.0	-17.7	-10.1	-27.4**	-0.4	0.6	-14.1
	R	29.7**	16.0	39.5**	2.9	-8.3	-1.7	11.9	-9.6	11.1	39.5**	-13.5	10.7
MR 825	K	-36.3**	-34.2**	-27.6**	-31.6**	-21.6*	-34.7**	-27.6**	-43.7**	-47.1**	-20.4*	-31.5*	-32.4
	R	20.5	6.8	3.8	-18.9	-7.5	5.3	13.0	3.2	7.1	25.5*	-18.9	3.6
MR 849	K	90.7**	68.3**	73.1**	85.8**	86.4**	108.8**	60.8**	65.7**	69.9**	49.4**	17.3	70.6
	R	19.1*	21.9*	8.6	0.4	-3.0	-5.3	-16.3	10.5	7.0	35.8**	-12.9	6.0
CS 3541	K	-20.8	-18.7	-22.2	-8.0	-22.1	-22.1	1.0	-34.3	-11.2	-17.5	-17.2	-17.5
	R	21.4	31.6*	32.0*	-3.2	-18.4	-15.1	2.1	2.0	37.0*	-4.6	101.2**	16.9
Average heterosis of female parents	K	-7.3	-6.5	-10.3	6.4	1.5	4.6	-5.4	-15.4	-3.6	4.5	-1.2	-3.0a
	R	32.5	25.6	35.9	2.5	4.0	3.0	5.6	5.1	24.7	26.9	25.0	17.4

*significant (p=0.05) **significant (p=0.01)

a = overall heterosis

Appendix B.5. Estimates of heterosis % for number of grains per panicle compared to superior parent in Kharif and Rabi experiments

Males		Females											Average heterosis of male parents
		MA 1	MA 2	MA 3	MA 4	MA 5	MA 6	MA 9	2219A	2077A	623A	296A	
MR 801	K	0.8	17.2	-18.3*	2.8	3.5	12.9	-14.4	-15.4	22.2*	24.8**	-2.4	3.1
	R	22.6	10.9	36.5*	9.7	16.3	11.6	0.0	-1.3	48.5**	-9.5	10.4	14.2
MR 861	K	29.2*	21.1	25.8*	18.0	16.9	12.6	18.3	28.1*	14.3	19.8*	-2.7	18.3
	R	30.3*	-2.2	39.4**	36.3**	24.6	20.7	3.1	15.9	49.9**	-10.6	0.7	18.9
MR 864	K	3.7	14.1	5.9	12.4	2.9	21.9*	3.0	-24.8**	-4.2	38.2**	11.5	7.7
	R	32.7**	21.2*	30.3**	15.3	11.6	6.1	10.9	0.9	39.0**	17.4*	13.7	18.1
MR 803	K	65.2**	26.0*	38.5*	27.2*	33.9**	5.0	7.9	41.8**	21.4*	28.5**	-2.2	26.6
	R	17.4	4.6	24.7*	9.4	17.4	11.2	9.8	6.0	27.2*	1.4	19.8	13.5
MR 867	K	20.6*	26.3**	12.8	12.0	18.2	46.6**	26.8**	15.2	45.4**	11.6	7.6	22.1
	R	29.0**	30.2**	34.5**	15.7	17.3	11.9	25.5*	21.3*	52.8**	11.5	66.6**	28.8
MR 824	K	-2.5	-11.7	8.4	8.6	9.2	15.8	12.5	4.9	3.0	22.1*	23.8**	8.6
	R	19.5*	11.5	29.3**	0.2	0.6	7.1	22.3*	-18.3	22.7*	16.6	10.6	11.1
MR 825	K	-28.3**	-21.9**	-19.8**	-17.4**	-10.5	-22.5**	-27.9**	-40.7**	-26.1**	-7.0	-14.9*	-21.5
	R	13.2	7.5	15.3	0.6	6.1	18.0*	18.5*	-4.8	8.4	20.8*	-8.5	8.7
MR 849	K	66.0**	48.0**	38.2**	36.1**	50.4**	43.2**	36.2**	47.8**	50.1**	33.5**	12.5	42.0
	R	-6.5	2.1	-12.5	-21.9**	-9.3	-10.8	-14.4*	-6.9	-6.0	2.7	-16.0*	-9.0
CS 3541	K	10.3	9.8	2.6	13.2	8.7	12.8	14.3	-17.0	18.4	0.2	5.9	7.2
	R	20.5	2.8	26.5*	25.8	35.6*	16.0	-8.5	33.4*	57.8**	-8.5	43.9**	22.3
Average heterosis of female parents	K	18.3	14.3	10.5	12.5	14.8	16.5	8.5	4.4	16.5	19.1	4.3	12.7[a]
	R	19.9	9.8	24.9	10.1	13.4	10.2	7.5	5.1	33.4	4.6	15.7	14.1

*significant (p = 0.05) **significant (p = 0.01)

a = overall heterosis

Appendix B.6 : Estimates of heterosis % for 1000 grain weight compared to superior parents in Kharif and Rabi Experiments

Males		Females											Average heteros of male parents
		MA 1	MA 2	MA 3	MA 4	MA 5	MA 6	MA 9	2219 A	2077 A	623 A	296 A	
MR 801	K	-20.7*	-22.3**	-22.1**	-8.8	-22.4**	-17.2	-15.5	-16.1	-17.2*	-11.2	2.0	-15.6
	R	65.5**	43.4**	37.7**	22.3**	31.3**	31.2**	11.9	42.5**	16.7	12.5	54.6**	33.6
MR 861	K	-36.0**	-35.1**	-36.3**	-23.6**	-30.2**	-26.4**	-36.5**	-39.5**	-33.6**	-46.4**	-33.8**	-34.3
	R	-17.8**	-19.8**	-14.0**	-31.1**	-22.3**	-26.6**	-20.8**	-31.6**	-28.9**	- 7.0	-23.9**	-22.2
MR 864	K	-28.7**	-25.2**	-19.6*	-10.0	-15.9	-30.9**	-26.3**	-11.6	-18.5*	-15.7*	-13.9	-19.7
	R	21.4**	9.0	19.5**	24.8**	19.6**	23.0**	10.2	19.9**	5.3	22.3*	24.4**	18.2
MR 803	K	-36.5**	-39.2**	-36.5**	-20.3**	-28.6**	-25.5**	-29.1**	-37.5**	-29.3**	-35.2**	-24.9**	-31.1
	R	-25.5**	-23.1**	-15.3**	-23.1**	-22.4**	-38.0**	-31.8**	-24.9**	-34.8**	0.1	-22.7**	-23.8
MR 867	K	-38.1**	-33.1**	-35.9**	-16.9**	-10.9	-19.4**	-20.6**	-33.1**	-28.9**	-20.0**	-18.3**	-25.0
	R	- 3.3	- 9.8*	3.9	1.3	-11.0*	- 2.7	-13.4**	- 9.5	- 8.1	2.2	- 0.6	- 4.6
MR 824	K	-21.8**	-16.2*	-21.9**	34.9**	-24.6**	-21.9**	-27.2**	-14.0	-29.7**	-18 0*	-23.9**	-16.7
	R	8.2	3.7	8.0	2.1	- 8.7	- 8.5	- 8.1	11.0	-10.4	8.9	-21.5**	- 1.4
MR 825	K	- 7.7	-16.1	-15.2	-16.8	-14.5	-24.6**	- 4.6	-15.8	-26.7**	-24.7**	-27.3**	-17.6
	R	6.8	- 0.4	-10.1	-19.4*	-15.2*	-10.8	- 4.3	8.6	1.8	3.9	- 8.6	- 4.3
MR 849	K	10.5	10.0	12.0	39.4**	20.5*	17.7	16.3	- 6.0	13.3	12.5	4.5	13.7
	R	29.1**	21.1**	25.8**	29.3**	8.9	5.8	- 0.3	20.1**	15.4*	29.5**	6.5	17.4
CS 3541	K	-28.1**	-26.0**	-24.2**	-19.1*	-29.9**	-34.4**	-11.2	-20.5**	-26.0**	-24.9**	-30.9**	-25.0
	R	-16.0**	-13.7*	-14.9**	-24.5**	-40.0**	-24.4**	-17.4**	-23.7**	-21.7**	-11.0	7.7	-18.1
Average heterosis of female parents	K	-23.0	-22.6	-22.2	- 4.6	-17.4	-20.3	-17.2	-21.6	-21.8	-20.4	-18.5	-19.0 a
	R	7.6	1.2	4.5	- 2.0	- 6.6	- 5.7	- 8.2	1.4	- 7.2	6.8	1.8	- 0.6

* Significant (P=0.05) ** Significant (P=0.01)

a = overall heterosis

Appendix B.7 : Estimates of heterosis % for breaking strength of grain compared to harder parents in Kharif (K) and Rabi (R) Experiments

Males		Females											Average heterosis of male parents
		MA 1	MA 2	MA 3	MA 4	MA 5	MA 6	MA 9	2219 A	2077 A	623 A	296 A	
MR 801	K	-25.9**	-31.8**	-32.0**	- 8.6	-18.7*	-24.6**	-15.7*	-23.8**	-12.4	-10.1	-22.9*	-20.6
	R	- 5.3	- 6.9	-13.4	-11.2	-16.0*	-14.4	- 0.5	2.7	-16.0*	-16.7*	1.1	- 5.7
MR 861	K	-23.2**	-22.9**	-19.7**	-13.1	-23.6**	-19.4**	-21.2**	-28.8**	-16.3*	-29.2**	1.9	-19.6
	R	-13.9*	-12.2	- 7.4	-20.9**	- 9.1	-14.3*	- 9.6	-16.5**	-17.8**	11.7	-10.9	-11.0
MR 864	K	-32.1**	-29.8**	-26.8**	-17.8*	-21.4**	-35.4**	-14.0	-23.7**	-25.7**	7.5	-35.6**	-23.2
	R	- 4.8	-13.7*	-15.0*	- 8.8	- 8.8	- 9.7	-11.4	- 2.2	-10.6	5.7	-21.6**	- 9.2
MR 803	K	-32.5**	-35.0**	-23.0**	-18.4**	-26.5**	-25.1**	-10.5	-30.5**	-11.4	- 1.1	-35.1**	-22.6
	R	-19.1**	-23.7**	-19.5**	-25.9**	-29.0**	-37.4**	-21.4**	-16.8**	-31.3**	3.8	-21.0**	-21.9
MR 867	K	-41.9**	-34.9**	-35.9**	-24.4**	-42.2**	-33.9**	-32.4**	-32.7**	-37.6**	11.0*	-55.1**	-32.7
	R	-31.3**	-37.1**	-30.0**	-33.9**	-34.7**	-28.7**	-28.9**	-34.5**	-35.8**	- 2.4	-42.4**	-30.9
MR 824	K	-40.4**	-45.0**	-45.1**	-19.5**	-48.8**	-36.3**	-26.1**	-40.5**	-37.9**	- 5.1	-42.3**	-35.5
	R	-29.7**	-29.7**	-26.5**	-25.2**	-38.0**	-34.2**	-27.5**	-28.4**	-31.0**	5.1	-39.0**	-27.6
MR 825	K	-41.0 **	-45.3**	-39.3**	-34.8**	-28.6**	-37.2**	-27.8**	-42.4**	-38.4**	-11.1	-44.6**	-35.5
	R	-26.8**	-28.3**	-33.1**	-37.8**	-31.9**	-34.2**	-17.3**	-22.0**	-36.2**	- 5.1	-27.9**	-27.3
MR 849	K	- 1.9	-13.2	- 5.8	20.5*	0.8	13.1	- 7.3	- 7.9	2.5	28.9**	- 4.3	2.3
	R	1.9	0.0	- 0.5	1.9	-16.9*	-13.5	-13.5	8.2	-3.4	40.1**	-18.4**	- 1.3
CS 3541	K	-26.0**	-29.4**	-20.1**	-19.8*	-27.2**	-33.0**	-11.1	-26.5**	-32.6**	-20.1**	-31.4**	-25.2
	R	-24.4**	-20.4**	-27.6**	-22.7**	-31.1**	-32.0**	-20.0**	-17.3**	-27.1**	2.7	-12.0	-21.1
Average heterosis of female parents	K	-29.8	-31.9	-27.5	-15.1	-26.2	-25.8	-18.5	-28.5	-23.3	- 3.3	-29.9	-23.7[a]
	R	-17.0	-19.1	-19.2	-20.5	-23.9	-24.3	-16.7	-14.1	-23.2	8.7	-21.3	-17.3

* Significant (P=0.05)   **Significant (P=0.01)

a = overall heterosis

Appendix B.8 : Estimates of heterosis % for floaters percentage based on denser parent in Kharif (K) and Rabi (R) Experiments

Males		Females											Average heterosis of male parents
		MA 1	MA 2	MA 3	MA 4	MA 5	MA 6	MA 9	2219 A	2077 A	623 A	296 A	
MR 801	K	-89.7**	-69.0**	-72.4**	-52.9*	-54.0*	-14.9	-41.4	-78.3*	- 8.0	-54.0*	108.0**	-38.8
	R	-62.1**	-66.1**	-68.8**	-35.4**	- 4.8	-47.1**	-34.1*	-60.9**	-13.8	-70.6**	-60.8**	8.3
MR 861	K	-76.9**	-77.4**	-58.9**	-56.0**	-24.3	-44.7*	-60.9**	-79.7*	-68.8**	-75.9**	9.2	-55.8
	R	-59.3	-69.5	-54.2	18.6	72.9	103.4**	71.2	-13.6	66.1	-54.2	10.2	8.3
MR 864	K	-84.6**	-70.6**	-73.0**	-75.0**	19.8	-26.9	-23.5	-31.9	-42.3**	-71.1**	19.9	-41.7
	R	-54.2*	-56.1**	-70.1**	-59.8**	5.6	2.8	-20.6	-95.3**	-21.5	-69.2**	-18.7	-42.6
MR 803	K	2.5	-70.4*	-49.4	-79.0**	49.4	12.3	-48.1	-42.0	-49.4	-77.8**	74.1**	-25.2
	R	-43.2	-13.5	-40.5	-32.4	-90.5**	70.3*	36.5	-56.8	- 4.0	-48.6	64.9	2.1
MR 867	K	-44.4	-25.0	-80.6	-58.3	58.3	-36.1	-33.3	44.4	-33.3	-80.6	238.9**	-12.6
	R	-24.3	-51.3	-29.7	-37.8	- 2.7	24.3	40.5	-64.9	54.0	13.5	194.6**	10.6
MR 824	K	-55.9	-64.7	-85.3	-29.4	97.1	105.9	-58.8	-67.6	8.8	-52.9	194.1**	- 0.8
	R	-75.0	-16.7	-50.0	- 3.3	65.0	8.3	1.7	-73.3	13.3	-48.3	88.3*	- 8.2
MR 825	K	-61.1	-40.7	-57.4	-57.4	100.0*	68.5	37.0	-61.1	14.8	-40.7	68.5	- 2.7
	R	-41.0	16.7	67.9*	70.5*	42.3	109.0**	17.9	-55.1	59.0	0.0	165.4**	41.1
MR 849	K	-70.0**	-78.4**	-15.0	-64.7**	-43.2*	-42.0*	-14.8	- 2.9	-34.5**	-43.9**	-22.0*	-39.2
	R	-73.7*	-56.2	-37.5	-41.2	40.0	48.7	20.0	-48.7	57.5	-30.0	40.0	- 7.4
CS 3541	K	-46.8	-29.0	-67.7	-56.4	109.7**	56.4	-12.9	-75.8	11.3	-58.1	112.9**	- 5.1
	R	-71.6**	-45.9	-59.6**	-39.4	98.2**	96.3**	-31.2	-53.2**	-25.7	-49.5*	- 2.7	-16.7
Average heterosis of female parents	K	-58.5	-58.3	-62.2	-58.8	34.8	8.7	-28.5	-53.7	-23.4	-61.7	89.3	-24.7a
	R	-56.0	-39.8	-38.1	-17.8	44.0	46.2	11.3	-58.0	20.5	-39.7	53.5	- 6.7

* significant (P=0.05)   ** significant (P=0.01)

a = overall heterosis

Appendix B.9: Estimates of Heterosis Percentage for Water Absorption over Superior Parent in Kharif and Rabi Experiments.

Males		Females: MA 5	MA 9	2077 A	296 A	Average heterosis of male parents
MR 861	K	4.4	8.4	-8.4	11.1	3.9
	R	24.1	18.6	17.6	12.1	18.1
MR 864	K	8.4	4.5	-4.9	-1.4	2.3
	R	-9.2	-2.7	-4.1	-13.7	-7.4
MR 824	K	15.1**	1.0	0.0	7.5	5.9
	R	3.6	1.7	0.0	1.0	1.6
MR 825	K	10.2	1.4	11.6*	5.5	7.2
	R	6.7	-3.7	4.7	2.0	2.4
CS 3541	K	7.7	4.6	1.0	8.4	5.4
	R	8.8	-6.8	-5.1	-12.9	-4.0
Average heterosis of female parents	K	9.2	4.0	-0.1	6.7	4.9 a
	R	6.8	1.4	2.6	-2.3	2.1

overall heterosis

Significant (P=0.05)
Significant (P=0.01)

Appendix B.10: Estimates of Heterosis Percentage for Particle Size Index over better parent in Kharif and Rabi Experiments.

Males		Females: MA 5	MA 9	2077 A	296 A	Average heterosis of male parents
MR 861	K	-13.4**	2.9	-15.9**	-3.9	-7.6
	R	0.0	3.3	11.4	2.0	4.2
MR 864	K	- 6.6	6.6	-9.9	-8.4	-4.6
	R	-19.2	10.8	35.9**	16.9	20.7
MR 824	K	-19.7**	-22.3**	-5.3	10.9	-9.1
	R	1.1	- 2.5	3.6	10.1	2.5
MR 825	K	- 5.6	- 1.3	-17.8**	-4.9	-7.4
	R	33.7**	2.3	24.6	21.8*	20.6
CS 3541	K	- 6.6	1.1	1.4	9.6	1.4
	R	21.4*	8.1	25.2*	24.5*	19.8
Average heterosis of female parents	K	-10.4	-2.6	-9.5	0.7	-5.5[a]
	R	14.6	4.4	20.1	15.1	13.6

overall heterosis

Significant (P=0.05)

Significant (P=0.01)

Appendix B.11: Estimates of Heterosis Percentage for Rolling Quality over better parent in Kharif and Rabi Experiments.

Males		Females: MA 5	MA 9	2077A	296 A	Average heterosis of male parents
MR 861	K	9.8*	4.5	6.8	13.0**	8.5
	R	1.6	1.2	-5.3	0.0	-0.6
MR 864	K	-9.9*	0.0	-8.6	-8.1*	-6.6
	R	0.0	-2.8	1.0	2.0	0.0
MR 824	K	-12.4**	-3.7	-9.7*	-4.6	-7.6
	R	0.0	-2.5	-1.0	-2.9	-1.6
MR 825	K	5.8	-1.5	-10.7*	1.9	-1.1
	R	1.3	-3.4	0.0	-3.8	-1.5
CS 3541	K	4.7	0.0	-8.1*	-3.3	-1.7
	R	2.0	-4.5	-2.9	1.2	-1.0
Average heterosis of female parents	K	-0.4	-0.1	-6.1	-0.2	-1.7a
	R	1.0	-2.4	-1.6	-0.7	-0.9

a = overall heterosis

* Significant (P=0.05)
** Significant (P=0.01)

Appendix B.12: Estimates of Heterosis Percentage for Gel Spreading over better parent in Kharif and Rabi Experiments

Males		Females: MA 5	MA 9	2077A	296 A	Average heterosis of male parents
MR 861	K	-7.5*	-6.2	-17.5**	-17.2**	-12.1
	R	-6.5**	3.4	-16.1**	-14.7**	- 8.5
MR 864	K	-10.8**	-12.2**	-14.1**	-13.7**	-12.7
	R	- 5.4*	- 4.0	-12.9**	-11.1**	- 8.3
MR 824	K	-11.8**	- 7.9	-21.0**	-20.5**	-15.3
	R	- 5.4*	0.0	-16.1**	-15.6**	- 9.3
MR 825	K	- 4.7	- 1.0	-17.2**	-19.4**	-10.6
	R	- 5.4*	2.7	-10.2**	- 9.1**	- 5.5
CS 3541	K	- 8.1*	- 1.9	-12.2**	-16.8**	- 9.7
	R	- 3.5	- 1.6	-12.9**	-15.2**	- 8.3
Average heterosis of female parents	K	- 8.6	- 5.8	-16.4	-17.5	-12.1^{a}
	R	- 5.2	0.1	-13.6	-13.1	- 8.0

a = overall heterosis

* Significant (P=0.05)

** Significant (P=0.01)

Appendix C.1 : Estimates of General and Specific Combining Ability effects for days to flowering in Kharif and Rabi Experiments

Males		Females: MA 1	MA 2	MA 3	MA 4	MA 5	MA 6	MA 9	2219 A	2077 A	623 A	296 A	GCA for males (gi)
		SCA effects (sij)											
MR 801	K	-1.20*	-0.61	-1.53**	0.06	-0.27	-0.75	1.88**	-0.50	3.80**	-0.72	-0.16	-1.73**
	R	0.38	-0.18	-0.81	0.53	0.19	0.23	0.23	0.49	-1.40**	-0.18	0.53	-0.12
MR 861	K	-0.26	1.00*	0.74	1.00*	0.00	-0.14	-1.19*	0.11	0.07	-1.11*	-0.22	0.00
	R	-0.08	-0.30	1.74**	-0.26	-0.26	0.11	-0.56	0.03	0.14	-0.97	0.40	0.34
MR 864	K	-0.29	0.64	0.71	-0.36	-0.03	-0.51	-0.55	0.41	0.04	-0.47	00.41	-0.97**
	R	0.53	-0.03	0.01	-0.32	-0.32	-0.29	0.71	-0.03	0.08	0.31	-0.66	0.06
MR 803	K	0.56	-0.18	-0.11	-0.18	0.81	-0.34	-0.70	-0.40	0.11	-0.37	-0.40	0.82**
	R	-0.35	-0.24	-0.54	0.13	1.46**	-0.16	0.17	-0.57	-0.13	0.43	-0.20	0.28
MR 867	K	0.50	-0.58	-0.83	-0.24	0.09	0.28	-0.13	0.13	-0.50	-0.98*	-0.53	-0.76**
	R	-0.02	-0.24	-0.87	-0.20	-0.20	0.50	-0.16	0.09	0.54	-0.24	0.80	-0.06
MR 824	K	-0.02	-0.09	0.32	0.91	0.24	0.43	0.39	-0.64	-0.68	0.13	-0.98*	-2.24**
	R	-0.29	-0.51	-0.81	0.53	0.53	-0.10	0.23	-0.80	1.27**	0.15	-0.14	-0.12
MR 825	K	-0.20	-0.27	-0.53	0.06	0.39	0.58	0.21	-0.82	-0.20	0.95*	-0.16	-0.73**
	R	0.16	0.28	0.31	-0.69	-0.69	-0.32	-0.32	-0.06	0.39	0.94	-0.02	-0.24
MR 849	K	0.80	-0.27	0.80	-0.27	-0.61	-0.42	-1.46**	1.84**	-2.86**	1.28**	1.17*	8.27**
	R	-0.47	0.64	1.01**	0.01	0.01	0.05	-0.95	0.97	-0.58	0.31	-0.99*	0.40*
CS 3541	K	0.10	0.36	0.44	-0.97*	-0.64	0.22	1.51**	0.14	0.44	-1.41**	-0.19	-1.03**
	R	0.13	0.58	-0.05	0.28	-0.72	-0.01	0.65	-0.09	-0.31	-0.75	0.28	-0.54**
GCA for females (gj)	K	-2.29**	-2.88**	-1.62**	0.45*	1.12**	1.27**	2.97**	-4.66**	3.05**	0.90**	1.68**	
	R	-0.29	-0.40*	0.23	0.23	-0.10	-0.47*	-0.14	-1.40**	1.16**	0.60**	0.57**	

Kharif S.E. (gi) = 0.14 (gj) = 0.16 (sij) = 0.48

Rabi S.E. (gi) = 0.15 (gj) = 0.17 (sij) = 0.50

* Significant (P=0.05) ** Significant (P=0.01)

Appendix C.2 : Estimates of General and Specific Combining Ability effects for plant height in Kharif and Rabi Experiments

Males		Females											GCA effects of males (gi)
		MA 1	MA 2	MA 3	MA 4	MA 5	MA 6	MA 9	2219 A	2077 A	623 A	296 A	
		SCA effects (sij)											
MR 801	K	-8.30*	-5.71	-9.01**	-3.19	-3.19	-0.60	4.77	4.03	14.14**	7.10*	-0.04	-15.10**
	R	6.50	-7.58	-2.02	-8.50	10.57*	0.39	1.87	1.13	-9.98	6.31	1.31	-12.05**
MR 861	K	5.70	9.62**	1.66	1.14	6.14	-3.93	-3.90	-2.63	4.47	-9.90**	-8.38**	- 8.44**
	R	10.29	-0.45	5.10	1.95	4.36	-0.82	2.32	-6.75	2.14	-8.23	-9.89	0.82
MR 864	K	-1.88	4.05	2.75	-4.43	-2.10	-13.51**	-5.47	0.12	-0.43	16.52**	4.38	- 2.53*
	R	4.07	11.67*	0.56	-0.93	-1.85	-3.70	-2.22	-2.96	-2.41	3.89	-6.11	2.04
MR 803	K	15.24**	-2.16	-1.13	-0.98	-3.65	-2.72	-8.02**	-8.75**	6.02	4.98	1.17	- 1.65
	R	2.10	1.36	0.25	0.44	-0.49	-4.01	-0.86	-3.27	0.62	-1.41	5.25	- 0.99
MR 867	K	-8.00*	-20.74**	-8.37*	-2.89	10.78**	16.04**	1.74	-10.00**	8.78**	-3.59	16.26**	58.59**
	R	0.89	-11.52*	-0.96	-0.77	-3.37	1.45	-3.74	- 1.14	6.08	-7.63	20.71**	51.88**
MR 824	K	-7.30*	-0.38	0.99	4.81	-0.19	11.73**	8.44**	0.69	-11.52**	3.44	-10.71**	-15.10**
	R	1.35	-6.06	-5.51	6.35	3.75	6.90	8.38	5.98	- 6.80	-2.17	-12.17	- 8.57**
MR 825	K	-4.48	-0.89	1.14	3.63	-1.71	0.88	6.92*	-1.48	- 9.70**	2.25	3.44	-11.92**
	R	2.41	0.00	0.56	-7.59	-5.19	1.30	-2.22	2.04	5.93	7.22	-4.44	-12.96**
MR 849	K	13.00**	18.92**	8.96*	2.44	1.44	3.70	-14.59**	11.67**	- 9.22**	-21.26**	-15.07**	24.92**
	R	-28.80**	8.79	2.68	2.86	8.60	8.42	-5.10	5.82	3.05	2.68	-8.99	1.58
CS 3541	K	-3.97	-2.71	2.99	-0.52	-7.53*	-11.59**	10.10**	6.36	-2.52	0.44	8.95**	-28.77**
	R	1.20	3.79	-0.66	6.20	-16.40**	-9.92	1.57	-0.84	1.38	-0.66	14.34**	-21.75**
GCA effects of females (gj)	K	-4.30**	1.10	0.40	-0.41	1.25	2.33	-32.38**	-20.30**	27.25**	20.62**	4.44**	
	R	-4.53*	9.55**	8.99**	-1.19	-5.27*	-10.08**	-34.90**	-9.16**	18.62**	18.99**	8.99**	

Kharif S.E. (gi) = 1.02 (gj) = 1.13 (sij) = 3.40 * significant (P=0.05)

Rabi S.E. (gi) = 1.60 (gj) = 1.77 (sij) = 5.30 ** significant (P=0.01)

Appendix C.3 : Estimates of General and Specific Combining Ability effects for panicle length in Kharif and Rabi Experiments

Males		Females											GCA effects of males (gi)
		MA 1	MA 2	MA 3	MA 4	MA 5	MA 6	MA 9	2219 A	2077 A	623 A	296 A	
		SCA effects (sij)											
MR 801	K	-0.96	-0.24	-0.90	1.21*	-1.10	0.18	0.14	-0.07	2.46**	0.24	-0.95	1.67**
	R	-0.84	0.74	-0.04	-0.66	0.11	-0.06	-1.56*	-0.86	4.83**	-1.11	-0.33	0.97**
MR 861	K	-0.98	-0.46	0.34	0.39	0.55	0.29	-0.14	0.17	-1.43*	0.22	1.03	-1.91**
	R	0.80	-1.08	0.13	-0.15	0.62	-0.55	-0.38	0.11	0.22	0.64	-0.36	-1.87**
MR 864	K	-0.95	-0.76	-1.43*	-1.18*	1.32*	0.46	0.35	0.40	-0.60	2.72	-0.34	1.65**
	R	0.18	-1.10	-0.42	0.30	0.84	0.29	-0.40	-0.37	-0.53	1.65*	-0.44	1.75**
MR 803	K	2.42**	-0.19	0.41	0.26	-0.58	-1.51*	-0.54	-0.96	-1.02	0.69	1.03	0.68**
	R	0.03	0.34	0.24	-0.78	-1.12	-0.66	0.32	-0.19	0.25	1.77**	-0.19	0.70**
MR 867	K	0.88	1.40*	0.47	-0.62	0.21	0.89	1.38*	-0.96	-1.16	-2.32**	-0.17	-2.71**
	R	0.33	1.79**	-0.20	-0.55	-0.06	-0.18	1.32	-0.80	-0.11	-1.93**	-0.02	-2.34**
MR 824	K	-0.58	-0.99	0.48	-0.34	-0.18	0.43	1.39*	0.31	1.24*	-1.25*	-0.50	-0.11
	R	0.60	1.19	1.00	-0.41	-0.07	-0.08	0.96	-0.81	-0.10	-1.73**	-0.68	-0.41
MR 825	K	-0.82	-0.76	-0.76	0.62	0.32	-0.74	-1.25*	-0.53	2.00**	1.85**	0.64	2.65**
	R	-0.35	-1.70**	-0.89	0.83	-0.22	-0.26	0.87	0.50	-1.20	2.85**	-0.44	1.68**
MR 849	K	1.72**	1.98**	1.05	-0.51	0.79	0.20	-0.44	1.41*	-1.72**	-2.81**	-1.66**	-0.85**
	R	-0.01	0.91	-0.21	1.44*	-0.15	1.64*	-0.46	1.24	-2.72**	-2.20**	0.50	0.87**
CS 3541	K	-0.73	0.00	0.33	0.18	-1.33*	-0.19	-0.89	0.23	0.23	0.67	1.49*	-1.10**
	R	-0.74	-1.09	0.39	-0.03	0.08	-0.50	-0.66	1.18	-0.65	-0.06	1.97**	-1.33**
GCA effects of females	K	-1.81**	-2.06**	-1.40**	0.49*	-2.01**	-2.08**	-0.98**	0.50*	5.04**	2.46**	1.84**	
	R	-1.82**	-2.07**	-0.68*	0.60*	-0.88**	-1.06**	-1.43**	0.87**	3.49**	1.71**	1.27**	

Kharif S.E. (gi) = 0.18 (gj) = 0.20 (sij) = 0.59 * significant (P=0.05)

Rabi S.E. (gi) = 0.20 (gj) = 0.23 (sij) = 0.68 ** significant (P=0.01)

Appendix C.4 : Estimates of General and Specific Combining ability effects for grain yield per panicle in Kharif and Rabi Experiments .

Males		MA 1	MA 2	MA 3	MA 4	MA 5	MA 6	MA 9	2219 A	2077 A	623 A	296 A	GCA effects of males (gi)
		Females											
		SCA effects (sij)											
MR 801	K	-0.16	4.61	-8.44	-1.25	-6.68	-0.41	-7.48	-1.35	9.93	6.06	5.16	-6.67**
	R	1.62	2.96	-2.96	-3.59	0.77	0.89	4.03	0.59	-2.46	-2.18	0.34	-14.19**
MR 861	K	-1.67	5.17	-1.61	4.16	2.01	4.41	0.17	-5.13	1.71	-8.96	-0.27	5.49**
	R	3,03	-0.22	10.42*	-2.34	0.46	-2.93	6.01	-8.10	2.10	0.34	-8.77*	0.96
MR 864	K	-3.42	2.23	4.49	4.50	-2.93	-5.15	-5.14	-4.20	-6.01	11.71*	3.91	- 5.44**
	R	4.82	-5.97	0.21	7.41	4.01	3.36	-4.74	-2.31	0.95	-7.41	-0.32	12.28**
MR 803	K	7.03	-4.85	-1.58	3.99	5.01	-9.51	-5.63	2.27	1.64	0.89	0.74	2.69
	R	-6.96	-1.18	1.46	1.90	6.70	-4.32	-0.58	0.44	-6.76	9.98*	-0.67	- 3.24*
MR 867	K	-9.83	-3.82	-10.23*	-4.75	6.70	16.54**	6.97	-3.23	9.35	-7.67	-0.02	14.67**
	R	-5.36	-3.98	1.63	0.70	-5.40	-1.92	-5.78	-2.37	7.54	-7.52	22.47**	19.42**
MR 824	K	-2.49	-4.98	4.73	1.18	-6.00	-1.03	-0.97	10.86*	-7,44	2.00	4.13	-2.44
	R	4.22	0.60	6.91	1.64	-2.56	1.49	4.50	-3.44	-1.82	2.49	-13.92**	-0.32
MR 825	K	1.40	1.54	8.67	-4.18	4.87	-5.21	4.59	0.58	-8.92	1.32	-4.66	-11.62**
	R	0.98	-1.57	-8.26	-4.89	1.38	7.53	7.00	5.66	-1.52	5.96	-12.96**	-10.89**
MR 849	K	7.46	-1.38	1.66	-3.30	2.62	7.08	-2.92	1.46	-4.00	0.50	-9.20	-16.72**
	R	2.79	7.71	-5.82	2.19	1.55	0.90	-9.63*	9.53*	-1.44	5.50	-13.28**	8.97**
CS 3541	K	1.68	1.47	2.30	-0.36	-5.60	-6.73	10.41*	-1.25	3.73	-5.86	0.20	-13.40**
	R	-5.14	1.67	-3.59	-3.02	06.92	-5.00	-0.80	-0.01	3.52	-7.14	26.42**	-12.99**
GCA effect of females (gj)	K	-0.48	-2.78	-5.42*	4.69*	2.49	3.66	-1.33	-8.25**	-1.08	6.81	5.29*	
	R	5.23**	1.99	7.41**	-5.60**	-7.03**	-7.78**	-3.95*	-6.77**	2.03	12.69**	1.77	

Kharif S.E. (gi) = 1.52 (gj) = 1.68 (sij) = 5.04 * significant (P=0.05)

Rabi S.E. (gi) = 1.31 (gj) = 1.45 (sij) = 4.36 ** significant (P=0.01)

Appendix C.5 : Estimates of General and Specific Combining Ability effects for number of grains per panicle in Kharif and Rabi Experiments

Males		Females											GCA effects of males (gi)
		MA 1	MA 2	MA 3	MA 4	MA 5	MA 6	MA 9	2219 A	2077 A	623 A	296 A	
		SCA effects (sij)											
MR 801	K	-51.26	345.31	-400.77*	13.31	-41.87	104.08	-339.11	-118.23	425.00*	217.20	-153.67	-105.53
	R	-75.34	166.49	120.28	-9.30	26.38	-6.66	-34.98	-116.38	145.18	-125.38	- 90.31	-282.14**
MR 861	K	-165.31	74.06	-18.56	8.66	-15.25	-88.37	171.50	-5.88	-75.39	116.54	-1.99	-263.08**
	R	102.10	-76.88	215.58	173.47	-83.23	-93.69	70.65	-49.75	81.19	-107.83	-231.61	-324.30**
MR 864	K	-96.00	148.97	111.35	146.97	-179.41	226.74	-6.19	-496.44*	-389.62	462.79*	70.85	60.28
	R	247.67	-22.97	83.95	147.44	-19.42	-99.92	-153.77	-106.38	182.30	-109.79	-149.10	358.39**
MR 803	K	420.01*	-27.36	58.63	-1.62	152.20	-471.18*	-264.04	328.70	-125.00	127.33	-197.67	-55.27
	R	-107.96	-71.85	-75.36	49.74	121.08	53.72	69.33	68.99	-134.60	40.58	- 13.67	-182.18**
MR 867	K	-48.71	63.39	-91.82	-247.74	-170.05	435.69*	214.03	173.92	481.54*	-591.12	-219.12	240.52**
	R	-126.09	-0.67	-118.48	-95.66	-140.38	-204.60	-86.81	107.04	155.00	-194-62	705.27**	301.69**
MR 824	K	-286.09	-559.32**	150.67	23.15	-36.56	40.18	220.99	266.81	-221.36	9.17	392.37	82.10
	R	73.00	-104.23	180.81	-41.43	-112.89	78.61	245.09	-364.72*	-71.44	190.40	-73.18	40.40
MR 825	K	-214.04	- 20.54	235.18	183.46	351.58	-168.63	-91.03	-296.61	-220.31	180.15	60.88	-44.08
	R	3.87	-127.31	-54.45	23.04	70.05	393.56*	236.69	-17.44	-320.57	240.27	-447.70	91.73
MR 849	K	440.49*	14.66	-23.49	-205.14	34.54	-75.37	-105.97	395.92	26.08	-231.25	-270.45	429.52**
	R	-8.81	244.95	-295.87	-160.58	137.37	139.80	-135.88	371.21*	-209.45	162.32	-245.05	281.81**
CS 3541	K	0.93	-39.17	-21.18	78.97	-95.08	-3.13	199.81	-248.17	99.05	-290.81	-318.79	-344.45**
	R	-108.42	- 7.53	-56.47	-86.72	1.05	-260.81	-210.33	107.42	172.41	-95.95	-545.34**	-285.39**
GCA effects of females	K	-24.28	6.41	-172.37*	-37.72	37.92	135.97	-133.23	-379.58**	58.79	333.32**	174.79*	
	R	85.49	87.53	192.87**	-223.08**	-143.49*	-191.52**	-23.94	-307.07**	299.86**	186.55**	36.79	

Kharif S.E. (gi) = 60.38 (gj) = 66.76 (sij) = 200.27 * significant (P=0.05)

Rabi S.E. (gi) = 48.98 (gj) = 54.16 (sij) = 162.47 ** significant (P=0.01)

Appendix C.6. General and specific combining ability effects for 1000 grain weight in Kharif and Rabi Experiments

Males		Females											GCA effects of males (g_i)
		MA 1	MA 2	MA 3	MA 4	MA 5	MA 6	MA 9	2219A	2077A	623A	296A	
		SCA effects (sij)											
MR 801	K	0.26	-0.36	-0.68	-1.74	-1.94	-0.64	-0.36	0.31	0.64	1.13	3.72*	-1.79**
	R	1.73	-0.07	-1.92	-2.38	-0.08	-0.18	1.70	1.10	-1.87	0.64	1.33	-3.33**
MR 861	K	0.76	0.83	0.04	0.78	1.11	2.69	-1.22	-1.52	1.25	-4.41**	-0.32	4.18**
	R	0.21	0.69	1.62	-2.63*	1.49	-0.08	1.69	-3.32**	-0.60	1.77	-0.83	3.99**
MR 864	K	-0.65	-0.14	0.80	-1.04	0.42	-2.84	-1.90	2.26	1.25	1.05	0.79	-2.26**
	R	-0.67	-2.03	-0.93	1.79	1.80	2.42	-0.46	0.28	-0.97	-2.26	1.03	1.61**
MR 803	K	-0.32	-1.43	-0.92	0.20	0.38	1.50	0.25	-1.57	1.59	-1.13	1.46	1.30*
	R	-1.85	0.10	1.42	0.67	1.94	-2.91*	-1.24	-0.42	-1.66	3.84**	0.09	0.50
MR 867	K	-2.73	-1.42	-2.65	-0.67	4.00*	1.48	0.99	-2.11	-0.24	1.74	1.60	3.15**
	R	-0.94	-1.59	1.29	2.16	-0.32	1.99	-1.31	-1.47	0.74	-1.48	0.93	4.70**
MR 824	K	0.17	1.27	-0.47	9.21**	-2.33	-1.52	-2.90	1.09	-2.13	-0.15	-2.24	-0.43
	R	0.87	1.03	0.95	1.25	-0.13	-0.18	-0.30	2.75*	-0.33	-1.12	-4.79**	-0.45
MR 825	K	2.40	0.66	1.64	-3.97*	-0.43	-0.65	2.04	1.96	-1.65	-0.24	-1.75	-3.77**
	R	0.49	0.38	-2.48	-2.55*	-0.71	0.01	0.97	2.07	2.60*	0.49	-1.25	-4.99**
MR 849	K	-0.54	-0.31	1.28	-0.96	0.39	2.51	0.22	-1.93	-1.47	1.82	-1.01	2.25**
	R	0.96	0.55	0.44	2.78*	-0.28	-1.00	-2.45	0.41	1.24	-0.14	-2.51	0.99*
CS 3541	K	0.65	0.89	0.96	-1.83	-1.60	-2.52	2.90	1.51	0.76	0.18	-1.91	-2.63**
	R	-0.79	0.95	-0.39	-1.08	-3.72**	-0.08	1.40	-1.40	0.85	-1.74	6.02**	-3.03**
GCA effects of females (g_j)	K	-1.39*	-1.13	-0.77	3.24**	0.44	0.28	0.39	-0.43	-0.99	-0.15	0.52	
	R	1.31*	0.11	1.18*	-0.45	-1.53**	-1.44**	-1.21*	0.06	-1.72**	3.46**	0.23	

Kharif S.E. (g_i) = 0.47 (g_j) = 0.52 (sij) =1.57

Rabi S.E. (g_i) = 0.38 (g_j) = 0.42 (sij) = 1.25

*significant (p = 0.05) **significant (p = 0.01)

Appendix C.7. Estimates of general and specific combining ability effects for breaking strength in Kharif and Rabi experiments

Males		Females											GCA effects of males (g_i)
		MA 1	MA 2	MA 3	MA 4	MA 5	MA 6	MA 9	2219A	2077A	623A	296A	
		SCA effects (s_{ij})											
MR 801	K	0.15	-0.11	-0.42	0.13	0.37	-0.09	-0.13	0.15	0.52	-0.97*	0.40	-0.59**
	R	-0.02	0.07	-0.37	-0.12	-0.11	-0.04	0.21	0.27	-0.17	-0.49	0.77**	-0.94**
MR 861	K	0.23	0.35	0.29	-0.15	-0.04	0.18	-0.55	-0.31	-0.25	-2.32**	2.09**	0.23
	R	-0.21	0.09	0.42	-0.51	0.68*	0.28	0.06	-0.64*	0.31	-0.55	0.41	-0.03
MR 864	K	-0.08	0.17	0.07	-0.28	0.37	-0.62	0.15	0.32	-0.15	0.32	-0.26	-0.65**
	R	0.32	-0.13	-0.32	0.30	0.56	0.52	-0.24	0.30	0.39	-1.15**	-0.54	0.02
MR 803	K	-0.21	-0.29	0.27	-0.32	-0.02	-0.01	0.43	-0.20	0.81	-0.10	-0.35	-0.07
	R	0.24	0.01	0.32	-0.08	-0.07	-0.81**	0.00	0.27	-0.34	-0.02	0.48	-0.03
MR 867	K	-0.49	0.36	-0.04	0.27	-0.76	0.03	-0.40	0.36	-0.51	3.07**	-1.86**	1.66**
	R	-0.10	-0.59*	0.24	-0.14	0.03	0.84**	0.18	-0.64*	-0.13	1.35**	-1.05**	1.91**
MR 824	K	-0.29	-0.29	-0.59	0.85	-0.97*	0.09	0.43	-0.11	-0.21	1.17*	-0.09	0.38*
	R	-0.19	-0.03	0.23	0.53	-0.53	-0.14	-0.07	-0.32	0.15	1.17**	-0.78**	0.70**
MR 825	K	0.05	-0.19	0.00	-0.57	0.81	0.03	0.18	-0.20	-0.22	0.31	-0.19	-0.42**
	R	0.03	0.09	-0.37	-0.61*	0.16	-0.06	0.77**	0.26	-0.26	-0.41	0.40	-0.70**
MR 849	K	0.21	-0.33	-0.20	0.36	0.13	0.73	-0.57	-0.27	-0.02	-0.17	0.13	0.25
	R	0.22	0.25	0.20	0.48	-0.52	-0.31	-0.93**	-0.44	0.34	0.59*	0.77**	-0.02
CS 3541	K	0.44	0.32	0.62	-0.28	0.12	-0.33	0.47	0.27	-0.46	-1.31**	0.14	-0.79**
	R	-0.28	0.26	-0.35	-0.14	0.20	-0.27	0.02	0.07	-0.05	-0.48	1.09**	-0.92**
GCA effects of females (g_j)	K	-0.49*	-0.59**	-0.30	0.62**	-0.25	-0.16	0.44*	-0.35*	-0.01	1.63**	-0.54**	
	R	0.00	-0.18	-0.13	-0.25*	-0.55**	-0.55**	0.07	0.21	-0.49**	2.27**	-0.41**	

Kharif SE (g_i) = 0.13 (g_j) = 0.15 (s_{ij}) = 0.45

Rabi SE (g_i) = 0.09 (g_j) = 0.10 (s_{ij}) = 0.29

*significant (p = 0.05) **significant (p = 0.01)

Appendix C.8. Estimates of general and specific combining ability effects for floaters percentage from hybrids' experiments in Kharif and Rabi

Males		Females											GCA effects of males (g_i)
		MA 1	MA 2	MA 3	MA 4	MA 5	MA 6	MA 9	2219A	2077A	623A	296A	
		SCA effects (sij)											
MR 801	K	-0.93	0.13	-0.30	0.57	-1.49**	0.05	0.13	-0.52	0.73	0.56	1.06	-0.18
	R	0.60	-0.12	-0.21	0.86	0.85	-1.08	0.02	0.05	1.13	-0.45	-1.65**	0.68**
MR 861	K	-0.12	-0.11	1.03	1.17*	-0.22	-0.10	-0.27	-0.76	-0.95	-0.03	0.11	0.10
	R	-0.21	-1.18*	-0.61	0.53	-0.06	0.55	0.86	1.15*	0.46	-0.48	-0.98	-0.30
MR 864	K	-1.05	-0.64	-0.26	-0.34	0.64	0.38	0.66	0.30	0.15	-0.18	0.33	0.69**
	R	1.12	0.46	-0.22	-0.40	-0.29	0.34	0.46	-1.31*	-0.10	-0.11	-0.14	-0.40*
MR 803	K	2.24**	-0.28	0.24	-1.07*	0.83	0.24	-0.56	0.62	-1.06	-1.00	-0.19	0.17
	R	0.28	0.61	-0.14	-0.74	0.59	0.03	0.43	0.10	-0.97	-0.36	-0.17	0.10
MR 867	K	0.67	1.00	-0.54	0.00	0.16	-1.25**	-0.24	0.88	-0.70	-0.58	0.59	-1.15**
	R	0.84	-0.30	0.26	-0.59	-1.61**	-1.01	0.02	0.15	-0.07	1.05	1.23*	-1.18**
MR 824	K	0.17	0.17	-0.89	0.46	0.41	0.78	-0.87	0.01	-0.22	0.06	-0.07	-1.04**
	R	-0.49	0.75	-0.10	0.36	0.19	-0.88	-0.14	-0.20	-0.24	-0.04	0.80	-0.60**
MR 825	K	-0.31	0.36	-0.37	-0.41	0.77	0.49	0.91	-0.13	0.06	-0.07	-1.30**	-0.08
	R	-0.67	0.44	1.50**	0.93	-1.38**	0.13	-1.02	-0.83	-0.30	-0.01	1.22**	1.17**
MR 849	K	-0.95	-1.55**	1.82**	-0.02	-2.28**	-1.04	0.17	0.46	1.87**	1.62**	-0.10	1.41**
	R	-0.85	-0.55	0.14	-0.64	-0.14	0.04	0.29	0.45	0.83	0.43	0.00	0.07
CS 3541	K	0.05	0.92	-0.73	-0.38	1.18*	0.44	0.06	-0.85	0.12	-0.39	-0.42	0.08
	R	-0.63	-0.11	-0.61	-0.32	1.85**	1.89**	-0.91	0.43	-0.94	-0.02	-0.65	0.46*
GCA effects of females (g_j)	K	-1.16**	-1.23**	-0.78**	-0.75**	1.31**	1.10**	0.02	-1.21**	0.56**	-0.75**	2.88**	
	R	-1.34**	-0.77**	-0.80**	-0.14**	1.49**	1.40**	0.58**	-1.67**	0.89**	-0.89**	1.24**	

Kharif SE (g_i) = 0.16   (g_j) = 0.18   (sij) = 0.54
Rabi SE (g_i) = 0.17   (g_j) = 0.19   (sij) = 0.58

*significant (p =0.05)   **significant (p = 0.01)

Appendix C.9: Estimates of General and Specific Combining ability effects for Water Absorption in Kharif and Rabi Experiments

Males		Females MA5	MA9	2077A	296A	GCA effects of the male parents (gi)
		SCA effects (sij)				
MR 861	K	-0.58	1.47	-1.99	1.10	-3.54**
	R	-0.22	0.52	-0.39	0.09	-4.45**
MR 864	K	0.84	1.02	-0.91	-0.95	-0.35
	R	-1.88	1.80	0.65	-0.56	-0.96
MR 824	K	0.38	-1.54	0.47	0.69	1.97
	R	-0.23	-0.29	-0.07	0.58	2.72**
MR 825	K	-0.62	-1.07	2.67*	-0.98	1.57
	R	-0.02	-1.64	0.44	1.23	2.44*
CS 3541	K	-0.03	0.12	-0.24	0.15	0.35
	R	2.37*	-0.39	-0.63	-1.35	0.25
GCA effects of female parents (gj)	K	0.72	-0.36	-1.10	0.74	
	R	1.40	-0.41	0.30	-1.29	

Kharif S.E. (gi) = 0.63 (gj) = 0.56 (sij) = 1.25

Rabi S.E. (gi) = 0.57 (gj) = 0.51 (sij) = 1.14

* Significant (P=0.05)

** Significant (P=0.01)

Appendix C.10: Estimates of General and Specific Combining ability effects for Particle Size Index in Kharif and Rabi Experiments.

Males		Females: MA 5	MA 9	2077A	296A	GCA effects of males(gi)
		SCA effects (sij)				
MR 861	K	0.25	-1.88	-0.12	1.75	4.18**
	R	-1.94	2.82	0.52	-1.40	1.02
MR 864	K	2.69	-0.77	0.78	-2.70	4.47**
	R	-0.87	-0.20	2.90	-1.83	1.15
MR 824	K	-3.24*	-2.34	1.85	3.73*	-4.86**
	R	-1.69	1.32	-1.95	2.32	-2.84
MR 825	K	2.36	2.50	-2.94*	-1.93	-1.84
	R	4.31	-3.32	0.88	-0.11	2.33
CS 3541	K	-2.06	2.48	0.43	-0.85	-1.95*
	R	0.20	-0.62	-0.59	1.01	-1.66
GCA effects of females(gj)	K	-0.75	-2.62*	-0.44	3.81**	
	R	0.35	-3.15	2.31	0.50	

Kharif S.E. (gi) = 0.70 (gj) = 0.63 (sij) = 1.40

Rabi (gi) = 1.43 (gj) = 1.27 (sij) = 2.85

Significant (P=0.05)
Significant (P=0.01)

Appendix C.11: Estimates of General and Specific Combining Ability effects for Rolling Quality in Kharif and Rabi Experiments.

Males		Females				GCA effects of males (gi)
		MA 5	MA 9	2077A	296A	
		SCA effects (sij)				
MR 861	K	0.57	-0.95	0.18	0.20	0.69
	R	0.09	0.80	-0-94	0.05	0.51
MR 864	K	-1.12*	1.12*	0.55	-0.56	0.11
	R	-0.48	-0.34	0.35	0.47	0.65
MR 824	K	-1.45**	0.39	0.59	0.47	-0.59
	R	-0.13	0.14	0.37	-0.37	-0.50
MR 825	K	1.06**	-0.53	-0.96	0.42	-0.37
	R	0.21	-0.09	0.48	-0.60	-0.81*
CS 3541	K	0.93	-0.03	-0.36	-0.54	0.16
	R	0.32	-0.50	-0.27	0.45	0.14
GCA effects of females (gj)	K	0.37	0.46	-1.00*	0.17	
	R	0.43	-0.34	-0.17	0.07	

Kharif S.E. (gi) = 0.25 (gj) = 0.23 (sij) = 0.50

Rabi S.E. (gi) = 0.27 (gj) = 0.24 (sij) = 0.54

· Significant (P=0.05)
Significant (P=0.01)

Appendix C.12: **Estimates of General and Specific Combining Ability effects for Gel Spreading in Kharif and Rabi Experiments.**

Males		Females: MA 5	MA 9	2077A	296 A	GCA effects of males (gi)
MR 861	K	0.20	-0.38	-0.21	0.39	-0.55
	R	0.15	0.88	-0.85	-0.18	-0.95
MR 864	K	0.70	-0.71	-0.38	0.39	2.11
	R	-0.68	-0.28	-0.02	0.98	0.55
MR 824	K	-0.51	-0.75	-0.75	2.01	-2.68
	R	1.23	-0.37	-0.43	-0.43	-1.37
MR 825	K	1.03	2.29	-1.04	-2.28	0.44*
	R	-2.02	0.38	0.65	0.98	1.88
CS 3541	K	-1.43	-0.44	2.39	-0.51	0.68
	R	1.32	-0.62	0.65	-1.35	-0.12
GCA effects of females (gj)	K	-1.41	-1.00	0.84	1.57*	
	R	0.02	-1.38	1.35	0.02	

Kharif S.E. (gi) = 0.53 (gj) = 0.48 (sij) = 1.07

Rabi S.E. (gi) = 0.54 (gj) = 0.48 (sij) = 1.08

Significant (P=0.05)
Significant (P=0.01)

V I T A

I, Jose Geraldo Eugenio de Franca, was born to Mrs. Marili Almeida de Franca and Mr. Darci Eugenio de Silva on January 13, 1957 in Limoeiro de Anadia (AL), Brazil. I completed my high school in 1974 from the Escola Prof. Jose Quintela Cavalcanti, Arapiraca (AL), Brazil and obtained the B.Sc. in Agriculture from the Universidade Federal Rural de Pernambuco, Recife (PE), Brazil in 1978.

Since January 1979 I am working as a researcher at IPA (Empresa Pernambucana de Pesquisa Agropecuaria), Cereals Project and I am associated with the breeding aspects of sorghum, maize and millets in the Experimental Station of Vitoria de Santo Antao (PE), Brazil. Since 1980 I am also teaching Biology courses at the Department of Biology of the Faculty of Education of Vitoria de Santo Antao (PE), Brazil.

Since June 1981 I am on deputation pursuing the requirements for a Master Degree in Agriculture (Genetics and Plant Breeding) at the Andhra Pradesh Agricultural University, Hyderabad (A.P), India, in collaboration with ICRISAT, Patancheru (A.P), India. I have been carrying out a research investigation in breeding of agronomic and grain quality characters of sorghum under the guidance of Dr. L.R. House and Dr. D.S. Murthy.

I have published five papers as a co-author in technical journals of Brazil.

Report of the External Examiner on the thesis entitled "Genetic and combining ability analysis of some agronomic and grain quality characters in Sorghum (Sorghum bicolor (L.) Moench) submitted by Sri Jose Geraldo Eugenio De Franca for the award of degree of Master of Science in Agriculture by the Andhra Pradesh Agricultural University, Hyderabad.

§§§

Sorghum is the second most important food crop of India. From this point of view, the problem chosen especially on the study of quality characters is most apt and required for the present day conditions. There are very few reports and also attempts to study the grain quality of the high yielding hybrids and consequently several of the high yielding hybrids released in India are not preferred for human consumption. In this regard, the study undertaken by the student is timely.

The Introduction is concise and to the point and therefore it is commendable.

The Review of Literature is comprehensive giving considerable amount of information that has been collected in the study of sorghum genetics and also grain quality characters. The review could have been shortened somewhat by avoiding references to sections like protein and amino-acid content, grain structure and on utilisation of sorghum for food. Although this forms extra information, the references do not pertain to the characters studied by the student.

The material collected is of optimum size for the study and the experimental layout. Recording of the observations have been correctly shown. The statistical analysis especially of the combining ability has been done with meticulous care and the data presented accordingly.

The Results have been presented in a systematic manner logically and the tables and one or two diagrams have been presented properly.

The Discussion is precise and to the point and indicates several of the important findings with regard to grain quality. An attempt has been made to work out the correlations between the grain quality characters and the combining ability effects and brings out certain conclusions that will help the practical breeder in combining ~~abiii~~ high yielding as well as good grain quality by following appropriate breeding methodoloty. In particular the cross 623A x MR849 has produced nearly 50% more yield than one of the parents of the popular hybrid ~~SM~~ CSH-5 viz., CS3541 both in the kharif season and in the rabi ~~season~~.

...2)

The study could have suggested as to how ~~important~~ to improve the grain quality of the such high yielding hybrids.

There are a few typographical and other errors which have been pointed out in the different pages and they may be corrected with black ink before presentation of the thesis to the library.

Finally "I recommend that the thesis submitted by Mrx Mr.Jose Geraldo Eugenio De Franca be accepted for the award of the Degree of Master of Science in Agriculture of the Andhra Pradesh Agricultural University, Hyderabad".

18/8/83

DHARWAR