STUDIES ON THE MAGNITUDE AND NATURE OF HYBRID VIGOUR UTILIZING MALE STERILE AND FERTILE LINES IN PIGEONPEA (*CAJANUS CAJAN* (L.) MILLSP.)

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MASTER OF SCIENCE IN AGRICULTURE

By

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CERTIFICATE

This is to certify that the thesis entitled "*Studies on the magnitude and nature of hybrid vigour utilizing male sterile and fertile lines in pigeonpea (Cajanus cajan (L.) Millsp.)*" submitted in partial fulfilment of the requirements for the degree of Master of Science in Agriculuture in the major subject of Genetics and Plant Breeding of the Andhra Pradesh Agricultural University, is a record of the bonafide research work carried out by Mr Paul G. Abuto Omanga 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. The assistance and help received during the course of this investigation have been fully acknowledged.

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VITA

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1. INTRODUCTION

Pigeonpea (Cajanus cajan (L.) Millsp.) is an important leguminous crop grown in tropical and subtropical countries. It ranks as the world's fifth most important pulse crop. The crop is cultivated on an estimated area of 2.9 million hectares in the world with an average of 684 kg/ha (Parpia, 1981). The major pigeonpea producing areas in the world are India, Eastern Africa, Central and South America, the Caribbean and West Indies. India with a total area of 2.6 million hectares and an average yield of 719 kg/ha (Sharma and Jodha, 1982) produces nearly 92% of the world's entire pigeonpea crop. Though the average seed yields are relatively low, the crop can yield 1600-2900 kg/ha under favourable management (Sharma and Jodha, 1982); while an exceptional yield of over 8000 kg/ha of dry has been reported in the first harvest in Australia by Wallis et al.,(1982).

Pigeonpea belongs to the monotypic genus Cajanus (n=11) which is closely related to the wild weedy species of genus Atylosia (Deodikar and Thakar, 1954). Purseglove (1968) construes this crop is a native of Africa, where it was cultivated before 2000 BC. However, the presence of maximum genetic variability for almost all characters in the germplasm of Cajanus and genus Atylosia suggests its Indian origin (van der Maesen, 1980).

Pigeonpea is a quantitative short day, bushy shrub grown either as an annual for intercropping during the main rainy season or as a perennial on field boundaries and home gardens (Kanwar and Singh, 1974). The long growth cycle of the existing day-length sensitive types is an important limiting factor in the spread of its cultivation. However, short-duration daylength insensitive types may be useful in extending the cultivation of the crop to areas where it can be grown with irrigation, during the short tropical summer season or in more temperate areas with or without irrigation (Byth, 1981).

Though pigeonpea floral biology appears to favour self-pollination, natural crosses ranging from 0 to 43% or even more have been reported (Bhatia et al., 1980; Green et al., 1979 and Onim, 1981). On the other hand, Reddy (1979) and Byth et al., (1982) identified cleistogamous and wrapped flower systems respectively which inhibits pollination.

Pigeonpea plays an important role in providing amino acid balanced diet in developing tropical countries where large sections of the population cannot afford animal protein. Green and dried seeds containing 20-28% protein are used as vegetable in African and Caribbean countries (Rachie and Wurster, 1971). In India, pigeonpea is primarily consumed as "dhal" a type of dry split peas used in soups or eaten with rice (Kanwar and Singh, 1974). The plant can also be used as animal feed, green manure and cover crop (Khan, 1973). The late maturity woody type varieties are used as a temporary shade for coffee, tea or cocao, as a source of fuel, and for thatching, making baskets and grain stores (El Baridi, 1978). Pigeonpea can fix nitrogen for its own use and leaves a residual nitrogen of about 40 kg/ha in the soil which can be used by the subsequent crop (Sheldrake and Narayana, 1979; and Rao _et al_., 1981).

Realizing the importance of this crop in semi-arid tropical agriculture, the Consultative Group on International Agricultural Research (CGIAR) included pigeonpea as one of the five mandate crops when it established the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT).

Pigeonpea improvement by breeding has been mostly limited to the testing of existing varieties and practising selection from available land races. This work has been backed up with limited genetic investigations. If a major breakthrough in yield is to be achieved, the future improvement in pigeonpea must be based on planned hybridization to identify parental combinations likely to produce superior segregates or to obtain F_1s with high heterosis.

The selection of parents for hybridization poses a serious problem to plant breeders. The common practise of selecting parents on the basis of yield, adaptation and dependability does not necessarily produce the most desirable recombinants. The ability of the parents to combine well depends on a complex interaction among genes which cannot be adequately adjudged by merely measuring yield performance and adaptation of the parents. Here, a proper understanding of combining ability and the nature of gene action for yield and other quantitative traits could greatly help in selecting desirable parents and crosses for economic exploitation.

Diallel studies in pigeonpea have shown that the estimated general combining ability of the parents is highly correlated with the per se mean performance of parents, but that the array means provide a better estimate. In the light of this information, line x tester design (Kempthorne, 1957), using three to four good cultivars as testers so that the value of a parent can be determined on the basis of its mean performance across testers was suggested for pigeonpea (Green, et al., 1979). With the existance of male sterility (Reddy et al., 1979; Wallis et al., 1981)and a considerable degree of natural outcrossing,(Green et al., 1979 and Onim, 1981) it is possible to easily test a large number of germplasm and exploit commercially the hybrid vigor which may be present in the crop.

As we will see in the following literature review, the information on combining ability, nature of gene action, relative importance of genetic components of variance and extent of heterosis for quantitative traits is meagre and inconsistent in pigeonpea. Hence, the present investigation involving three testers and seven lines was designed to collect information on the (i) nature and magnitude of heterosis in hybrids derived from parents of Indian, West Indian, and African origin using three different male sterile stocks, (ii) general and specific combining abilities of the parents; and (iii) correlations among yield and yield components.

2. REVIEW OF LITERATURE

The present study was undertaken in order to understand the genetic architecture of yield and yield components in pigeonpea. Since a relatively limited amount of work has been done on this crop, the work done on other important grain legumes such as soybean, green grams, chickpea and cowpea has also been reviewed.

2.1 Combining ability

The concept of general and specific combining abilities were precisely formalized by Sprague and Tatum (1942). They defined General Combining Ability (GCA) as the average performance of a line in hybrid combinations while Specific Combining Ability (SCA) referred to those cases in which certain hybrid combinations do relatively better or worse than would be expected on the basis of the average performance of the lines involved.

Griffing (1956) pointed out the usefulness of information on the relative magnitude of additive and non-additive gene effects in designing an efficient breeding program. He stated that such information could be obtained through the study of combining ability as the variance due to GCA involves mostly additive gene action while that due to SCA involves dominance and epistatic components of genetic variances. Jinks and Jones (1958) pointed out that the superiority of hybrids *per se* does not always mean that they can produce transgressive segregates because many types of unfixable gene effects are also involved in the components of variance. Therefore, a breeder has to evaluate the potentialities of the available germplasm so as to find its capability to give transgressive segregates.

Allard (1960) stressed the need to study combining ability in self-pollinated crops because phenotypically equally promising parents do not always produce equally superior offsprings in the segregating generations while certain combinations nick well and give superior segregants.

2.2 Gene action in pulses other than pigeonpea

Genetic variability for a number of traits of soybean has shown the predominance of additive gene action. However, significant non-additive gene effects have also been reported.

Laffel and Weiss (1958), Weber *et al.*, (1970) and Pascal and Wilcox (1975) reported the predominance of additive gene action for yield per plants, maturity, height and seed size. Although SCA was significant for maturity, seed size and height, the GCA was comparatively much greater.

Singh *et al.*, (1974) in a diallel study of soybean showed that complex characters like grain yield, pods and clusters per plant were controlled both by additive and non-additive gene action. They also reported highly significant additive genetic variance for 100 grain weight and plant height though non-additive variance also played some role in the inheritance of seed weight. Srivastava et al., (1978) observed highly significant GCA and SCA variances in soybean. This indicated that both the additive and non-additive components influence the expression of grain yield per plant and most of the yield contributing traits except for days to flowering where SCA was not significant. Kaw and Madhava (1980) in diallel studies reported a high magnitude of GCA variance indicating the importance of additive gene action in the inheritance of the characters in soybean. However, Kaw and Madhava (1978) using line x tester analysis of combining ability involving 3 testers and 10 selected lines revealed that for none of the traits studied did the genetic variability appear to be predominantly additive. They observed that varieties from USA had generally negative GCA effects for all characters except for seed size unlike the tropical varieties which had significant GCA for almost all characters.

In green gram (Vigna radiata), Singh and Singh (1974b) showed that GCA and SCA variances were important for yield while GCA was more important for seed size, pod number, cluster number and pods per cluster. Jeswani (1970) reported in green gram that variance due to GCA was several times larger than that of SCA. He also found that characters and crosses showing the highest SCA involved one parent with a high GCA. Gupta *et al.* (1978) using line x tester analysis found the predominance of additive gene action for 100 seed weight, plant height and days to maturity; whereas, non-additive gene action was predominant in grain yield, number of pods per plant and number of seeds per pod. Singh and Jain (1971) found that additive gene effects were important for seed size and pod length in green gram. Non-additive gene action in green gram for economically important characters such as grain yield and pods per plant has also been reported by Singh and Singh (1972) and Singh *et al.* (1975). Basheeruddin and Nagur (1981) also observed a preponderance of non-additive gene action for the expression of grain yield and its components in green gram except for pod length which showed both additive and non-additive gene action.

Combining ability studies in chickpea (*Cicer arietinum*) suggests that additive genetic variance is more important than non-additive variance in the inheritance of plant height, 100 seed weight, days to flowering and pod number (Gowda and Bahl, 1978). Studies in chickpea by Athwal and Sandha (1967); Zafar and Khan (1968); Lal (1972); and Dhaliwal and Gill (1973) showed predominant additive gene action for yield and its contributing traits. Bhatt and Singh (1980) in a line x tester combining ability analysis of chickpea reported predominantly additive gene action for plant height, pods per plant and seeds per pod and primarily non-additive gene action for days to maturity and yield per plant. For primary branches, both types of gene action were important. Singh and Ramanujam (1981) reported that both additive and non-additive gene actions were important for all the characters they studied in chickpea. However, Gupta and Ramanujam (1974), reported non-additive gene action to be more prominent for all the characters studied.

A series of diallel studies conducted in other minor grain legumes have shown that both GCA and SCA variances are important for most of the characters studied. In field beans, Bond (1966) reported that most of the variance for seed yield, pods per plant, seed weight, plant height and days to flowering was associated with GCA while SCA was of lower magnitude. In winter beans, Bond (1967) found that GCA accounted for most of the variation for yield. The highest yielding cross had parents of high GCA effects and yield of the crosses was observed to be correlated with those of their parents.

Kheradnam and Niknejad (1971) reported in cowpea (*Vigna unguiculata* (L) Walp.) that both the GCA and SCA effects were significant for yield per plant, pod cluster per plant, seeds per 25 pods, seed weight and flowering date, but not significant for branches per plant. The ratio of GCA to SCA was close to one for yield and pod clusters per plant, but GCA was more important for seed weight, days to flowering and seeds per 25 pods. Das and Dana (1981) in rice bean (Vigna umbellata (Thunb.) Ohwi and Ohashi) concluded that the additive genetic variance had a major role for the number of seeds per plant, 100 seed weight and seed yield per plant, but the dominance component was more important for the number of seeds per pod.

2.3 Combining ability and gene action in pigeonpea

A relatively limited amount of work has been done to obtain information about the nature of gene action and interaction in pigeonpea. Sidhu and Sandhu (1981) and Reddy *et al*., (1981) summarised the results of these genetic studies in pigeonpea. Although there is some controversy in the literature, the general consensus seems to be that yield in pigeonpea is additively inherited (Green *et al*., 1979), in spite of the fact that some yield components are non-additively inherited. The presence of both additive and non-additive gene action for 100 seed weight has also been reported (Sindhu and Sandhu, 1981; Dahiya and Brar, 1977; and Sharma *et al*., 1974).

In a study involving ten pigeonpea varieties differing in maturity group and seed size, Sharma *et al*., (1972) reported the predominance of additive gene effects along with partial dominance. They found that seed size has a high narrow sense heritability value (0.82). Sharma *et al*., (1973a) studied the combining ability for yield per plant, plant height, plant width, days to flowering and maturity and 100 seed weight in diallel crosses of ten varieties of pigeonpea. They found that the GCA variances were greater than SCA variances indicating the predominance of additive gene action. The estimates of the GCA effects of individual parental lines indicated a good agreement between the ranking of the lines for GCA and ranking based on parental performance *per se*. The same authors (1973b) conducted a diallel analysis for flower initiation involving parents, F_1 and F_2 populations of 10 varieties of pigeonpea using the procedure developed by Jinks (1954). The study indicated the predominance of additive genetic variance and the degree of dominance was found to be in the partial dominance range. Dominant genes were found to be associated with early maturity. The proportion of dominant and recessive genes in the parents was almost equal. Heritability in the narrow-sense was high indicating the improvement for flower initiation can be made in the desired direction by simple selection procedures.

Gupta *et al*., (1981) studied the inheritance of days taken to flower and of seed size (g/100 seeds) in four generations of the cross Prabhat x ICP 8504. Partial dominance was observed for earliness. Additive gene effects were found to be most important in the expression of both earliness and seed size. Both of these characters were found to be under comparatively simple genetic control. The study indicated the possibility of improving seed size in early maturing cultivars by simple selection procedures.

Components of genetic variation, estimates of heritability and genetic advance were computed for six quantitative characters by Laxman and Pandey (1974). The experimental material was obtained by crossing two widely diverse cultivars of pigeonpea, "T 21" (early maturing, tall compact plant type and bold seeded) and "R 3" (late maturing, tall compact plant type and bold seeded). Six populations viz. P_1 (T_{21}), P_2(R_3), F_1, F_2, BC_1(P_1) and BC_1(P_2) of the above crosses were used for genetic analysis. Heritability estimates ranged from 54.9 for plant width to 96.6 for seed yield (broad sense) and 28.7 for plant width to 95.2 for days to flowering (narrow sense). Additive genetic effects were significant for days to flowering and seed size, with partial dominance for small seed size. The magnitude of additive gene effects was large for plant height, plant spread, and protein content when compared to non-additive ones. Though none of the characters showed significant non-additive gene effects, characters like yield and plant spread, had a predominance of non-additive gene effects.

Dahiya and Brar (1977) found that additive inheritance was important in determining flowering time, but that the dominance component was higher than the additive component. Over-dominance was observed for pod numbers, 100-seed weight and yield. Their graphical analysis of the diallel cross was in close agreement with the findings from variance component analysis.

Dahiya and Satija (1978) studied days to maturity and grain yield in four generations of two crosses of pigeonpea and observed partial dominance for early maturity. Heritabilities, both broad sense and narrow sense, were close to each other, indicating the importance of additive gene effects in the expression of days to maturity. Dominance interaction components were greater than additive components for the inheritance of grain yield. There was a considerable level of non-additive effects on these traits. It was observed that lines with high yield and early maturity can be isolated which can best fit into multiple cropping systems.

GCA and SCA variances were determined from a 10 x 10 group diallel, a 28 x 28 variety diallel and a 7 x 7 variety diallel in pigeonpea by Reddy *et al.*, (1981). All the diallels indicated the predominance of additive gene action for most of the characters studied. However, highly significant SCA variances were observed for yield in all the diallels. They concluded that breeding programs should aim at exploiting both additive gene action and non-additive gene action through F_1 hybrids and bulk hybrid advance by single-pod descent. In general, a high rank correlation was observed between the mean performance *per se* and the GCA of the parents, indicating that the parents can be chosen for a crossing program on their *per se* performance.

Diallel analysis for nine cultivars of pigeonpea having a wide range of variability in different characters was conducted to determine genetic parameters for plant height by Sharma (1980). The D and H components indicated the importance of both additive and dominance gene effects and that the degree of dominance was in the over-dominance range. The scatter of parental arrays indicated that genes controlling tall stature were dominant over genes controlling short stature.

Venkateswarlu and Singh (1982) also reported the importance of both additive and non-additive gene effects for pods per plant, seeds per pod, 100 seed weight and seed yield per plant. However, the additive gene effects were predominant. The *per se* performance of the parents was highly associated with their GCA effects. They found that most of the crosses showing significant SCA effects involved one good and one poor or even negative general combiner.

Genetic architecture of six characters in pigeonpea was studied in a diallel set involving eight parents by Sidhu and Sandhu (1981). They found that days to flowering and maturity, plant height and seed size appears to be governed by additive gene effects, whereas seed yield and pod number showed more non-additivity. Genes with positive and negative effects were asymmetrically distributed in the parents. Heritability estimates were found to be relatively low for seed yield and pod number, but was medium for the remaining characters.

A full half-diallel cross of seven early-flowering pigeonpea lines was evaluated in the F_1 and F_2 generations by Saxena et al., (1981). The F_1 trial was space planted (1m x 1m); the F_2 trial was in higher density (0.5 x 0.2m). They found a clear effect of method of evaluation on the genetic differences among the progenies. The implications of this and the inclusion of a parent with only moderately different phenology are discussed in relation to the accuracy and meaningfulness of genetic parameters estimated in this and similar studies. Despite these biases, it was shown that GCA variance predominated for all characters considered. The SCA variance was significant for some characters, but was small compared with GCA.

Most of the reports have indicated the predominance of additive gene effects in pigeonpea. However, Reddy et al., (1979a) conducted a combining ability study in crosses involving diverse maturity groups and plant types. They reported the predominance of non-additive gene effects for all the characters studied. They found that the GCA effects for most characters were generally negative for early and medium parents and positive for late parents. They inferred that specific medium x late and early x late cross combinations are likely to yield recombinants of economic worth.

In another experiment, Reddy *et al.*, (1979b) carried out an F_2 diallel analysis involving 45 crosses and ten parents. They reported that the estimates of SCA variance was several times larger than that of GCA indicating the predominance of non-additive gene action in influencing most characters in pigeonpea. They concluded that tall plant height, large seeds, long pod bearing region and many pod bearing branches be used for selection to obtain high yield.

2.4 Heterosis

The term "heterosis" coined by Shull (1914) refers to the phenomenon in which the F_1 population obtained by crossing two genetically dissimilar gametes or individuals shows increased or decreased vigour over the mid-parent or better parental value. Recently, a new term "heterobeltiosis" has been proposed (Bitzer *et al.*, 1968 ; Fonseca and Patterson 1968) to describe the performance of a heterozygote in relation to the better parent of the cross, and now this term is generally being used to connote the expression of heterosis over the better parent.

In terms of increasing the productivity of crop plants, the relative power and potency of heterosis breeding is enormous. It has already become a thoroughfare in the breeding of cross pollinated crops like maize, millet, onion, sugarbeet and sunflower and is being utilized in increasing the productivity of predominantly self-pollinated crops like sorghum, wheat etc. (Rai, 1979). However, the biological requirement for successful commercial hybrid seed production which includes the presence of hybrid vigour, elimination of fertile pollen in the female parent and adequate pollination by the male parent (Forsberg and Smith, 1980) has limited its use in a number of crops.

2.4.1 Heterosis in other pulses

The discovery of heterosis in chickpea (Pal, 1945) opened the way for heterosis study in pulse crops. Varying degree of heterosis with respect to yield and its components in pulses have been observed. In mungbean, Bhatnagar and Singh (1964) reported that F_1 hybrids were superior to the mid parent value for all eight yield component characters studied. As regards pods and seed yield, the hybrids were considerably higher than the better parent. Singh and Singh (1971) observed heterosis over the mid parent value for grain yield, cluster number, pod number and branch number. Fifty-six % and 33 % of the hybrids exceeded the better parent and standard check respectively. Singh and Srivastava (1981) observed heterosis for yield ranging from 2.2 to 98.9 % over the better parent. Singh and Jain (1970) found heterosis over the better parent for grain yield, pod length, branch number and plant height. The hybrid vigour for grain yield over the better parent was present to the extent of 173% in 15 out of 20 crosses.

Marked heterosis for yield and its components has been reported in green gram. Singh (1974) recorded heterosis for yield to an extent of 48% over mid-parent. Singh and Singh (1974a) found that F_1 means were higher for pods per plant and grain yield than mid-parental values. Ramanujam (1975) recorded heterosis ranging from 50 to 82 % over better parent for yield in five crosses. Swindel and Poehlman (1976) reported heterosis for plant height, pods per plant, seeds per pod and yield over mid-parent values. Ramanujam (1978) observed heterosis for pods and number of seeds over their respective better parent in nine hybrids.

Records on soybean have also indicated significant heterosis for yield and its components. Chaudhary et al., (1974) observed heterosis ranging from -30.3 to 67.8 % for seed yield over better parent. Seeds per plant and pods per plant also showed considerable better parent heterosis. Tian (1981), Weber et al., (1970) and Brim and Cockerham (1961) observed heterosis for yield over the better parent ranging from 13 to 48%. Zhan and Cao (1982) observed heterosis over the better parent for yield in 7 out of 12 crosses. Laffel and Weiss (1958) found that of 45 hybrids, 14 showed significant high parent heterosis for yield. Weber et al., (1970) observed that mid-parent and better parent heterosis for yield averaged 25.1% and 13.4% respectively.

Singh and Singh (1976) observed high heterosis for yield and number of pods over better parental values in chickpea, Heterosis for 100 seed weight showed negative values. Gowda and Bahl (1976) reported heterosis over better parental values for number of pods per plant (36%),branches per plant (28%) and seed yield per plant (35%). For 100 seed weight, the majority of crosses again showed negative heterosis. Singh and Mehra (1980) recorded significant heterosis for single plant yield over the better parents in six crosses. Deshmukh and Bhapkar (1980) observed that four crosses out of 36 gave significantly higher yield than their respective better parents. However, Singh and Ramanujam (1981) did not observe any substantial heterosis over the better parent.

Substantial heterosis has also been reproted in other pulses such as cowpea (Singh and Jain, 1972); Lentil (Singh and Jain, 1971); pea (Singh and Singh, 1970 ; Singh et al., 1975; Srivastava and Sachan, 1975; Venkateswarlu and Singh, 1981). In most of the reported cases, it was noted that heterosis in yield is reflected through heterosis in other yield components. Genetic diversity among the parents appeared to play an important role in the manifestation of heterosis. In some cases, it was noted that high yielding parents tended to produce high yielding hybrids (Singh, 1974).

2.4.2 Heterosis in pigeonpea

Solomon et al., (1957) were the first to report hybrid vigour in pigeonpea for grain yield. This was to the extent of 25%. They concluded that by exploiting genetically diverse material, more conspicuous vigour could perhaps be obtained. But even if Cajanus proved a good crop for exploiting heterosis, the difficulty of commercial hybrid seed production existed. However, with the discovery of genetic male sterility (Reddy et al., 1978; Wallis et al., 1981) and the existence of a high degree of outcrossing (Green et al., 1979; Onim, 1980) it became possible to produce hybrid pigeonpea seed with relative ease. Studies on large scale hybrid seed production in isolation blocks have shown that enough pollen vectors are naturally present in the field at ICRISAT center that seed setting on sterile plants is almost equal to that on fertile plants (Green et al., 1979).

Sharma et al., (1973) reported high heterosis effects for plant height and grain yield over the better parent. They suggested the development of composite varieties in pigeonpea. Veeraswamy et al., (1973) using intervarietal hybrids in pigeonpea between CO.1 (a short term, high yielding strain) and 19 genetically diverse varieties, observed heterosis for plant height, plant spread, number of branches, number of clusters, number of pods per plant and days to

50% flowering. Srivastava et al., (1976) reported a mean heterosis of 80% for number of pods per plant over the better parental values. Medium x medium and low x medium crosses generally resulted in high heterotic performance over the better parent.

The magnitude of heterosis for yield and related characters between crosses involving different maturity groups was determined by Reddy et al., (1979a). The study revealed that plant height, days to flower and maturity and seed weight tended to exhibit negative heterosis over the better parent although some individual crosses had positive values. Heterosis for pod number and seed yield over the better parent was generally positive although some individual crosses showed negative values.

To investigate the potential of hybrid pigeonpea, Green et al., (1979) hand crossed 15 elite lines in 1976 and 12 lines in 1977 with two ma sterile stocks MS-3A and MS-4A. Comparison of the hybrids and their pollen parents indicated that the best hybrids in the 2 years yielded 31.5 and 17.0 % higher than the best cultivar in each of the experiments.

2.5 Correlation of yield and its components

Correlation studies in pigeonpea by Munoz and Abrams (1971); Sharma et al.,(1971); Beohar and Nigam (1972); Ganguli and Srivastava, (1972); Joshi (1973); Kumar and Haque (1973); Mukewar and Muley, (1974);

Ram *et al.*, (1976); Dahiya and Brar (1978); Awatade *et al.*, (1980); Beohar *et al.*, (1981) and Asawa *et al.*, (1981) have indicated that grain yield is highly and positively correlated with number of primary branches, secondary branches, clusters, pods and seeds per plant and effective pod bearing length of the branch.

Ganguli and Srivastava (1972) and Mukewar and Muley (1974) found that the average pod length, number of seeds per pod and 100 seed weight are negatively correlated with yield. While Munoz and Abrams (1971) and Singh and Malhotra (1973) reported that 100 seed weight and pod length did not exhibit any significant association with yield. Positive association between yield and 100 seed weight was observed by Dahiya *et al.* (1978) and Godawat (1980).

Grain yield has been reported to be negatively correlated with days to flower and maturity and plant height (Munoz and Abrams, 1971; Kumar and Haque, 1973; Mukewar and Muley, 1974; and Dahiya *et al.*, 1978). However, positive correlation between yield and plant height was reported by Ganguli and Srivastava (1972); Veeraswamy *et al.* (1973), and Upadhaya and Sharma (1980). The last two authors also found positive correlation between yield and days to flower.

The inter-component relationship studied by Veeraswamy et al. (1973) indicated that plant height is positively correlated with number of days to flower, number of branches, pods and cluster per plant at both the genotypic and the phenotypic level. They found that number of branches per plant was positively correlated with number of clusters and pods per plant and days to flower, while clusters per plant was positively correlated with days to flower. Beohar et al. (1981) also reported positive correlation between plant height and primary branches. Beohar and Nigam (1972) observed that pods per plant was negatively correlated with pod length.

Ganguli and Srivastava (1972) found that the average pod length, seeds per pod and 100 seed weight which were negatively correlated with yield, and the rest of the characters were positively correlated among themselves. Reddy et al. (1975) reported that as the duration to maturity increased, the pod number, yield and seed size also increased.

Saxena et al. (1981) observed that phenotypic and genotypic correlations among characters in F_1 and F_2 pigeonpea trials were generally similar in magnitude and direction. In the F_1 trial of a 7 x 7 diallel, yield per plant and days to flower were associated with each other and with all other characters. Seed size (100 seed weight) was statistically independent of seeds per pod and pods per plant. Yield in the F_2 of the same 7 x 7 diallel was negatively associated with seed size and seeds per pod. When they removed the progenies of the latest parent (3D-8103), the F_2 of the resulting 6 x 6 diallel showed strong positive association between yield per plot and days to flower. This marked change in association occurred because the progenies of the latest flowering parent formed a distinct and relatively low yielding, late flowering group in the F_2 trial.

3. MATERIALS AND METHODS

The data for the present investigation were collected during the 1982-83 rainy season at ICRISAT Center, Hyderabad. The crosses that produced the F_1s studied were made during the rainy season of 1981-82.

3.1 Source of material

Three male-sterile lines viz. MS-3A, MS-4A and MS-Prabhat were used as the female parents and pollinated by each of the seven pollen fertile lines chosen for their wide genetic and geographical diversity. The parental material was obtained from ICRISAT. These crossed gave 21 hybrids which were used in this investigation.

The origin, days to flowering, plant height, seeds per pod, 100 seed weight, and growth habit are presented in Table 1.

3.2 Field plot technique and layouts

3.2.1 Crossing

Up to 10 tightly closed buds, approximately two thirds the size of mature buds, were selected on each branch of the female plant for crossing. Smaller buds and mature open buds were removed to prevent competition within the inflorenscence. No crosses were made when these chosen buds had opened.

Table 1 . Origin, pedigree and some plant characters of the ten parents.

Varieties	Origin	Pedigree	Plant characters: Days to 50% flower	Plant height in cm	Seeds per pod	100-seed weight in grams	Growth habit
Females							
MS-3A	India (Andhra Pradesh)	ICP-1555	121	213	4.1	7.9	NDT spreading
MS-4A	India (Maharashtra)	ICP-1596	117	216	3.8	7.5	NDT spreading
MS-Prabhat	India (ICRISAT)	(MS-3A x Prabhat) x [a]BC 4	62	92	3.9	5.8	DT
Males							
BDN-1	India	ICP-7182	103	180	3.7	10.7	NDT spreading
C-11	India (Maharashtra)	ICP-7118	117	203	3.8	10.7	NDT spreading
ICP-7035	India (Madhya Pradesh)	Bheda Ghat collection	126	204	4.8	20.1	NDT semi spreading
ICP-9150	Kenya	JM-2412	157	219	5.7	14.4	NDT
ICP-9180	Kenya	JM-2477	160	222	5.4	11.5	NDT
Royes	West Indies (Trinidad)	UQ-50	116	168	4.4	11.3	DT
C-322	West Indies		104	126	5.3	13.3	DT

a = Four generations of backcross to Prabhat.
NDT = Non-determinate
DT = Determinate

Large, unopened buds in which the anthers would dehisce on that day were collected between 0800 and 1000 hours from male plants and bulked for each male parent.

The staminal column of the pollen bud was used to brush pollen on the stigma of the female. Each female plant was pollinated by several male parents. Different colored threads were tied to each flower to identify each cross. Pollinated buds were not bagged because pod setting is greatly reduced under glassine bags (Sharma and Green, 1980) although bagging ensures little or no outcrossing.

3.2.2 Field layout

The 31 entries comprising of ten parents and 21 F_1 hybrids were grown in a randomized block design and replicated four times. Each plot consisted of four rows, four meters long. Spacing between and within rows was 75 and 30 cm respectively.

3.2.3 Crop management

The experiment was planted on a medium deep vertisol at ICRISAT Center, Patancheru on 25th of June 1982 without fertilizer or rhizobium inoculation. Two seeds were sown per hill. On the 15th day and 21st day after sowing, gap filling and thinning were done respectively, the latter leaving a single plant per hill. Hand weeding was done twice. Spraying for insect pests particularly *Heliothis armigera* was done twice, thrice and four times for early, medium and late maturity groups, respectively. The time for spraying was decided on the number of eggs observed on the flowers and pods.

3.3 Observations

Apart from days to flowering and maturity, observation on each of the characters under study was restricted to ten randomly selected competitive plants in the middle two rows of each plot. Hybrid plants were identified at flowering and pod formation by comparing various plant characteristics, such as flower pod and stem pigmentation, with the parents. Care was taken to avoid plants which were gap filled or next gap filled plants.

Plant samples and pods were dried in a drier at 80°C for 24 hours and 40°C for 48 hours respectively.

Observations studied

3.3.1 Plant basis

Data were collected on the following characters on each of the 10 plants chosen.

a) Plant height

The height to the nearest centimeters of a stretched plant from ground level to the tip of the main stem at harvest.

b) Number of primary branches

Number of branches (productive and unproductive) arising from the main stem was counted at harvest.

c) Number of secondary branches

Total number of branches arising from primary branches counted at harvest.

d) Number of pods

Total number of matured pods obtained at harvest.

e) Seeds per pod, pod length and shelling percentage

From each selected plant, 10 fully developed,matured and undamaged pods were taken at random. On these pods, the following characters were measured for each plant after drying.

i) Number of seeds/pod

The average of the 10 pods.

ii) Pod length

The average pod length measured to the nearest millimeter was recorded.

iii) Shelling percentage

The weight of the 10 unshelled pods was recorded in grams. After threshing, seed weight was recorded. Shelling percentage was calculated as follows:

$$\text{Shelling percentage} = \frac{\text{seed weight}}{\text{unshelled pod weight}} \times 100$$

f) Plant seed yield

The seed weight to the nearest grams per plant.

g) 100-seed weight

The weight to the nearest milligrams of one hundred clean whole dry seeds selected from each plant.

h) Plant pod weight

The total weight to the nearest grams of dried pods from each selected plant.

i) Plant dry weight

The weight to the nearest grams of each selected plant cut at ground level. Thus the weight of fallen leaves and roots was excluded.

j) Biological efficiency (harvest index)

The ratio of plant seed yield (item f) to the total plant weight (item h and i) expressed as a percentage for each plant.

$$HI = \frac{\text{Plant seed yield}}{\text{Total plant dry weight}} \times 100$$

3.3.2 Plot basis

k) Days to 50% flowering

Number of days from sowing to the day when 50% of the plants had shown their first flower in each plot.

l) <u>Days to maturity</u>

Number of days taken from sowing to the day when 75% of the pods turned brown.

m) <u>Plant stand</u>

Total plant count for each plot at the time of harvesting.

n) <u>Plot yield</u>

Grain yield to the nearest gram for each plot. (Variation caused by differences in plot stand was adjusted by obtaining the covariance of yield on plot stand.)

3.4 Statistical Analysis

3.4.1 Heterosis

The performance of the F_1 hybrid over the mid parent value and that of the best parent for each cross expressed as a percent was calculated using the formula suggested by Liang *et al*. (1972) and Rai (1980)as follows :

a) Heterosis = $\frac{F_1 - MP}{MP} \times 100$

MP (mid parent) = mean of parental values.

F_1 = mean of F_1 values.

b) Heterobeltiosis = $\frac{F_1 - BP}{BP} \times 100$

where BP = mean of the better parental values.

The significance of heterosis was tested using t-test suggested by Snedecor and Cochran (1967, p268-271) and Paschal and Wilcox (1975).

a) Heterosis = $t = \frac{F_1 - MP}{\sqrt{\frac{1.5}{r} EMS}}$

b) Heterobeltiosis = $t = \frac{F_1 - BP}{\sqrt{\frac{2 EMS}{r}}}$

where r = number of replications
EMS = error mean squares

Significance of "t" is tested by referring to "t" tables at the appropriate error degrees of freedom.

3.4.2 Combining Ability Analysis

The analysis of combining ability was based on the method of Kempthorne (1957) and Comstock and Robinson (1952). The covariance of half-sibs and full-sibs was used to obtain estimates of general and specific combining ability and their variance as follows :

Source	Degrees of freedom	Sum of squares	Mean sum of squares	Expected Mean Squares
Replications	(r-1)	$\frac{X^2_{..k}}{mf} - \frac{X^2_{...}}{mfr}$		
Hybrids	(mf-1)	$\frac{X^2_{ij}}{r} - \frac{X^2_{...}}{m.f.r}$		
Males	(m-1)	$\frac{X^2_{i..}}{f.r} - \frac{X^2_{...}}{mfr}$	M_1	σ^2+r[Cov.(F.S)-2Cov.(H.S)] +fr Cov.(H.S)
Females	(f-1)	$\frac{X^2_{j..}}{m.r} - \frac{X^2_{...}}{mfr}$	M_2	σ^2+r[Cov.(F.S)-2Cov.(H.S)]+ mr Cov.(H.S)
Males x Females	(m-1) (f-1)	$\frac{X^2_{(ij)}}{r} - \frac{X^2_{i..}}{f.r} - \frac{X^2_{.j.}}{mr} - \frac{X^2_{...}}{mfr}$	M_3	σ^2+r(Cov.(F.S)-2 Cov.(H.S)
rror	(f-1) (m.f-1)	by difference	M_4	σ^2
Total	(m.f.r-1)	$X^2_{ijk} - \frac{X^2_{...}}{mfr}$		

r = number of replications
m = number of male parents
f = number of female parents
X = sum of all the ij hybrid combinations
$X_{..k}$ = sum of kth replication
$X_{(ij)}$ = sum of ijth hybrid combination over all replications
X_i = sum of ith male parent over all females and replications
X_j == sum of jth female parent over all males and replications
X_{ijk} = ijth observation in kth replication

From the expectations of the Mean Sum of Squares (M), Covariance (Cov) of full-sibs (F.S) and Covariance of half-sibs (H.S) were estimated by using the formulae of Kempthorne (1957) as shown below:

$$\text{Covariance of (H.S)} = \frac{(M_1-M_3) + (M_2-M_3)}{r\ (m+f)}$$

$$\text{Covariance of (F.S)} = \frac{(M_1-M_4)+(M_2-M_4)+(M_3-M_4)}{3r} + \frac{6r\ \text{Cov.}(H.S) - r(m+f)\text{Cov.}(H.S)}{3r}$$

Assuming no epistasis, the following equations may be written to describe the covariate relationships (Kempthorne, 1957).

$$\text{Cov (H.S)} = \frac{(1+F)}{4}\ \sigma^2_A$$

$$\text{Cov.(F.S)} = \frac{(1+F)}{2}\ \sigma^2_A + \frac{(1+F)}{2}\ \sigma^2_D$$

Thus, $\sigma^2_A = \frac{4 \text{ Cov } (H.S)}{1+F}$

$$\sigma^2_D = \frac{4(\text{Cov.}(F.S)-2 \text{ Cov.}(H.S)}{(1+F)}$$

$$\sigma^2_G = \sigma^2_A + \sigma^2_D$$

Since the males and females were assumed to be unrelated, the inbreeding coefficient (F) is equal to zero.

σ^2_A = additive genetic variance

σ^2_D = dominance variance

σ^2_G = total genotypic variance

3.4.3 Estimation of variances

After estimating the covariance of (H.S) and (F.S) using the above equations, variances due to general combining ability (GCA) and specific combining ability (SCA) were estimated as follows (Kempthorne, 1957).

σ^2GCA = Cov. of (H.S)

σ^2SCA = Cov. of (F.S) - 2 Cov.(H.S)

3.4.4 Estimation of GCA and SCA effects

The lines used as male and female parents were crossed in accordance with the pattern described for Design II by Comstock and Robinson (1952).

The additive model used to estimate the GCA and SCA effects of observation ijk was

$$Y_{ijk} = u + g_i + g_j + S_{ij} + e_{ijk}$$

where u = population mean
g_i = GCA effect of ith male parent
g_j = GCA effect of jth female parent
S_{ij} = SCA effect of ijth combination
e_{ijk} = Error associated with the observation X_{ijk}
i = number of male parent
j = number of female parent
k = number of replication

The individual effects were estimated as follows :

(i) $\mu = \frac{X_{\ldots k}}{m.f.r}$

where $X_{\ldots}$ = total of all hybrid combinations over all replications

(ii) $g_i = \frac{X_{i\ldots}}{f.r} - \frac{X_{\ldots}}{m.f.r}$

where $X_{i..}$ = total of ith parent over all females and replications

(iii) $g_j = \frac{X_{j..}}{m.r} - \frac{X_{...}}{m.f.r}$

where $X_{j..}$ = total of jth female parent over all male parents and replications

(iv) $S_{ij} = \frac{X_{(ij)}}{r} - \frac{X_i}{m.f} - \frac{X_j}{m.f.} - \frac{X_{...}}{m.f.r.}$

where (X_{ij}) = ijth combination total over all replications

3.4.5 Standard errors for combining ability effects

The S.E.'s pertaining to GCA effects of males and females and SCA effects of different combinations were calculated as shown below using the procedures of (Singh and Chaudhary, 1979).

$$SE\ (g_i)\ \text{males} = \sqrt{\frac{\text{Error variance}}{r.f}}$$

$$SE\ (g_j)\ \text{females} = \sqrt{\frac{\text{Error variance}}{r.m}}$$

$$SE\ (S_{ij})\ \text{male x female combinations} = \sqrt{\text{Error variance}}$$

where r = number of replications
m = number of males
f = number of females

Proportional contribution of males, females and males x females to the total hybrid variance was calculated following the method suggested by Singh and Chaudhary (1979) as follows:

Contribution of males $= \dfrac{SS_{(m)} \times 100}{SS_{(h)}}$

Contribution of females $= \dfrac{SS_{(f)} \times 100}{SS_{(h)}}$

Contribution of males x females $= \dfrac{SS_{(mf)} \times 100}{SS_{(h)}}$

where SS = sum of squares
m = males
f = females
h = hybrids

3.4.6 Correlations

Simple correlation coefficients (r) among different characters of the hybrids were calculated following the method of Panse and Sukhatme (1957).

$$r = \frac{\text{Cov. XY}}{\sqrt{\text{Var.X. Var.Y}}}$$

where $\text{Cov.XY} = \varepsilon XY - \dfrac{\varepsilon X.\varepsilon Y}{n}$

$$\text{Var.X} = \varepsilon X^2 - \frac{(\varepsilon X)^2}{n}$$

$$\text{Var.Y} = \varepsilon Y^2 - \frac{(\varepsilon Y)^2}{n}$$

where r = correlation efficient
Cov.= covariance
Var.= variance
X and Y= two independent variables
n = number of pairs of observations

The significance can be tested by referring to the correlation coefficient tables at (n-2) degrees of freedom.

4. EXPERIMENTAL RESULTS

The results presented herein were obtained from an experiment conducted during the rainy season 1982-83 at ICRISAT Center (Hyderabad) in Vertisols.

The weather condition during this period is presented in Figure 1. During the crop season a total of 527 mm rainfall was recorded which was below the normal (690 mm). The dates of planting, 50% flowering and maturity for early, medium and late maturity groups are marked on the figure.

Highly significant correlation was observed between the mean yield of the ten selected plants and plot yield. This indicated that the selected plants from each plot were truely representative of the net plot.

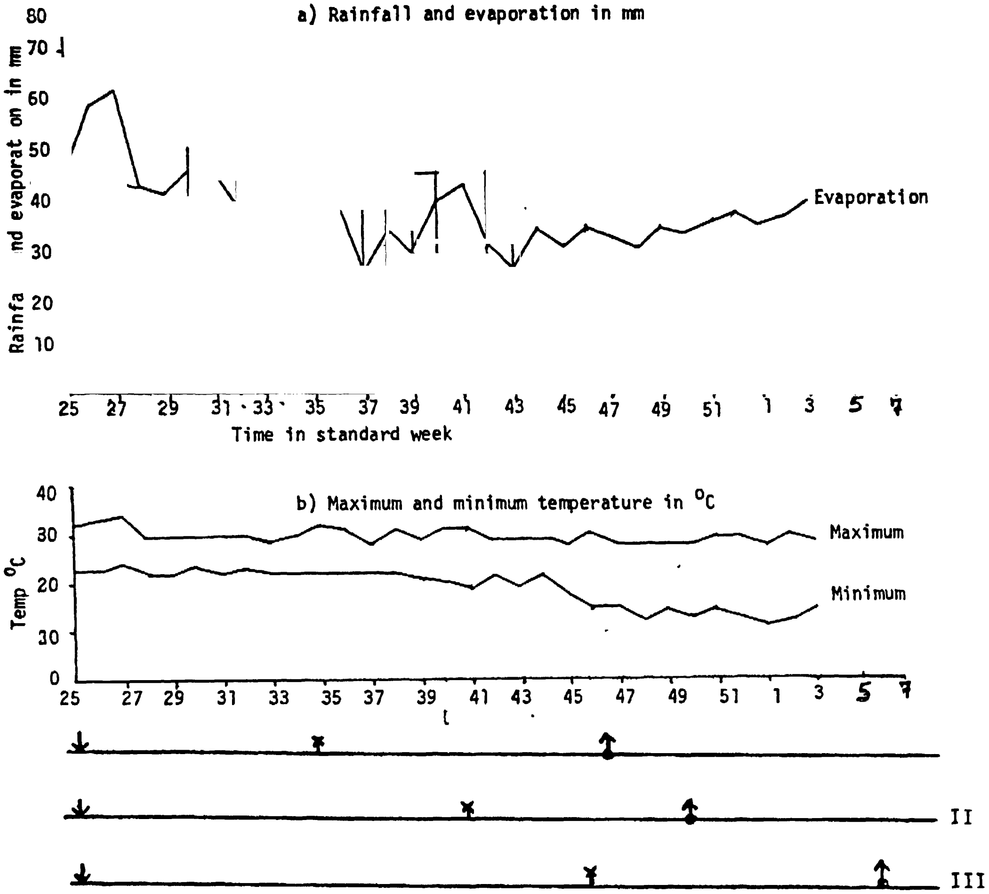
The results are presented in the following order:

1. Analysis of variance for the whole experiment
2. Heterosis
3. Hybrid analysis
4. Correlations

4.1. Analysis of variance

The analysis of variance (Table 2) revealed the existence of highly significant differences among the treatments for all the characters studied. On partitioning the treatments into parents (9 degrees of freedom) and crosses (20 degrees of freedom) highly

Fig. 1. Meteorological data for ICRISAT meteorological station from July 1982 to January 1983.



- Planting date
- Flowering
- Maturity

I - Early group including (MS-Prabhat and its crosses with Royes, C-322, and BDN-1)

II - Medium group (MS-3A, MS-4A and crosses involving them, MS-Prabhat x 9150, MS-Prabhat x 9180)

III - Late group (ICP-9150, ICP-9180)

Table 2. Analysis of variance for parents and hybrids for twelve characters

Source	DF	Mean sum of squares					
		Plant height	Primary branches	Secondary branches	Pods per plant	Seeds per pod	Single plant yield
Replications	3	1352.88	1.19	3.03	13440.50**	0.04	1494.89**
Treatments	30	4910.27**	14.29**	176.49**	9619.46**	1.07**	480.54**
Parents	9	7668.68**	21.74**	185.61**	17834.08**	2.25**	486.39**
Crosses	20	3607.41**	11.29**	181.23**	6137.25**	0.58**	402.07**
Parents vs Crosses	1	6141.90**	7.39	0.02	5332.00	0.01	1997.30**
Experimental error	90	115.03	2.68	18.84	1860.89	0.01	179.56
SE		10.73	1.63	4.34	43.14	0.12	13.40
CV %		5.50	16.30	24.20	26.50	2.80	29.10

* - Significant at 5% level

** - Significant at 1% level

CV % - Coefficient of variation

Table 2. Analysis of variance for parents and hybrids for the characters studied.

Source	DF	Mean sum of squares						
		100-seed weight	Shelling (%)	Total plant weight	Days to 50% flower	Days to maturity	Harvest index	Pod length
Replications	3	1.95	6.70	39060.00**	9.765	10.37	9.76	0.12
Treatments	30	26.45**	77.35**	10893.65**	91.280**	1432.74**	91.28**	2.94**
Parents	9	65.70**	184.67**	10296.00**	136.230**	3075.85**	136.23**	6.79**
Crosses	20	7.81**	19.42**	11181.00**	71.200**	733.47**	71.10**	1.19**
Parents vs Crosses	1	46.33**	268.22**	111.31**	90.110**	630.207**	90.11**	3.29**
Experimental error	90	1.08	3.73	3920.00	8.13	3.96	8.13	0.02
SE		1.04	1.93	60.80	1.99	3.88	2.80	0.07
CV %		10.00	2.70	28.40	1.70	2.40	13.90	2.69

* - Significant at 5% level

** - Significant at 1% level

CV % - Coefficient of variation

significant differences were still realized for all the characters. However, parents vs. crosses did not show significant difference for primary branches, secondary branches, pods per plant and seeds per pod. Significant replication differences appeared for the characters plant height, pods per plant, single plant yield and total plant weight.

The coefficient of variation (CV%) was reasonable for most characters but was high for secondary branches (24.2), pods per plant (26.5), single plant yield (29.1), primary branches (16.3), and total weight per plant (28.4).

4.2 Means of F_1 hybrids, parents and hybrid vigour

The means of F_1 hybrids, their parents and the hybrid vigour for the characters studied are presented in Tables 3-16.

a) Plant height (cm)

The mean plant height for the female parents ranged from 92 (MS-Prabhat) to 216 cm (MS-4A). Among the male parents, it ranged from 126 (C-322) to 222 cm (ICP-9180) (Table 3).

The F_1's means ranged from 118 (MS-Prabhat x C-322) to 234 cm (MS-3A x ICP-9180). Generally, most crosses were taller than their mid-parent value and closer to the better parent's value. Two crosses (MS-3A x ICP-9150 and MS-4A x ICP-9150)were statistically taller than the tallest parent.

The overall mean of F_1's was 199 cm which showed an increase of 8.1% over the mean of the parents. Heterosis ranged from -6.7 (MS-3A x BDN-1) to 39.1% (MS-Prabhat x ICP-9180) over mid parent values and from -24.3 (MS-Prabhat x Royes) to 6.7% (MS-3A x ICP-9150) over the better parent. Eight crosses had significant negative heterosis when compared to the better parent. Among the eight crosses, MS-Prabhat x Royes, MS-3A x BDN-1, MS-3A x C-322 and MS-Prabhat x ICP-7035 had the shortest plant height.

Table 3. Mean plant height in F_1 hybrids and their parents and the extent of hybrid vigour

S.No.	Crosses	Mean of F_1s	Parents P_1	Parents P_2	Mean of parents	F_1 as % of Mid parent	F_1 as % of Better parent
1	MS-3A x BDN-1	183	213	180	196	-6.7*	-13.9**
2	MS-3A x C-11	215	213	203	208	3.3	0.8
3	MS-3A x ICP-7035	205	213	204	208	-1.6	-3.7
4	MS-3A x ICP-9150	234	213	219	216	8.3**	6.7*
5	MS-3A x ICP-9180	225	213	222	217	3.3	1.3
6	MS-3A x Royes	210	213	168	198	10.2**	-1.3
7	MS-3A x C-322	192	213	126	170	12.9	-9.8**
8	MS-4A x BDN-1	200	216	180	198	1.0	-7.3*
9	MS-4A x C-11	217	216	203	209	3.7	0.5
10	MS-4A x ICP-7035	207	216	204	210	-1.2	-4.0
11	MS-4A x ICP-9150	232	216	219	218	6.6*	5.9*
12	MS-4A x ICP-9180	223	216	222	219	2.0	0.7
13	MS-4A x Royes	202	216	168	192	5.4	-6.3*
14	MS-4A x C-322	198	216	126	171	15.5**	-8.3**
15	MS-Prabhat x BDN-1	174	92	180	136	27.5**	-4.4
16	MS-Prabhat x C-11	205	92	203	147	38.7**	1.0
17	MS-Prabhat x ICP-7035	184	92	204	148	24.3**	-9.5*
18	MS-Prabhat x ICP-9150	216	92	219	156	38.7**	-1.3
19	MS-Prabhat x ICP-9180	219	92	222	157	39.1**	-1.3
20	MS-Prabhat x Royes	127	92	168	130	-2.4	-24.3**
21	MS-Prabhat x C-322	118	92	126	109	7.8	- 6.7*
	Mean	199		(184)		8.1	
	S.Em	4.7		6.5			
	LSD	13.4		19.0			

*, ** Significant at 5% and 1% levels respectively

( ) Mean of 10 parents

b) Number of primary branches

The average number of primary branches for the female parents ranged from 9.9 (MS-3A) to 13.7 branches (MS-Prabhat). The range was from 6.5 (Royes) to 10.0 branches (BDN-1) for the male parents (Table 4).

The hybrid means ranged from 6.8 (MS-3A x BDN-1) to 13.5 branches (MS-4A x C-11). The hybrid means were higher than the mid parent value in twelve out of 21 crosses. For the crosses MS-3A x C-11, MS-3A x ICP-7035 and MS-3A x ICP-9150, the hybrids had more primary branches than the better parent value.

The overall mean of the hybrids was 10.2 branches which showed an increase of 5.3% over the overall parental mean (9.7). Heterosis for primary branches ranged from -31.4 (MS-3A x BDN-1) to 30.7% (MS-3A x ICP-7035) compared to the mid parent value and from -42.0 (MS-Prabhat x ICP-7035) to 21.2% (MS-3A x ICP-9150) compared to the better parent value. Only one cross (MS-3A x ICP-9150) showed significant positive heterosis over the better parent. While three crosses (MS-3A x ICP-7035, MS-3A x ICP-9150 and MS-4A x C-11) showed significant positive heterosis over their mid parent value.

c) Number of secondary branches

The average number of secondary branches for female parents ranged from 15.0 (MS-Prabhat) to 34.8 branches (MS-4A). The range was from 10.3 (ICP-9150) to 20.9 branches (C-11) for the male parents (Table 5).

Table 4 : Mean number of primary branches in F_1 hybrids and their parents and the extent of hybrid vigour

S.No.	Crosses	Mean of F_1s	Parents		Mean of parents	F_1 as % of	
			P_1	P_2		Mid parent	Better parent
1	MS-3A x BDN-1	6.8	9.9	10.0	10.0	-31.4**	-31.7**
2	MS-3A x C-11	11.0	9.9	9.3	9.6	14.1	10.7
3	MS-3A x ICP-7035	11.7	9.9	7.9	8.9	30.7**	17.5
4	MS-3A x ICP-9150	12.1	9.9	8.8	9.4	28.7**	21.2*
5	MS-3A x ICP-9180	8.3	9.9	9.7	9.8	-15.6	-16.6
6	MS-3A x Royes	9.7	9.9	6.5	8.2	17.5	-2.8
7	MS-3A x C-322	9.5	9.9	7.4	8.7	9.3	-4.5
8	MS-4A x BDN-1	10.7	13.3	10.0	11.7	-8.5	-19.8
9	MS-4A x C-11	13.5	13.3	9.3	11.3	18.8*	1.1
10	MS-4A x ICP-7035	11.0	13.3	7.9	10.6	3.3	-17.5*
11	MS-4A x ICP-9150	12.0	13.3	8.8	11.1	8.8	-9.7
12	MS-4A x ICP-9180	10.6	13.3	9.7	11.5	-8.0	-20.5*
13	MS-4A x Royes	10.2	13.3	6.5	9.9	3.1	-23.2**
14	MS-4A x C-322	9.9	13.3	7.4	10.4	-4.9	-26.0**
15	MS-Prabhat x BDN-1	8.3	13.7	10.0	11.9	-30.0**	-39.2**
16	MS-Prabhat x C-11	9.9	13.7	9.3	11.5	-14.2	-27.8**
17	MS-Prabhat x ICP-7035	7.9	13.7	7.9	11.8	-26.6**	-42.0**
18	MS-Prabhat x ICP-9150	8.4	13.7	8.8	11.2	-25.0*	-38.4**
19	MS-Prabhat x ICP-9180	12.1	13.7	9.7	11.7	3.1	-11.8
20	MS-Prabhat x Royes	9.0	13.7	6.5	10.1	-11.1	-34.4**
21	MS-Prabhat x C-322	11.6	13.7	7.4	10.5	9.5	-15.4
	Mean	10.2		(9.7)		5.3	
	S.Em	0.78		0.93			
	LSD	2.21		2.68			

*, ** Significant at 5% and 1% levels respectively
( ) Mean of 10 parents

Table 5. Mean number of secondary branches in F_1 hybrids and their parents and the extent of hybrid vigour

S.No.	Crosses	Mean of F_1s	Parents		Mean of parents	F_1 as % of	
			P_1	P_2		Mid parent	Better parent
1	MS-3A x BDN-1	11.8	19.7	20.3	20.0	-41.1**	-42.1**
2	MS-3A x C-11	23.7	19.7	20.9	20.3	16.8	13.5
3	MS-3A x ICP-7035	13.8	19.7	13.8	16.7	-17.18	-30.0
4	MS-3A x ICP-9150	17.9	19.7	10.3	15.0	19.2	-9.2
5	MS-3A x ICP-9180	19.1	19.7	14.6	17.2	11.4	-2.7
6	MS-3A x Royes	17.6	19.7	16.0	17.8	-1.6	-10.8
7	MS-3A x C-322	9.8	19.7	12.9	16.8	-41.7**	-50.3**
8	MS-4A x BDN-1	20.4	34.8	20.3	27.6	-25.9**	-41.3**
9	MS-4A x C-11	36.1	34.8	20.9	27.8	29.5**	3.5
10	MS-4A x ICP-7035	18.5	34.8	13.8	24.5	-23.7**	-46.6**
11	MS-4A x ICP-9150	20.2	34.8	10.3	22.5	-10.5	-42.0**
12	MS-4A x ICP-9180	19.8	34.8	14.6	24.7	-19.7	-42.9
13	MS-4A x Royes	10.4	34.8	16.0	25.4	-59.1**	-70.0**
14	MS-4A x C-322	15.5	34.8	13.9	24.3	-36.2**	-55.3**
15	MS-Prabhat x BDN-1	16.5	15.0	20.3	17.7	-6.8	-19.0
16	MS-Prabhat x C-11	14.6	15.0	20.9	15.9	-18.6	-30.0
17	MS-Prabhat x ICP-7035	11.7	15.0	13.8	14.4	-18.4	-21.7
18	MS-Prabhat x ICP-9150	5.8	15.0	10.3	12.6	-53.8**	-61.1**
19	MS-Prabhat x ICP-9180	28.0	15.0	14.6	14.8	88.3**	86.0**
20	MS-Prabhat x Royes	23.1	15.0	16.0	15.5	48.7**	44.1**
21	MS-Prabhat x C-322	22.0	15.0	13.9	14.4	52.0**	46.3**
	Mean	17.9		(17.8)		-0.7	
	S.Em	1.71		2.87			
	LSD	4.85		8.33			

*, ** Significant at 5% and 1% level respectively
( ) Mean of 10 parents

The hybrid means ranged from 5.8 (MS-Prabhat x ICP-9150) to 36.1 branches (MS-4A x C-11). For the crosses MS-3A x C-11, MS-4A x C-11, MS-Prabhat x C-322, MS-Prabhat x ICP-9180 and MS-Prabhat x Royes, the mean number of secondary branches were higher than the better parental value.

The overall parent's and hybrid's number of secondary branches were similar. Heterosis ranged from -53.8 (MS-Prabhat x ICP-9150) to 88.3% (MS-Prabhat x ICP-9180) when compared to the mid parental value and from -70.0 (MS-4A x Royes) to 86.0% (MS-Prabhat x ICP-9180) compared to the better parent. MS-Prabhat x ICP-9180, MS-Prabhat x Royes, MS-Prabhat x C-322 showed significant positive heterosis over the better parent value. MS-4A x C-11, MS-Prabhat x ICP-9180, MS-Prabhat x C-322 and Ms-Prabhat x Royes showed a significant positive mid parent heterosis.

d) Number of pods per plant

The average number of pods per plant for female parents ranged from 210 (MS-Prabhat) to 246 pods (MS-4A). Among the male parents, it ranged from 75 (ICP-9150) to 205 pods (BDN-1) (Table 6).

The hybrid means ranged from 88 (MS-Prabhat x ICP-9150) to 271 pods (MS-4A x C-11). The mean of three hybrids, MS-3A x C-11, MS-4A x C-11 and MS-Prabhat x C-11 was higher than their better parental values.

Table 6. Mean number of pods per plant in F_1 hybrids and their parent and the extent of hybrid vigour.

S.No.	Crosses	Mean of F_1s	Parents P_1	Parents P_2	Mean of parents	F_1 as % of Mid parent	F_1 as % of Better parent
1	MS-3A x BDN-1	154	211	205	208	-26.2*	-27.2*
2	MS-3A x C-11	232	211	198	205	13.1	9.5
3	MS-3A x ICP-7035	140	211	76	144	-2.7	-33.7*
4	MS-3A x ICP-9150	156	211	75	143	9.1	-26.0
5	MS-3A x ICP-9180	176	211	103	157	11.8	-16.6
6	MS-3A x Royes	189	211	115	163	15.6	-10.6
7	MS-3A x C-322	122	211	88	150	-18.4	-42.1**
8	MS-4A x BDN-1	171	246	205	226	-24.0*	-30.3**
9	MS-4A x C-11	271	246	198	222	21.8	9.9
10	MS-4A x ICP-7035	181	246	76	161	12.3	-26.3*
11	MS-4A x ICP-9150	136	246	75	161	-14.9	-44.4**
12	MS-4A x ICP-9180	161	246	103	175	-8.9	-34.6**
13	MS-4A x Royes	146	246	115	181	-18.9	-40.4**
14	MS-4A x C-322	157	246	88	167	-6.0	-36.1**
15	MS-Prabhat x BDN-1	189	210	205	208	-9.0	-10.0
16	MS-Prabhat x C-11	219	210	198	204	7.4	4.4
17	MS-Prabhat x ICP-7035	157	210	76	143	9.4	-25.3
18	MS-Prabhat x ICP-9150	88	210	75	142	-37.9*	-57.8**
19	MS-Prabhat x ICP-9180	159	210	103	157	1.5	-24.1
20	MS-Prabhat x Royes	163	210	115	162	0.2	-22.3
21	MS-Prabhat x C-322	138	210	88	149	-7.4	-34.1**
	Mean	167		(153)		9.1	
	S.Em	22.3		20.9			
	LSD	62.9		60.3			

*, ** Significant at 5% and 1% level respectively,

( ) Mean of 10 parents

The overall hybrid mean (167 pods) was higher than the overall parental mean (153 pods) by 9.1%. Heterosis ranged from -37.9 (MS-Prabhat x ICP-9150) to 21.8% (MS-4A x C-11) when compared to the mid parent value and from -57.8 (MS-Prabhat x ICP-9150) to 9.9% (MS-4A x C-11) when compared to the better parent value. No cross showed significant positive heterosis over its better parent value. However, ten out of 21 crosses had higher number of pods compared to mid parental values though not significantly so.

e) Number of seeds per pod

The average number of seeds per pod for female parents ranged from 3.8 (MS- 4A) to 4.0 seeds (MS-3A). Among the male parents it ranged from 3.6 (BDN-1) to 5.7 seeds (ICP-9150) (Table 7).

The hybrid means ranged from 3.7 (MS-4A x C-11) to 4.9 seeds (MS-Prabhat x ICP-7035, MS-Prabhat x ICP-9180, MS-Prabhat x C-322). Four crosses viz., MS-3A x Royes, MS-Prabhat x C-11, MS-Prabhat x ICP-7035 and MS-Prabhat x Royes had more seeds per pod than their better parents.

The overall hybrid mean (4.4) was very close to the parental mean (4.5). Heterosis ranged from -3.9 (MS-3A x ICP-9150) to 12.7% (MS-Prabhat x ICP-7035) compared to the mid parent value and from -18.0 (MS-4A x ICP-9150) to 5.9% (MS-Prabhat x Royes)

Table 7. Mean number of seeds per pod for F_1 hybrids and their parents and the extent of hybrid vigour

S.No.	Crosses	Mean of F_1s	Parents		Mean of parents	F_1 as % of	
			P_1	P_2		Mid parent	Better parent
1	MS-3A x BDN-1	4.0	4.0	3.6	3.8	4.5**	-0.7
2	MS-3A x C-11	4.0	4.0	3.8	3.9	2.1	-0.4
3	MS-3A x ICP-7035	4.5	4.0	4.8	4.4	2.0	-6.3**
4	MS-3A x ICP-9150	4.7	4.0	5.7	4.8	-3.9**	-17.6**
5	MS-3A x ICP-9180	4.6	4.0	5.4	4.7	-1.2	-13.3**
6	MS-3A x Royes	4.5	4.0	4.4	4.2	6.0**	2.0
7	MS-3A x C-322	4.8	4.0	5.3	4.7	4.0**	-8.0**
8	MS-4A x BDN-1	3.8	3.8	3.6	3.7	1.8	-1.0
9	MS-4A x C-11	3.7	3.8	3.8	3.8	-2.5	-2.8
10	MS-4A x ICP-7035	4.5	3.8	4.8	4.3	3.7**	-6.7**
11	MS-4A x ICP-9150	4.6	3.8	5.7	4.8	-2.5	-18.0**
12	MS-4A x ICP-9180	4.5	3.8	5.4	4.6	-2.6	-16.3**
13	MS-4A x Royes	4.4	3.8	4.4	4.1	6.0**	-0.2
14	MS-4A x C-322	4.6	3.8	5.3	4.6	0.5	-12.9**
15	MS-Prabhat x BDN-1	3.8	3.9	3.6	3.8	1.9	-1.2
16	MS-Prabhat x C-11	4.1	3.9	3.8	3.8	6.5**	5.8**
17	MS-Prabhat x ICP-7035	4.9	3.9	4.8	4.4	12.7**	1.6
18	MS-Prabhat x ICP-9150	4.7	3.9	5.7	4.8	-0.7	-16.2**
19	MS-Prabhat x ICP-9180	4.9	3.9	5.4	4.6	6.4**	-8.1**
20	MS-Prabhat x Royes	4.6	3.9	4.4	4.1	12.1**	5.9**
21	MS-Prabhat x C-322	4.9	3.9	5.3	4.6	8.0**	-6.2**
	Mean	4.4		(4.5)		-0.4	
	S.Em	0.06		0.07			
	LSD	0.16		0.20			

*, ** Significnat at 5% and 1% level respectively
( ) Mean of 10 parents

compared to the better parental value. Two crosses MS-Prabhat x Royes and MS-Prabhat x C-11 showed significant positive better parent heterosis.

f) Single plant yield

The average grain yield per plant for female parents ranged from 31.5 (MS-Prabhat) to 54.5 g (MS-3A) and for the male parents from 22.8 (ICP-9150) to 54.4 g (C-11) (Table 8).

The hybrid means ranged from 33.3 (MS-Prabhat x ICP-9150) to 70.0 g (MS-3A x C-11). In most cases, the hybrid means were higher than their mid parent values. In ten crosses, the hybrid yield was above the better parent. The highest yielding hybrids were MS-3A x C-11, MS-4A x C-11, MS-4A x ICP-7035 and MS-Prabhat x ICP-7035.

The overall hybrid mean (48.0 g) was higher than the parental mean by 21.3%. Heterosis ranged from -23.2 (MS-3A x BDN-1) to 85.6% (MS-Prabhat and ICP-7035) compared to the mid parent value and from -25.3 (MS-3A x BDN-1) to 85.6% (MS-Prabhat x ICP-7035) compared to the better parent value. Three crosses (MS-3A x C-11, MS-Prabhat x ICP-7035 and MS-Prabhat x ICP-9180) showed significant positive better parent heterosis.

Table 8. Mean of single plant yield for F_1 hybrids and their parents and the extent of hybrid vigour

S.No.	Crosses	Mean of F_1s	Parents		Mean of parents	F_1 as % of	
			P_1	P_2		Mid parent	Better parent
1	MS-3A x BDN-1	36.4	48.8	46.1	47.4	-23.2	-25.3
2	MS-3A x C-11	70.0	48.8	54.4	51.8	35.1*	27.7*
3	MS-3A x ICP-7035	55.1	48.8	31.5	40.2	37.2*	13.0
4	MS-3A x ICP-9150	51.7	48.8	22.8	35.8	44.4*	5.9
5	MS-3A x ICP-9180	48.9	48.8	30.7	39.7	21.9	-0.6
6	MS-3A x Royes	48.1	48.8	44.2	46.7	3.1	-1.3
7	MS-3A x C-322	41.0	48.8	37.5	43.1	-4.9	-15.9
8	MS-4A x BDN-1	42.6	54.5	46.1	50.3	-15.3	-21.8
9	MS-4A x C-11	67.9	54.5	54.4	54.7	22.6	22.2
10	MS-4A x ICP-7035	64.9	54.5	31.5	43.1	50.7**	19.0
11	MS-4A x ICP-9150	44.5	54.5	22.8	38.7	15.2	-18.2
12	MS-4A x ICP-9180	43.1	54.5	30.7	42.6	1.2	-20.8
13	MS-4A x Royes	41.6	54.5	44.2	49.5	-15.9	-23.6
14	MS-4A x C-322	46.0	54.5	37.5	46.0	0.1	-15.5
15	MS-Prabhat x BDN-1	39.4	31.5	46.1	38.8	1.4	-14.4
16	MS-Prabhat x C-11	56.2	31.5	54.4	43.2	30.1	2.5
17	MS-Prabhat x ICP-7035	58.6	31.5	31.5	31.6	85.6**	85.6**
18	MS-Prabhat x ICP-9150	33.3	31.5	22.8	27.2	22.6	5.6
19	MS-Prabhat x ICP-9180	52.1	31.5	30.7	31.1	67.2**	64.9**
20	MS-Prabhat x Royes	42.8	31.5	44.2	38.1	12.6	-3.7
21	MS-Prabhat x C-322	43.0	31.5	37.5	34.5	24.5	14.7
	Mean	48.0		(40)		21.3	
	S.Em	7.2		5.7			
	LSD	20.3		16.6			

*, ** Significant at 5% and 1% level respectively

( ) Mean of 10 parents

g) <u>100-seed weight</u>

The average 100-seed weight ranged from 5.7 (MS-Prabhat) to 7.9 g (MS-3A) and from 10.7 (BDN-1) to 20.1 g (ICP-7035) for female and male parents respectively (Table 9).

The hybrid means ranged from 7.9 (MS-Prabhat x BDN-1) to 14.0 g (MS-4A x ICP-7035). Most of the hybrids had mean values lower than their mid parent values. No cross had 100-seed weight above the better parent.

The overall hybrid mean (10.0 g) was lower than the parental mean (10.3 g) by 2.9%. Heterosis ranged from -17.9 (MS-3A x ICP-7035) to 18.2 % (MS-Prabhat x ICP-9150) compared to the mid parent values and from -45.2 (MS-Prabhat x ICP-7035) to -8.6 (MS-3A x C-11) compared to the better parent values. Nineteen crosses showed significant negative better parent heterosis. Only one cross (MS-Prabhat x ICP-9150) showed significant positive mid parent heterosis.

h) <u>Total weight per plant</u>

The average total weight per plant ranged from 107 (MS-Prabhat) to 260 g (MS-3A) and from 156 (C-322) to 260 g (ICP-7035) for female and male parents respectively (Table 10).

The hybrid means ranged from 147 (MS-Prabhat x C-322) to 324 g (MS-3A x C-11). Generally, the hybrid means were higher than the

Table 9. Mean of 100-seed weight for F1 hybrids and their parents and the extent of hybrid vigour

S.No.	Crosses	Mean of F_1s	Parents		Mean of parents	F_1 as % of	
			P_1	P_2		Mid parent	Better parent
1	MS-3A x BDN-1	9.3	7.9	10.7	9.3	0.5	-12.4
2	MS-3A x C-11	9.8	7.9	10.7	9.3	5.0	-8.6
3	MS-3A x ICP-7035	11.5	7.9	20.1	14.0	-17.9**	-42.7**
4	MS-3A x ICP-9150	11.3	7.9	14.4	11.1	1.7	-21.1**
5	MS-3A x ICP-9180	9.4	7.9	11.4	9.7	-2.3	-17.4**
6	MS-3A x Royes	9.6	7.9	11.2	9.6	0.3	-14.6*
7	MS-3A x C-322	9.9	7.9	13.2	10.5	-6.2	-25.0**
8	MS-4A x BDN-1	8.8	7.5	10.7	9.1	-2.9	-17.4*
9	MS-4A x C-11	9.2	7.5	10.7	9.1	1.7	-13.5*
10	MS-4A x ICP-7035	14.0	7.5	20.1	13.8	2.1	-29.9**
11	MS-4A x ICP-9150	11.3	7.5	14.4	10.9	3.3	-21.3**
12	MS-4A x ICP-9180	9.5	7.5	11.4	9.4	0.1	-17.3**
13	MS-4A x Royes	9.4	7.5	11.2	9.4	0.6	-16.2*
14	MS-4A x C-322	9.3	7.5	13.2	10.3	-9.6	-29.2**
15	MS-Prabhat x BDN-1	7.9	5.7	10.7	8.2	-3.9	-25.9**
16	MS-Prabhat x C-11	8.6	5.7	10.7	8.2	4.7	-19.3**
17	MS-Prabhat x ICP-7035	11.0	5.7	20.1	12.9	-15.0**	-45.2**
18	MS-Prabhat x ICP-9150	11.9	5.7	14.4	10.1	18.2**	-17.0**
19	MS-Prabhat x ICP-9180	9.7	5.7	11.4	8.6	12.2	-15.5*
20	MS-Prabhat x Royes	9.0	5.7	11.2	8.5	6.4	-19.4**
21	MS-Prabhat x C-322	8.9	5.7	13.2	9.5	-5.5	-32.1**
	Mean	10.0		(10.3)		-11.5	
	S.Em	0.60		0.23			
	LSD	1.71		0.66			

*, ** Significant at 5% and 1% level respectively
( ) Mean of 10 parents

Table 10. Mean of total weight per plant for F_1 hybrids and their parents and the extent of hybrid vigour

S.No.	Crosses	Mean of F_1s	Parents P_1	Parents P_2	Mean of parents	F_1 as % of Mid parent	F_1 as % of Better parent
1	MS-3A x BDN-1	164	260	193	226	-27.2*	-36.6*
2	MS-3A x C-11	324	260	251	255	27.1*	24.9
3	MS-3A x ICP-7035	263	260	260	260	1.2	1.1
4	MS-3A x ICP-9150	312	260	218	239	30.7*	20.3
5	MS-3A x ICP-9180	276	260	227	243	13.4	6.3
6	MS-3A x Royes	267	260	240	250	6.8	2.7
7	MS-3A x C-322	192	260	156	208	-7.3	-25.8
8	MS-4A x BDN-1	207	252	193	222	-6.9	-17.8
9	MS-4A x C-11	295	252	251	251	17.5	17.3
10	MS-4A x ICP-7035	307	252	260	256	19.8	17.9
11	MS-4A x ICP-9150	288	252	218	235	22.6	14.4
12	MS-4A x ICP-9180	260	252	227	239	8.6	3.2
13	MS-4A x Royes	227	252	240	246	-7.5	-9.8
14	MS-4A x C-322	233	252	156	204	14.2	-7.5
15	MS-Prabhat x BDN-1	171	107	193	150	14.1	-11.3
16	MS-Prabhat x C-11	208	107	251	179	16.3	-17.0
17	MS-Prabhat x ICP-7035	205	107	260	183	11.9	-21.1
18	MS-Prabhat x ICP-9150	202	107	218	162	24.2	-7.5
19	MS-Prabhat x ICP-9180	242	107	227	167	45.2**	6.8
20	MS-Prabhat x Royes	174	107	240	173	0.3	-27.5
21	MS-Prabhat x C-322	147	107	156	131	12.0	-5.6
	Mean	236		(216)		9.3	
	S.Em	33.3		26.9			
	LSD	94.0		78.1			

*, ** Significant at 5% and 1% level respectively
( ) Mean of 10 parents

mid parental values. The total weight per plant for hybrids was statistically higher than the better parent values in 10 out of 21 crosses.

The overall hybrid mean (236 g) was higher than the parental mean (216 g) by 9.3%. Heterosis ranged from -27.2 (MS-3A x BDN-1) to 45.2% (MS-Prabhat x ICP-9180) when compared to the mid parent values and from -36.6 (MS-3A x BDN-1) to 24.9% (MS-3A x C-11) compared to the better parental values. Three crosses viz., MS-3A x C-11, MS-3A x ICP-9150 and MS-Prabhat x ICP-9180 had significant positive mid parent heterosis.

i) Harvest index

The average harvest ranged from 18.2 (MS-3A) to 28.8% (MS-Prabhat) for the females and for the males from 10.6 (ICP-9150) to 23.7% (BDN-1) (Table 11).

The hybrid means ranged from 15.3 (MS-4A x ICP-9150) to 31.0% (MS-Prabhat x ICP-7035). Generally, the hybrid harvest index were higher than their mid parent values.

The overall hybrid mean (21.1%) was higher than the parental mean (19.3%) by 9.3%. Heterosis ranged from -18.1 (MS-Prabhat x ICP-9150) to 51.8% (MS-Prabhat x ICP-7035) compared to the mid parent values and from -43.8 (MS-Prabhat x ICP-9150) to 13.8% (MS-3A x ICP-7035)

Table 11. Mean of harvest index for F_1 hybrids and their parents and the extent of hybrid vigour

S.No.	Crosses	Mean of F_1s	Parents P_1	P_2	Mean of parents	F_1 as % of Mid parent	Better parent
1	MS-3A x BDN-1	21.8	18.2	23.7	20.9	4.1	-7.8
2	MS-3A x C-11	20.8	18.2	21.9	20.1	3.7	-4.9
3	MS-3A x ICP-7035	20.7	18.2	12.1	15.2	36.6*	13.8
4	MS-3A x ICP-9150	16.3	18.2	10.6	14.3	12.4	-10.9
5	MS-3A x ICP-9180	17.3	18.2	13.1	15.7	10.3	-5.1
6	MS-3A x Royes	18.5	18.2	18.7	18.5	0.2	-1.2
7	MS-3A x C-322	21.0	18.2	23.3	20.8	0.9	-10.1
8	MS-4A x BDN-1	20.2	22.2	23.7	22.9	-11.9	-14.8*
9	MS-4A x C-11	23.4	22.2	21.9	22.0	6.1	5.5
10	MS-4A x ICP-7035	21.0	22.2	12.1	17.1	22.7*	-5.0
11	MS-4A x ICP-9150	15.3	22.2	10.6	16.4	-6.4	-30.7**
12	MS-4A x ICP-9180	16.2	22.2	13.1	17.6	-8.2	-26.9**
13	MS-4A x Royes	18.1	22.2	18.7	20.4	-11.4	-18.2*
14	MS-4A x C-322	20.6	22.2	23.3	22.7	-9.6	-12.0
15	MS-Prabhat x BDN-1	23.2	28.8	23.7	26.3	-11.7	-19.5**
16	MS-Prabhat x C-11	26.8	28.8	21.9	25.3	5.9	-6.7
17	MS-Prabhat x ICP-7035	31.0	28.8	12.1	20.5	51.8**	7.9
18	MS-Prabhat x ICP-9150	16.2	28.8	10.6	19.7	-18.1*	-43.8**
19	MS-Prabhat x ICP-9180	20.9	28.8	13.1	20.9	-0.1	-27.3**
20	MS-Prabhat x Royes	24.7	28.8	18.7	23.8	3.8	-14.2*
21	MS-Prabhat x C-322	29.1	28.8	23.4	26.1	11.4	0.9
	Mean	21.1		(19.3)		9.3	
	S.Em	1.32		1.56			
	LSD	3.74		4.53			

*, ** Significant at 5% and 1% level respectively

( ) Mean of 10 parents

compared to the better parent values. Three crosses viz., MS-3A x ICP-7035, MS-4A x ICP-7035, and MS-Prabhat x ICP-7035 displayed significant positive mid parent heterosis.

j) Days to 50% flower

The mean days to flower for the female parents ranged from 62.0 (MS-Prabhat) to 121.5 days (MS-3A). Among the male parents it ranged from 103.0 (BDN-1) to 160 days (ICP-9180) (Table 12).

The hybrid means ranged from 86.5 (MS-Prabhat x BDN-1) to 128.5 days (MS-3A x ICP-9180). The hybrid values were lower than or close to their mid parental values in most cases. No hybrid flowered earlier than the earliest or later than the latest parent.

The overall hybrid mean (113.0 days) was 4.0% less than the parental mean (118.0 days). Heterosis ranged from -10.0 (MS-4A x ICP-9180) to 9.4% (MS-Prabhat x ICP-9150) compared to the mid parent values and from -25.4 (MS-Prabhat x ICP-9180) to 1.8% (MS-3A x Royes) compared to the better parent. Thirteen out of 21 crosses showed significant negative heterosis compared to the better parent. MS-Prabhat x ICP-9180, MS-Prabhat x ICP-9150, MS-Prabhat x Royes and MS-4A x ICP-9180 were the earliest.

Table 12: Mean of days to flower for F_1 hybrids and their parents and the extent of hybrid vigour

S.No.	Crosses	Mean of F_1s	Parents		Mean of parents	F_1 as % of	
			P_1	P_2		Mid parent	Better parent
1	MS-3A x BDN-1	107.2	121.5	103.0	112.2	-4.4**	-11.7**
2	MS-3A x C-11	117.7	121.5	117.5	119.5	-1.5	-3.1
3	MS-3A x ICP-7035	123.0	121.5	126.5	124.0	-0.8	-2.7
4	MS-3A x ICP-9150	127.5	121.5	157.0	139.2	-8.4**	-18.7**
5	MS-3A x ICP-9180	128.5	121.5	160.0	140.7	-8.7**	-19.7**
6	MS-3A x Royes	123.7	121.5	116.2	118.8	4.1**	1.8
7	MS-3A x C-322	117.7	121.5	104.2	112.8	4.3**	-3.1
8	MS-4A x BDN-1	109.7	121.5	103.0	110.3	-0.3	-6.4**
9	MS-4A x C-11	118.0	121.5	117.5	117.4	0.5	0.4
10	MS-4A x ICP-7035	122.7	117.2	126.5	121.8	0.7	-2.9
11	MS-4A x ICP-9150	128.2	117.2	157.0	137.1	-6.4**	-18.3**
12	MS-4A x ICP-9180	124.7	117.2	160.0	138.6	-10.0**	-22.0**
13	MS-4A x Royes	119.0	117.2	116.2	116.7	1.9	1.5
14	MS-4A x C-322	118.0	117.2	104.2	110.7	6.5**	0.6
15	MS-Prabhat x BDN-1	86.5	62.0	103.0	82.5	4.8**	-16.0**
16	MS-Prabhat x C-11	98.0	62.0	117.5	89.7	9.2**	-16.6**
17	MS-Prabhat x ICP-7035	102.0	62.0	126.5	94.2	8.2**	-19.3**
18	MS-Prabhat x ICP-9150	119.7	62.0	157.0	109.5	9.4**	-23.7**
19	MS-Prabhat x ICP-9180	119.2	62.0	160.0	111.0	7.4**	-25.4**
20	MS-Prabhat x Royes	88.7	62.0	116.2	89.1	-0.4	-23.6**
21	MS-Prabhat x C-322	87.5	62.0	104.2	83.1	5.3**	-16.1**
	Mean	113		(118)		-4.2	
	S.Em	0.84		1.29			
	LSD	2.37		3.74			

*, ** Significant at 5% and 1% level respectively
( ) Mean of 10 parents

k) Days to maturity

The mean days to maturity for the female parents ranged from 101.5 (MS-Prabhat) to 169.0 days (MS-3A). The male parent means ranged from 156..0 (BDN-1) to 231.5 (days) (ICP-9150) (Table 13).

The hybrid means ranged from 125.7 (MS-Prabhat x BDN-1) to 179.2 days (MS-3A x ICP-9150). As in days to flower, the hybrid values were generally lower than or close to the mid parent values. No crosses matured earlier than the earliest parent or later than the latest parent.

The overall mean of hybrids was 159.0 days which showed a decrease of 6.0% over the overall parental mean of 169.0 days. Heterosis ranged from -12.8 (MS-3A x ICP-9180) to 4.3 (MS-Prabhat x ICP-7035) compared to the mid parent values and from -27.8.(MS-Prabhat x ICP-9150) to 3.9% (MS-4A x Royes) compared to the better parent. Fifteen out of 21 crosses had significant negative heterosis compared to the better parent. Among these seventeen crosses, MS-Prabhat x ICP-9150, MS-Prabhat x ICP-9180, MS-3A x ICP9180 and MS-4A x ICP-9150 had the highest negative better parent heterosis.

Table 13. Mean of days to maturity for F1 hybrids and their parents and the extent of hybrid vigour

S.No.	Crosses	Mean of F_1s	Parents P_1	Parents P_2	Mean of parents	F_1 as % of Mid parent	F_1 as % of Better parent
1	MS-3A x BDN-1	157.0	169.0	156.0	162.5	-3.3**	-7.1**
2	MS-3A x C-11	165.7	169.0	165.5	167.2	-0.9	-1.9**
3	MS-3A x ICP-7035	169.7	169.0	168.2	168.6	0.6	0.4
4	MS-3A x ICP-9150	179.2	169.0	231.5	200.2	-10.4**	-12.5**
5	MS-3A x ICP-9180	172.0	169.0	225.7	197.4	-12.8**	-23.8**
6	MS-3A x Royes	170.7	169.0	162.2	165.6	3.0**	1.0
7	MS-3A x C-322	164.0	169.0	157.0	163.0	0.6	-2.9**
8	MS-4A x BDN-1	156.2	162.7	156.0	159.4	-1.9*	-3.9**
9	MS-4A x C-11	167.0	162.7	165.5	164.1	1.7*	0.9
10	MS-4A x ICP-7035	167.0	162.7	168.2	165.5	0.9	-0.7
11	MS-4A x ICP-9150	177.0	162.7	231.5	197.1	-10.2**	-23.5**
12	MS-4A x ICP-9180	176.0	162.7	225.7	194.2	-9.4**	-22.0**
13	MS-4A x Royes	169.2	162.7	162.2	162.5	4.1**	3.9**
14	MS-4A x C-322	165.5	162.7	157.0	159.9	3.5**	1.6*
15	MS-Prabhat x BDN-1	125.7	101.5	156.0	128.7	-2.3*	-19.3**
16	MS-Prabhat x C-11	138.2	101.5	165.0	133.5	3.5**	-16.4**
17	MS-Prabhat x ICP-7035	140.7	101.5	168.2	134.9	4.3**	-16.3**
18	MS-Prabhat x ICP-9150	167.0	101.5	231.5	166.5	0.3	-27.8**
19	MS-Prabhat x ICP-9180	164.2	101.5	225.7	163.6	0.3	-27.2**
20	MS-Prabhat x Royes	130.2	101.5	162.2	131.9	-1.2	-19.7**
21	MS-Prabhat x C-322	131.5	101.5	157.0	129.2	1.7	-16.2**
	Mean	159		(169)		-6.0	
	S.Em	1.86		2.16			
	LSD	5.25		6.28			

*, ** Significant at 5% and 1% level respectively
( ) Mean of 10 parents

l) Shelling percentage

The average shelling % of the pods for the female parents ranged from 71.4 (MS-4A) to 76.7% (MS-Prabhat) and from 56.1 (ICP-9180) to 77.1% (C-11) for the male parents (Table 14).

The hybrid means ranged from 69.4 (MS-Prabhat x ICP-9180) to 76.8% (MS-3A x C-11). Generally, the hybrid means were higher than the mid parent values and lower than the better parent values.

The overall hybrid mean (72.0%) was higher than the parental mean 69.0% by 4. %. Heterosis ranged from -3.3 (MS-Prabhat x C-11) to 9.6% (MS-4A x ICP-9180) compared to the mid parent values and from -9.6 (MS-Prabhat x ICP-9180) to 2.9 (MS-3A x BDN-1) compared to the better parental values. No cross had significant positive better parent heterosis. Among the five crosses with significant positive mid parent heterosis, MS-4A x ICP-9180, MS-4A x ICP-9150 and MS-3A x ICP-9180 had the highest heterosis values.

m) Pod length

The mean pod length for the female parents ranged from 4.3 (MS-Prabhat) to 4.5 cm (MS-4A). Among the male parents it ranged from 4.6 (BDN-1) to 7.7 cm (ICP-9150) (Table 15).

The hybrid means ranged from 4.4 (MS-3A x BDN-1 and MS-4A x BDN-1) to 6.2 cm (MS-Prabhat x C-322). Generally, most

Table 14. Mean shelling percentage for F1 hybrids and their parents and the extent of hybrid vigour

S.No.	Crosses	Mean of F_1s	Parents		Mean of parents	F_1 as % of	
			P_1	P_2		Mid parent	Better parent
1	MS-3A x BDN-1	74.3	72.2	72.0	72.1	3.0*	2.9
2	MS-3A x C-11	76.8	72.2	77.1	74.7	2.8	-0.4
3	MS-3A x ICP-7035	73.8	72.2	71.8	72.0	2.5	2.2
4	MS-3A x ICP-9150	71.1	72.2	60.4	66.3	7.2**	-1.5
5	MS-3A x ICP-9180	69.5	72.2	56.1	64.1	8.4**	-3.7*
6	MS-3A x Royes	69.7	72.2	67.2	69.7	-0.1	-3.5*
7	MS-3A x C-322	72.4	72.2	65.5	68.9	4.9**	0.1
8	MS-4A x BDN-1	73.8	71.4	72.0	71.7	2.9	2.6
9	MS-4A x C-11	74.2	71.4	77.1	74.3	-0.1	-3.9*
10	MS-4A x ICP-7035	72.7	71.4	71.8	71.6	1.5	1.3
11	MS-4A x ICP-9150	71.9	77.4	60.4	65.9	9.1**	0.7
12	MS-4A x ICP-9180	69.9	71.4	56.1	63.7	9.6**	-2.1
13	MS-4A x Royes	69.6	71.4	67.2	69.3	0.4	-2.4
14	MS-4A x C-322	71.5	71.4	65.5	68.5	4.5*	0.2
15	MS-Prabhat x BDN-1	75.7	76.7	72.0	74.4	1.8	-1.4
16	MS-Prabhat x C-11	74.4	76.7	77.1	76.9	-3.3*	-3.5*
17	MS-Prabhat x ICP-7035	73.4	76.7	71.8	74.3	-1.2	-4.4**
18	MS-Prabhat x ICP-9150	71.4	76.7	60.4	68.6	4.2*	-6.9**
19	MS-Prabhat x ICP-9180	69.4	76.7	56.1	66.4	4.5*	-9.6**
20	MS-Prabhat x Royes	70.4	76.7	67.2	72.0	-2.1	-8.2**
21	MS-Prabhat x C-322	70.0	76.7	65.5	71.1	-1.6	-8.8**
	Mean	72.2		(69.0)		4.6	
	S.Em	0.87		1.17			
	LSD	2.47		3.40			

*, ** Significant at 5% and 1% level respectively

( ) Mean of 10 parents

Table 15. Mean of pod length for F_1 hybrids and their parents and the extent of hybrid vigour

S.No.	Crosses	Mean of F_1s	Parents		Mean of parents	F_1 as % of	
			P_1	P_2		Mid parent	Better parent
1	MS-3A x BDN-1	4.4	4.4	4.6	4.5	-2.2	-4.3*
2	MS-3A x C-11	4.8	4.4	4.7	4.5	6.6**	2.1
3	MS-3A x ICP-7035	5.3	4.4	6.5	5.4	-1.8	-18.4**
4	MS-3A x ICP-9150	5.8	4.4	7.7	6.1	-4.9**	-24.6**
5	MS-3A x ICP-9180	5.3	4.4	6.7	5.5	-3.6*	-22.3**
6	MS-3A x Royes	5.3	4.4	6.3	5.3	0	-0.2
7	MS-3A x C-322	5.7	4.4	7.2	5.8	-1.7	-20.8**
8	MS-4A x BDN-1	4.4	4.5	4.6	4.6	-4.3*	-4.3
9	MS-4A x C-11	4.7	4.5	4.6	4.6	2.1	2.1
10	MS-4A x ICP-7035	5.2	4.5	6.5	5.5	-5.5**	-20.0**
11	MS-4A x ICP-9150	5.8	4.5	7.7	6.1	-4.9**	-24.8**
12	MS-4A x ICP-9180	5.4	4.5	6.6	5.6	-3.6*	-18.2**
13	MS-4A x Royes	5.3	4.5	6.3	5.4	-1.9	-15.9**
14	MS-4A x C-322	4.7	4.5	7.1	5.8	-18.9**	-33.8**
15	MS-Prabhat x BDN-1	4.5	4.3	4.6	4.5	0	-2.2
16	MS-Prabhat x C-11	4.8	4.3	4.7	4.5	6.7**	2.1
17	MS-Prabhat x ICP-7035	5.8	4.3	6.5	5.4	9.2**	-9.2**
18	MS-Prabhat x ICP-9150	5.8	4.3	7.7	6.0	-3.3*	-24.7**
19	MS-Prabhat x ICP-9180	5.5	4.3	6.6	5.5	0	-15.2**
20	MS-Prabhat x Royes	5.6	4.3	6.3	5.3	5.6**	-0.11**
21	MS-Prabhat x C-322	6.2	4.3	7.1	5.7	8.7**	-12.6**
	Mean	5.3		(5.7)		-7.0	
	S.Em	0.07		0.08			
	LSD	0.20		0.24			

*, ** Significant at 5% and 1% level respectively
( ) Mean of 10 parents

crosses had pod length close to their mid parent values and less than the better parents.

The overall hybrid mean was 5.3 cm which showed a decrease of 7.0% compared to the parental mean (5.7 cm). Heterosis ranged from -18.9 (MS-4A x C-322) to 9.2% (MS-Prabhat x ICP-7035) compared to the mid parent values and from -33.8 (MS-3A x C-322) to 2.1% (MS-3A x C-11, MS-4A x C-11 and MS-Prabhat x C-11) compared to the better parent. No cross had significant positive better parent heterosis. MS-3A x C-11, MS-Prabhat x C-11, MS-Prabhat x ICP-7035, MS-Prabhat x Royes and MS-Prabhat x C-322 had significant positive heterosis over the mid parents.

n) Plot yield

The mean plot yield for the female parents ranged from 834 (MS-Prabhat) to 2231 g (MS-4A). Among the male parents, the range was from 936 (ICP-9180) to 2179 g (C-11) (Table 16).

The hybrid means ranged from 654 (MS-3A x ICP-9180) to 3050 g (MS-4A x C-11). Generally, most crosses had higher grain yield than their mid and better parent values.

Table 16. Mean plot yield for F1 hybrids and their parents and the extent of hybrid vigour

S.No.	Crosses	Mean of F_1s	Parents		Mean of parents	F_1 as % of	
			P_1	P_2		Mid parent	Better parent
1	MS-3A x BDN-1	2748	1479	2093	1786	53.9**	31.3*
2	MS-3A x C-11	2637	1479	2179	1829	44.2**	21.0
3	MS-3A x ICP-7035	2806	1479	937	1208	131.7**	89.7**
4	MS-3A x ICP-9150	1946	1479	952	1215	60.2**	31.6
5	MS-3A x ICP-9180	654	1479	936	1207	-45.8**	-55.8**
6	MS-3A x Royes	1980	1479.	1775	1627	21.7	11.5
7	MS-3A x C-322	2742	1479	1249	1364	101.0**	85.4**
8	MS-4A x BDN-1	2367	2231	2093	2162	9.5	5.7
9	MS-4A x C-11	3050	2231	2179	2205	38.3**	36.7**
10	MS-4A x ICP-7035	2324	2231	937	1584	47.7**	4.2
11	MS-4A x ICP-9150	2214	2231	952	1592	39.1*	-0.1
12	MS-4A x ICP-9180	1087	2231	936	1584	-31.4*	-51.3**
13	MS-4A x Royes	2625	2231	1775	2003	31.1*	17.7
14	MS-4A x C-322	2414	2231	1249	1740	38.7**	8.2
15	MS-Prabhat x BDN-1	2304	834	2093	1464	57.4**	10.1
16	MS-Prabhat x C-11	2346	834	2179	1506	55.7**	7.7
17	MS-Prabhat x ICP-7035	1902	834	937	886	114.7**	99.8**
18	MS-Prabhat x ICP-9150	1801	834	952	893	101.8**	89.2**
19	MS-Prabhat x ICP-9180	1206	834	936	885	36.3	28.8
20	MS-Prabhat x Royes	1119	834	1775	1305	-36.9	-14.3*
21	MS-Prabhat x C-322	972	834	1249	1042	-6.7	-22.2
	Mean	2059		(1466)		39.2	

*, ** Significant at 5 and 1% levels respectively ( ) Mean of the ten parents

The overall mean of hybrids was 2059 which showed an increase of 39.2% over the parental mean. Heterosis ranged from -45.8 (MS-3A x ICP-9180) to 131.7% (MS-3A x ICP-7035) compared to the mid parent value and from -55.8 (MS-3A x ICP-9180) to 99.8% (MS-Prabhat x ICP-7035) compared to the better parent values. Seven crosses had significant positive better parent heterosis. Among the seven crosses, MS-Prabhat x ICP-7035, MS-3A x ICP-7035, MS-Prabhat x ICP-9180 had the highest heterosis.

4.3 Hybrid analysis

4.3.1 Array means

The means of hybrids averaged over the common females and over the common males are given in Table 17. In the same table, the means of the common female parent and male parent are also presented for comparison. The results are discussed below characterwise:

a) Plant height

The mean values of the females when averaged over the seven males ranged from 177 cm (MS-Prabhat) to 211 cm (MS-4A). Slight differences existed between the averaged means of hybrids derived from MS-3A and MS-4A and also from their female parent values. Substantial difference was realized when MS-Prabhat was the common female parent.

The range for common male parent across females was from 169 cm (C-322) to 227 cm (ICP-9150). When Royes, C-322, ICP-9150 and C-11 were common males, the array means across the three females were greater than the common parental means. The height of BDN-1 was greater than the array mean for this parent.

Table 17 : Array means of F_1 hybrids and their parents for the 12 characters.

Female parents	Male parents BDN-1	C-11	ICP-7035	ICP-9150	ICP-9180	Royes	C-322	Mean of females over males	Mean of common female parent
Plant height (cm)									
MS-3A	183	215	205	234	225	210	192	209	213
MS-4A	200	217	207	232	223	202	198	211	216
MS-Prabhat	174	205	184	216	219	127	118	177	92
Mean of male over females	186	212	199	227	222	180	169	199[a]	
Mean of common male parent	213	203	204	219	222	168	126		184[b]
Number of primary branches									
MS-3A	6.8	11.0	11.7	12.1	8.3	9.7	9.5	9.9	9.9
MS-4A	10.7	13.5	11.0	12.0	10.6	10.2	9.9	11.1	13.3
MS-Prabhat	8.3	9.9	7.9	8.4	12.1	9.0	11.6	9.6	13.7
Mean of male over females	8.6	11.4	10.2	10.8	10.3	9.6	10.3	10.2[a]	
Mean of common male parent	10.0	9.3	7.9	8.8	9.7	6.5	7.4		9.7[b]
Number of secondary branches									
MS-3A	11.8	23.7	13.8	17.9	19.1	17.6	9.8	16.2	19.7
MS-4A	20.4	36.1	18.5	20.2	19.8	10.4	15.5	20.1	34.8
MS-Prabhat	16.5	14.6	11.7	5.8	28.0	23.1	22.0	17.4	15.0
Mean of male over females	16.2	24.8	14.7	14.6	22.3	17.0	15.7	17.9[a]	
Mean of common male parent	20.3	20.9	13.8	10.3	14.6	16.0	13.9		17.9[b]
Number of pods per plant									
MS-3A	154	232	140	156	176	189	122	167	211
MS-4A	171	271	181	136	161	146	157	175	246
MS-Prabhat	189	219	157	88	159	163	138	159	210
Mean of male over females	171	240	159	127	165	166	139	167[a]	
Mean of common male parent	205	198	76	103	115	88	205		153[b]

a = Mean of all hybrids, b = Mean of all parents

Table 17 (contd.)

Female parents	Male parents							Mean of females over males	Mean of common female parent
	BDN-1	C-11	ICP-7035	ICP-9150	ICP-9180	Royes	C-322		
Number of seeds per pod									
MS-3A	4.0	4.0	4.5	4.7	4.6	4.5	4.8	4.4	4.0
MS-4A	3.8	3.7	4.5	4.6	4.5	4.4	4.6	4.3	3.8
MS-Prabhat	3.8	4.1	4.9	4.7	4.9	4.6	4.9	4.6	3.9
Mean of male over females	3.9	3.9	4.6	4.7	4.7	4.5	4.8	4.4[a]	
Mean of common male parent	3.6	3.8	4.8	5.7	5.4	4.4	5.3		4.5[b]
Single plant yield (g)									
MS-3A	36.4	70.0	55.1	51.7	48.9	48.1	41.0	50.1	48.8
MS-4A	42.6	67.9	64.9	44.5	43.1	41.6	46.0	49.9	54.5
MS-Prabhat	39.4	56.2	58.6	33.3	52.1	42.8	43.0	46.5	31.5
Mean of male over females	39.4	64.4	59.5	43.2	47.9	44.2	43.3	48.8[a]	
Mean of common male parent	46.1	54.4	31.5	22.8	30.7	44.2	37.5		40.3[b]
100-seed weight (g)									
MS-3A	9.3	9.8	11.5	11.3	9.4	9.6	9.9	10.1	7.9
MS-4A	8.8	9.2	14.0	11.3	9.5	9.4	9.3	10.2	7.5
MS-Prabhat	7.9	8.6	11.0	11.9	9.7	9.1	8.9	9.6	5.7
Mean of male over females	8.7	9.2	12.2	11.5	9.5	9.4	9.4	10.0[a]	5.9
Mean of common male parent	10.7	10.7	20.1	14.4	11.4	11.2	13.2		10.3
Shelling %									
MS-3A	74.3	76.8	73.8	71.1	69.5	69.7	72.4	72.5	72.2
MS-4A	73.8	74.2	72.7	71.9	69.9	69.6	71.5	71.9	71.4
MS-Prabhat	75.7	74.4	73.4	69.4	70.4	70.0	72.1	72.2	76.7
Mean of male over females	74.6	75.1	73.3	71.5	69.6	69.9	71.3	72.2[a]	
Mean of common male parent	72.0	77.1	71.8	60.4	56.1	67.2	65.5		69.1

Table 17 (contd.)

Female parents	BDN-1	C-11	ICP-7035	ICP-9150	ICP-9180	Royes	C-322	Mean of female over males	Mean of common female parent
	Male parents								
Total weight per plant (g)									
MS-3A	164	324	263	312	276	267	192	257	260
MS-4A	207	295	307	288	260	277	233	260	252
MS-Prabhat	170	208	205	202	242	174	147	192	107
Mean of male over females	180	276	258	267	259	223	191	236[a]	
Mean of common male parent	193	251	260	218	227	240	150		216[b]
Harvest index									
MS-3A	21.8	20.8	20.7	16.2	17.3	18.5	21.0	19.5	18.2
MS-4A	20.1	23.3	21.0	15.3	16.2	18.1	20.5	19.2	22.1
MS-Prabhat	23.1	26.8	31.0	16.1	20.9	24.7	20.0	24.5	28.8
Mean of male over females	21.7	23.6	24.3	15.9	18.1	20.4	23.5	21.1[a]	
Mean of common male parent	23.7	21.9	12.1	10.6	13.1	18.7	23.3		19.3[b]
Days to 50% flower									
MS-3A	107.2	117.2	123.0	127.5	128.5	123.7	117.7	120.7	121.5
MS-4A	109.7	118.0	122.7	128.2	124.7	119.0	118.0	120.0	117.2
MS-Prabhat	86.5	98.0	102.0	119.7	119.2	88.7	87.5	100.2	62.0
Mean of male over females	101.1	112.2	115.9	125.1	124.7	110.5	107.5	113.7[a]	
Mean of common male parents	103.0	117.5	126.5	157.0	160.0	116.2	104.2		118.0[b]
Days to maturity									
MS-3A	157.0	165.7	169.7	179.2	172.0	170.7	164.0	168.3	169.6
MS-4A	156.2	167.0	167.0	177.0	176.0	169.2	165.5	168.0	162.7
MS-Prabhat	125.7	138.2	140.7	167.0	164.2	130.2	131.5	142.5	101.5
Mean of male over females	146.3	157.0	159.1	174.4	170.7	156.7	153.6	159.0[a]	
Mean of common male parent	156.0	165.5	168.2	231.5	225.7	162.2	157.0		169.0[b]

Table 17 (contd.)

Female parents	Male parents: BDN-1	C-11	ICP-7035	ICP-9150	ICP-9180	Royes	C-322	Mean of females over males	Mean of female parents
Pod length (cm)									
MS-3A	4.4	4.7	5.3	5.8	5.3	5.2	5.7	5.2	4.4
MS-4A	4.4	4.6	5.2	5.8	5.4	5.3	5.7	5.2	4.5
MS-Prabhat	4.5	4.8	5.9	5.8	5.5	6.2	5.5	4.3	4.3
Mean of male over females	4.4	4.7	5.4	5.8	5.4	5.4	5.9	5.3[a]	
Mean of common male parent	4.6	4.7	6.4	7.7	6.6	6.2	7.1		5.6[b]
Plot yield									
MS-3A	2748	2637	2806	1946	654	1980	2742	2216	1479
MS-4A	2367	3050	2324	2214	1087	2625	2414	2297	2231
MS-Prabhat	2304	2346	1902	1801	1206	1119	972	1664	834
Mean of males over females	2473	2678	2344	1987	982	1908	2043	2059	
Mean of common male parent	2093	2179	937	952	936	1775	1249		1466

b) Primary branches

The array means for females ranged from 9.6 (MS-Prabhat) to 11.1 (MS-3A) and for males from 8.6 (BDN-1) to 11.4 (C-11). Small differences were found among the mean values of females when averaged across the males though MS-4A was greater. Males averaged across females also did not differ much except BDN-1 which differed significantly from both C-11 and ICP-9150.

The array means for the females were lower than the means of their common parents, while the males were higher than the means of the common parent except when BDN-1 was the common parent.

c) Secondary branches

The array means for females ranged from 16.2 (MS-3A) to 20.1 (MS-4A) but these differences were not significant. They were lower than the common female parent means except for MS-Prabhat.

Among the array means over the females, Royes, BDN-1, ICP-7035, C-322 and ICP-9150, which did not differ significantly with one another, differed significantly from both C-11 and ICP-9180. The means, ranging from 14.6 (ICP-9150) to 24.8 (C-11), were generally much higher than their common male parents except for BDN-1.

d) Pods per plant

The array means for females ranging from 159 (MS-Prabhat) to 175 (MS-4A) did not differ significantly. All were substantially lower than the common female parents.

In the case of males, the range was from 127 (ICP-9150) to 240 (C-11). Significant differences were observed between C-11 and each of the remaining male parents. The means across females were higher than the common male parent means except for the cases when BDN-1 and C-322 were common.

e) Seeds per pod

Array means for females ranged from 4.3 (MS-4A) to 4.6 (MS-Prabhat). The array mean of MS-4A differed significantly from both MS-3A and MS-Prabhat. These means were generally higher than the common female parent means.

The array means for males ranged from 3.9 (BDN-1) to 4.8 (C-322). Royes, C-11 and BDN-1 array means showed significant differences among themselves and with other males. When BDN-1, Royes and C-11 were the common males, the array means were higher while in the remaining cases array mean was lower than the mean of the common parent.

f) Single plant yield

The array means for female parents ranged from 46.5 (MS-Prabhat) to 50.1 g (MS-3A). They did not differ significantly. Except for MS-4A, they were higher than the common female parent means.

When averaged across the females, the range for males was from 39.4 g (BDN-1) to 64.4 (C-11). C-11 array mean showed significant differences from C-322, ICP-9150 and BDN-1 array means. The means were higher than the common male parent means except for BDN-1 where it was lower and Royes where the two means were equal.

g) 100-seed weight

The array means for the females ranging from 9.6 (MS-Prabhat) to 10.2 (MS-4A) showed no significant differences. However, they were higher than the means of the common female parents.

Range for the males was from 8.7 g (BDN-1) to 12.2 g (ICP-7035). The array means for ICP-7035 and ICP-9150 were significantly different with those of ICP-9180, C-322, Royes, C-11 and BDN-1. The means were lower than the common male parent means.

h) Shelling percentage

Array means for females ranged from 71.9 (MS-4A) to 72.2 (MS-Prabhat) with no significant differences. The array mean for

MS-Prabhat across the males was lower than that of the common female parent while slight differences existed between the array means of MS-3A and MS-4A hybrids with their common parents.

Array means for males ranged from 69.6 (ICP-9180) to 75.1 (C-11). The array mean for C-11, ICP-7035 and BDN-1 differed significantly from the array means of ICP-9150, C-322, Royes and ICP-9180. They were generally higher than the common male parent means except for C-11.

i) Total weight per plant

The array means for females ranged from 192 g (MS-Prabhat) to 260 g/plant (MS-4A), but these differences were not significant. These weights were higher than the common female parent except for MS-3A which showed a slightly lower value.

In the case of males, the means ranged from 180 g (BDN-1) to 276 g (C-11). C-11 and BDN-1 were the only two male arrays significantly different from each other. When C-11, ICP-9150, ICP-9180 and C-322 were the common males, the array means were higher than the common male parent means, while Royes, BDN-1 and ICP-7035 array means were lower.

j) Harvest index

The array means of females ranged from 19.2 (MS-4A) to 24.5 (MS-Prabhat) with significant differences between means of MS-Prabhat and either MS-3A or MS-4A.

The array means for males ranged from 15.9 (ICP-9150) to 24.3 (ICP-7035). The array means for ICP-7035, C-11 and C-322 differed significantly from the array means of Royes, ICP-9180, and ICP-9150. Generally, the means were higher than those of common male parents except for BDN-1.

k) Days to 50% flower

The array means for females ranged from 100.2 (MS-Prabhat) to 120.7 days (MS-3A). The means of hybrids derived from MS-3A and MS-4A did not show much difference between themselves and with their common female parents. MS-Prabhat hybrids averaged over males differed significantly with both MS-3A and MS-4A and was much higher than the common parent mean.

The array means for males ranged from 101.1days (BDN-1) to 125.1 days (ICP-9150). Array for ICP-9150 and ICP-9180 differed significantly from those for ICP-7035, C-11, Royes, C-322 and BDN-1. All the means were lower than the common parent means except for C-322.

l) Days to maturity

The array means for females ranged from 142.5 days (MS-Prabhat) to 168.3 days (MS-3A). The means involving MS-3A and MS-4A showed no significant differences while they differed significantly with that of MS-Prabhat. The array mean for MS-Prabhat was much higher than the mean of the common parent.

The array means for males ranged from 146.3 days (BDN-1) to 174.4 days (ICP-9150). Array means for ICP-9150 and ICP-9180 differed significantly from array means of ICP-7035, C-11, Royes, C-322 and BDN-1. These means were consistently lower than their common parent means.

m) Pod length

The array means for the females ranged from 5.2 cm (MS-4A) to 5.5 cm (MS-Prabhat). They were higher than the common female parent means.

Male array means ranging from 4.4 cm (BDN-1) to 5.9 cm (C-322) were lower than the common male parent mean value. The array means for BDN-1 and C-11 differed significantly from those of ICP-9150 and C-322.

n) Plot yield (g)

The array means for females ranged from 1664 g (MS-Prabhat) to 2297 g (MS-4A). The means of the hybrids derived from MS-3A and MS-4A did not show much difference between themselves while they differed significantly with the mean of MS-Prabhat hybrids.

The array means for males ranged from 982 g (ICP-9180) to 2678 g (C-11). Array for C-11, BDN-1 and ICP-7035 differed significantly with those of ICP-9150, ICP-9180, Royes and C-322. All the array means were higher than their common male parent mean.

The lines that ranked best in hybrid combination with each of the three females for the eleven characters are given in Table 18.

Table 18. The male lines that ranked best in hybrid combination with each of the three females for the characters studied.

Character	Females		
	MS-3A	MS-4A	MS-Prabhat
Plant height*	BDN-1(183)	C-322(198)	C-322(118)
Primary branches	ICP-9150(12.1)	C-11(13.5)	ICP-9180(12.1)
Secondary branches	C-11(23.7)	C-11(36.1)	ICP-9180(28.0)
Pods per plant	C-11(232)	C-11(271)	C-11(219)
Seeds per pod	C-322(4.8)	C-322 } ICP-9150 } (4.6)	C-322 } ICP-7035 } (4.9)
100-seed weight	ICP-7035(11.5)	ICP-7035(14.0)	ICP-9150(11.9)
Shelling %	C-11(76.8)	C-11(72.2)	BDN-1(75.7)
Total plant weight	C-11(324)	C-11(295)	ICP-9180(242)
Harvest index	BDN-1(21.8)	C-11(23.3)	ICP-7035(31.0)
Days to 50% flower*	BDN-1(107)	BDN-1(109)	BDN-1(86)
Days to maturity*	BDN-1(157)	BDN-1(156)	BDN-1(125)
Pod length	ICP-9150(5.8)	ICP-9150(5.8)	Royes(6.2)
Single plant yield	C-11	C-11	ICP-7035
Plot yield	ICP-7035	C-11	C-11

( ) The mean of hybrid between the male line and the corresponding female.

Lowest values were considered to be the best.

MS-3A and MS-4A ranked the same lines best for most of the characters. Many of the lines that were ranked best by using MS-Prabhat female parent were different from those using MS-3A and MS-4A. From Table 17 and 18, it can also be seen that the best female and male general combiner for each character resulted into crosses with highest mean values.

4.3.2 Mean sum of squares

The analysis of variance for combining ability was carried out for the hybrids. The results are presented in Table 19 for all the characters studied. The analysis revealed that the mean sum of squares for males was highly significant for all the characters studied. Females and males x female interaction were not singificant for pods per plant, single plant yield, 100-seed weight and shelling percentage; while for pod length, the mean sum of squares due to females was not significant.

The percentage contribution of sum of squares arising from males, females and male x female interaction to the hybrids mean square are presented in Table 20. The contribution of males was found to be consistently larger than the females. Males plus

Table 19. Analysis of variance for combining ability in a line x tester experiment for eleven characters

Source	DF	Mean sum of squares										
		Plant height (cm)	Primary branches	Secondary branches	Pods/plant	Seeds/pod	Single plant yield (g)	100 seed weight (g)	Shelling (%)	Harvest index	Days to 50% flowering	Days to maturity
Replications	3	759.98**	0.82	14.30	11655.20**	0.03	1119.77**	2.32	5.47	15.11	6.46	92.52**
Hybrids	20	3607.41**	11.29**	181.23**	6137.25**	0.58**	402.07**	7.81**	19.42**	71.10**	733.47**	1067.12**
Males	6	5915.69**	9.77**	192.46**	15730.50**	1.67**	1059.17**	20.61**	57.75**	118.47**	909.36**	1140.05**
Females	2	10058.50**	18.99**	122.78**	1775.24	0.56**	116.99	3.39	2.42	251.62**	3803.87**	6205.80**
Males x females	12	1378.08**	10.77**	187.02**	2067.61	0.05**	121.04	2.14	3.09	17.36**	133.79**	174.21**
Error	60	89.33	2.45	11.75	1981.34	0.01	205.88	1.45	3.05	7.01	2.82	13.78

* Significant at 5% level

** Significant at 1% level

Table 19. (Contd...)

Source	DF	Pod length (cm)	Total plant weight (g)
Replications	3	0.09	39060.00**
Hybrids	20	23.88**	11151.00**
Males	6	9.14**	17820.10**
Females	2	0.22	40336.60*
Males x females	12	14.52**	2951.75
Error	60	1.15	4423.08

Table 20. Percentage contribution of males, females and their interaction to the total variance of hybrids.

	Plant height	Primary branches	Secondary branches	Pods per plant	Seeds per pod	Single plant yield	100-seed weight	Shelling %	Harvest index	Days to 50% flower	Days to maturity	Total plant weight	pod length
Males[a]	49.2	25.9	31.9	76.8	86.4	79.0	79.2	89.2	50.1	37.2	32.1	47.9	38.3
Females[a]	27.9	16.8	6.7	2.8	9.65	2.9	4.3	1.3	35.4	51.8	58.2	36.2	0.01
Males x females[b]	22.9	57.2	61.9	20.2	5.2	18.1	16.4	9.6	14.7	10.9	9.8	15.9	60.8

[a] Sum of males and female contribution represents GCA contribution

[b] Males x females represents SCA contribution.

females percentage contribution (i,e, GCA) was greater than males x female contribution for most of the characters except primary branches, secondary branches and pod length where male x female contribution was greater.

4.3.3 Components of genetic variation

Observations made for the components of genetic variation in respect of all the characters under study are presented in Table 21. For most of the characters, the GCA variance component was higher than that due to SCA. In the case of primary branches and secondary branches, the SCA variance component was higher. The SCA and GCA variance components were almost equal for plant height. Secondary branches and pod length recorded negative GCA while negative SCA was observed for single yield and total plant weight.

The ratio $2\sigma^2 GCA : 2\sigma^2 GCA + \sigma^2 SCA$ as suggested by Griffing (1956b) is also presented in Table 22. For primary and secondary branches and pod length, the ratio was zero or close to zero. For plant height and seeds per pod, the ratio was 0.67 and 0.71 respectively. While for the remaining characters the ratio was over 0.85.

Table 21. General and specific combining ability variance components and their ratio.

	Plant height (cm)	Primary branches	Secondary branches	Pods/ plant	Seeds/ pod	Single plant yield(g)	100-seed weight (g)	Shelling %	Harvest index	Days to 50 % flowering	Days to maturity	Total plant weight	Pod length
σGCA	330.45	0.18	-1.72	334.26	0.053	23.35	0.493	1.35	8.38	111.14	174.95	1306.33	-0.02
σSCA	322.19	2.08	43.82	21.57	0.009	-21.21	0.172	0.01	2.59	32.74	40.11	-367.84	0.29
σGCA/σSCA	1.03:1	0.09:1	a	15.49:1	5.89:1	a	2.87:1	135:1	3.24:1	3.39:1	4.36:1	a	a

σGCA = general combining ability variance component

σSCA = Specific combining ability variance component

a = Negative ratios are interpreted as zero.

Table 22. The ratio of twice GCA to the total genetic variance

Variance components	Characters												
	Plant height	Primary branches	Secondary branches	Pods/ plant	Seeds/ pod	Single plant yield	100-seed weight (g)	Shelling %	Harvest index	Days to 50% flower	Days to maturity	Total plant weight	Pod length
2GCA	660.90	0.36	0[a]	668.52	0.11	46.70	0.99	2.70	16.76	222.28	349.90	2613.46	0[a]
2GCA+SCA	983.09	2.44	40.38	690.09	0.15	46.70	1.16	2.71	19.35	255.02	390.01	2613.46	0.29
2GCA / 2GCA+SCA	0.67	0.15	0	0.97	0.71	1	0.85	0.99	0.87	0.87	0.90	1	0

a = negative values are interpreted as zero
2GCA = twice general combining ability
SCA = specific combining ability
2GCA+SCA = total genetic variance

4.3.4 General and Specific Combining Ability effects

The general and specific combining ability (GCA) effects for the parents and specific combining ability (SCA) effects for crosses are presented in Table 23 and 24 respectively for different characters.

It was found that the characters plant height, days to 50% flower, days to maturity and harvest index showed significant GCA effects for all the three females (Table 23). Pods per plant, single plant yield, 100-seed weight, pod length and shelling percentage did not show any significant GCA effects for the three females. The female parent MS-4A showed significant positive GCA effects for primary branches, secondary branches and negative for seeds per pod, while MS-Prabhat showed significant positive GCA effects for seeds per pod, and harvest index and negative for plant height, total plant weight, days to flower and maturity.

Table 23. General comgining ability effects for the characters studied

Parents	Plant height	Primary branches	Secondary branches	Pods per plant	Seeds per pod	Single plant yield	100-seed weight	Shelling (%)	Total plant weight	Harvest Index.	Days to 50% flower	Days to Maturity	Pod Length
MS-3A	9.64**	-0.33	-1.69	- 0.01	0.01	1.25	0.14	0.33	20.60	-1.61*	7.08**	8.63**	-0.06
MS-4A	12.20**	0.94*	2.22**	7.97	-0.14	1.11	0.25	-0.24	23.19	-1.85**	6.36**	8.56**	0.06
MS-Prabhat	-21.84**	-0.61	-0.53	- 7.96	0.14**	-2.36	-0.89	0.09	-43.80*	3.46**	-13.45**	-17.19**	0.01
SE of the difference (females)	2.53	0.42	0.916	11.89	0.03	3.83	0.32	0.467	17.77	0.71	0.45	0.99	0.04
BDN-1	-13.65**	-1.59*	-1.70	4.31	-0.56**	-9.40	-1.30**	2.43**	-55.82*	0.62	-12.54**	-13.39**	-0.49**
C-11	12.92**	1.26	6.87**	73.60**	-0.49**	15.54**	-0.76	2.94**	39.45	2.57	- 2.45**	- 2.73	0.16**
ICP-7035	- 0.60	0.006	-3.23*	- 7.70	0.21**	10.69	2.18**	1.09	22.05	3.18**	2.21**	- 0.56	-0.39**
ICP-9150	28.12**	0.65	-3.30*	-39.93*	0.23**	-5.67	1.53**	-0.69	30.92	-5.19**	11.46**	14.69**	0.17**
ICP-9180	22.89**	0.12	4.40**	- 1.59	0.23**	-0.98	-0.45	-2.58**	22.89	-2.96**	10.46**	11.02**	-0.14*
Royes	-19.57**	-0.57	-0.90	- 0.91	0.04	-4.67	-0.61	-2.27**	-13.87	-0.66	- 3.20**	- 2.98	0.19**
C-322	-30.11**	0.11	-2.15	-27.79	0.35**	-5.52	0.58	-0.92	-45.60	2.44*	- 5.95**	- 6.06**	0.50**
SE of the difference (males)	3.86	0.64	1.39	18.17	0.04	5.86	0.49	0.73	27.15	1.08	0.68	1.52	0.71
SE of mean	1.03	0.17	0.37	4.86	0.012	1.57	0.13	0.19	7.26	0.29	0.18	0.41	0.02

* Significant at 5% level

** Significant at 1% level

Table 24. Specific combining ability effects for the characters studied.

Parents	Plant height	Primary branches	Secondary branches	Pods per plant	Seeds per pod	Single plant yield	100-seed weight	Shelling %	Total plant weight	Harvest index	Days to 50% flower	Days to maturity	Pod length
MS-3A x BDN-1	-12.23*	-1.44	-2.76	-17.62	0.12*	-4.30	0.52	-0.61	-36.71	1.72	-1	2.04	-0.37**
MS-3A x C-11	- 7.22	-0.11	0.60	-8.94	0.06	4.35	0.41	1.35	27.89	-1.26	-0.58	0.12	0.40**
MS-3A x ICP-7035	-3.63	1.82*	0.77	-19.41	-0.13*	-5.65	-0.84	0.19	-15.95	-1.93	0	1.95	0.86**
MS-3A x ICP-9150	-3.05	1.55	4.94**	29.25	-0.24**	7.24	-0.33	-0.68	24.42	1.94	-4.75**	-3.79**	-0.24**
MS-3A x ICP-9180	-7.26	-1.69*	-1.49	10.84	-0.05	-0.68	-0.23	-0.39	-4.07	0.77	-2.75**	-7.38**	0.20**
MS-3A x Royes	20.53**	0.37	2.45	22.83	-0.03	2.65	0.10	-0.58	23.59	-0.30	6.17**	5.37**	-0.67**
MS-3A x C-322	12.85**	-0.49	-4.30*	-16.96	0.05	-3.61	0.36	0.70	-18.98	-0.93	2.92**	1.70	-0.19**
MS-4A x BDN-1	2.26	1.15	1.98	-7.80	-0.08	2.00	-0.13	-0.55	2.94	0.31	2.21**	1.36	-0.13
MS-4A x C-11	-7.23	1.10	9.06**	22.31	-0.08	1.50	-0.23	-0.72	-3.62	1.54	0.38	1.44	-0.17*
MS-4A x ICP-7035	-3.61	-0.15	1.64	14.03	-0.0	4.22	1.64**	-0.37	25.30	-1.39	0.46	-0.73	-0.59**
MS-4A x ICP-9150	-7.50	0.26	3.33	1.56	0.10	0.26	-0.47	0.64	-2.45	1.28	-3.29**	-5.98**	0.31**
MS-4A x ICP-9180	-11.01*	-0.66	-4.69**	-12.54	-0.05	-5.88	-0.31	0.52	-22.59	-0.11	-5.78**	-3.31	0.48**
MS-4A x Royes	10.48*	-0.32	-8.86**	-27.60	0.02	3.67	-0.19	-0.04	-18.53	-0.48	2.13*	3.94*	0.32**
MS-4A x C-322	16.62*	-1.38	-4.46*	10.05	-0.06	1.57	-0.32	0.52	18.95	-1.13	3.88**	3.27	-0.21**
MS-Prabhat x BDN-1	9.97*	0.29	0.78	25.42	-0.19**	2.29	-0.39	1.16	33.96	-2.02	-1.21	-3.39	0.50**
MS-Prabhat x C-11	14.45**	-0.98	-9.66**	-13.37	0.02	-5.85	-0.19	-0.63	-24.27	0.28	0.20	-1.56	-0.23**
MS-Prabhat x ICP-7035	7.24	-1.67	-2.41	5.38	0.13*	1.43	-0.80	0.18	-9.35	3.33*	-0.46	-1.23	0.26**
MS-Prabhat x ICP-1950	10.55*	-1.82*	-8.27**	-30.81	-0.08	-7.50	0.80	0.03	-21.97	-3.22*	8.04**	9.77**	-0.07
MS-Prabhat x ICP-1980	18.27**	2.36**	6.18**	1.71	0.10	6.56	0.54	-0.14	26.66	-0.65	8.54**	10.69**	-0.68**
MS-Prabhat x Royes	-31.01**	-0.05	6.61**	4.77	0.01	1.02	0.09	0.63	-5.06	0.79	-8.29**	-9.31**	0.35**
MS-Prabhat x C-322	-29.47**	1.87*	6.76**	6.89	0.02	2.03	-0.04	-1.22	0.03	2.07	-6.79**	-4.98*	0.40**
SE of the difference	4.83	0.80	1.75	22.77	0.05	7.34	0.61	0.89	34.03	1.35	0.85	1.89	0.07

* Significant at 5% level

** Significant at 1% level.

An examination of the GCA effects for the male parents (Table 23) revealed that BDN-1, Royes and C-322 tended to show negative GCA effects for most of the characters while C-11, ICP-7035, ICP-9150 and ICP-9180 tended to show positive GCA effects for most of the characters studied.

An examination of SCA effects (Table 24) revealed that crosses showing significant SCA effects were derived from high x high, high x medium, medium x medium, high x low, and medium x low GCA effect parents, but not from low x low GCA effect parents.

For the characters pod per plant, single plant yield, 100-seed weight, shelling %, total plant height and harvest index, very few crosses showed significant SCA effects.

4.4 Correlations

Correlation coefficients for the characters studied was computed between the performance *per se* and the GCA effects (Table 25). Significant correlations were observed for the characters plant height (0.86), seeds per pod (0.77), 100-seed weight (0.68), shelling % (0.75), total plant weight (0.76), days to 50% flower (0.87) and days to maturity (0.83). Single plant yield showed no significant correlation with its GCA effects.

Table 25 : Correlations between the mean performance of parental lines and their respective gca effects for each characters.

Character	GCA
Plant height	0.8607**
Primary branches	0.0507
Secondary branches	0.4152
Pods per plant	0.5271
Seeds per pod	0.7752**
Single plant yield	0.2985
100-seed weight	0.6870**
Shelling %	0.7452**
Total plant weight	0.7798**
Harvest index	0.5803
Days to flower	0.8721**
Days to maturity	0.8365**

** significant at 1% level

The simple phenotypic correlation coefficient for the association among the characters studied for the 21 hybrids are shown in Table 26 . Single plant yield was found to be positively correlated with number of primary and secondary branches, number of pods per plant, total plant weight and harvest index. The three yield components, viz. number of primary and secondary branches and number of pods per plant were positively correlated among themselves. Number of seeds per pod was positively associated with 100-seed weight, days to flower and maturity but negatively associated with secondary branches, pods per plant and 100-seed weight. Days to flower and maturity were positively correlated between themselves and with plant height, 100-seed weight, and total plant weight, but negatively correlated with harvest index and shelling %. Plant height was found to be positively correlated with total plant weight and negatively correlated with harvest index.

The 21 crosses were divided in to 2 groups according to days taken to 50% flower, e.g.:

Group	No.of hybrids	Range of days to flower	Mean
I	7	60-114	98.0
II	14	115 - 135	122.0

The correlation coefficients were computed among the different characters studied for each group (Table 27). Differences were observed among the two groups. A close observation

Table 26. Correlation coefficients among different agronomic characters for 21 hybrids

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Plant height		0.12	0.12	0.16	0.03	0.32	0.23	-0.14	0.66**	0.57	0.76**	0.69	-0.11	0.40*
2 Number of primary branches			0.53**	0.50**	-0.23	0.36*	-0.26	0.10	0.29	0.16	-0.07	-0.06	0.09	0.42*
3 Number of secondary branches				0.55**	-0.37*	0.42*	-0.25	0.15	0.31	0.17	-0.07	-0.09	-0.16	0.40*
4 Number of pods per plant					-0.58**	0.77**	-0.44**	0.34*	0.53**	0.39*	-0.26	-0.25	-0.37*	0.81**
5 Number of seeds per pod						-0.23	0.50**	-0.69**	-0.02	-0.31	-0.46**	0.48**	0.92**	-0.69**
6 Single plant yield							-0.07	0.20	0.79**	0.33*	-0.03	-0.05	-0.42*	0.94**
7 100-seed weight								-0.31	0.23	-0.44**	0.47**	0.44**	0.32	0.21
8 Shelling %									-0.08	0.42*	0.42	-0.58	-0.65**	-0.44*
9 Total plant weight										-0.27	0.43*	0.39*	0.41*	0.83**
10 Harvest index											-0.75**	-0.73**	-0.22	0.22
11 Days to 50% flower												0.97**	0.13	0.20
12 Days to maturity													0.12	0.23
13 Pod length														0.64**
14 Plot yield														

* signficant at 5% level ** significant at 1% level

Table 27. Correlation coefficient among different agronomic characters for the seven early flowering hybrids

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1 Plant height	-	0.29	-0.66	0.62	-0.64	0.33	0.05	0.85**	0.77*	-0.30	0.71*	0.57	-0.72*	0.37
2 Number of primary branches			0.71*	-0.01	0.19	0.09	-0.32	-0.49	-0.02	0.13	-0.23	0.19	0.32	0.51
3 Number of secondary branches				-0.22	0.18	-0.34	-0.42	-0.69	-0.33	-0.15	-0.48	-0.36	0.33	0.50
4 Number of pods per plant					-0.57	0.35	-0.46	0.61	0.57	-0.17	-0.01	-0.14	-0.53	0.71*
5 Number of seeds per pod						0.42	0.63	-0.77*	-0.24	0.85**	-0.35	-0.37	0.98**	-0.21
6. Single plant yield							0.54	0.03	0.69	0.72*	0.11	-0.12	0.37	0.95**
7 100-seed weight								-0.21	0.28	0.57	0.40	0.29	0.49	0.28
8 Shelling %									0.44	-0.39	0.39	0.29	-0.82**	0.36
9 Total plant weight										0.01	0.56	0.34	-0.28	0.66
10 Harvest index											-0.34	-0.46	0.83**	0.23
11 Days to flower												0.96**	-0.48	0.64
12 Days to maturity													-0.49	0.22
13 Pod length														-0.20
14 Plot yield														

* significant at 5% lelvel ** significant at 1% level

for the early group Table 27 revealed that plant height was positively correlated with shelling %, total plant weight and days to flower and negatively correlated with pod length. High positive correlation was found between primary branches and secondary branches. Number of seeds per pod was highly and positively correlated with pod length and harvest index, but negatively correlated with shelling %. Single plant yield and harvest index were positively correlated. Total plant weight was negatively correlated with pod length. Harvest index and pod length were highly positively correlated. Days to flower and maturity were also found to be positively correlated.

A number of significant correlation coefficients was observed in the medium maturity group (Table 28). Plant height was found to be positively correlated with total plant weight, days to flower and maturity but negatively correlated with harvest index. Number of primary branches recorded positive correlation with secondary branches, single plant yield and total plant weight. There was significant positive correlation between number of secondary branches and pods per plant, seeds per pod, single plant yield, total plant weight and harvest index. Pods per plant was negatively correlated with seeds per pod, but positively correlated with single plant yield, total plant weight and harvest index. Single plant yield was positively correlated with shelling %, total plant weight and harvest index. Harvest index was

Table 28. Phenotypic correlation coefficient among different characters for the 14 medium flowering hybrids

Characters	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1 Plant height	-	0.31	0.40	0.12	-0.02	0.06	0.09	-0.15	0.55*	-0.58*	0.69**	0.73**	-0.12	0.06
2 Primary branches			0.71**	0.49	-0.42	0.59*	0.07	0.37	0.54*	0.35	-0.05	0.16	-0.33	0.64**
3 Secondary branches				0.83**	-0.55*	0.71**	-0.28	0.24	0.61**	0.55*	-0.16	-0.12	-0.59*	0.76**
4 Pods/plant					-0.84**	0.83**	-0.31	0.43	0.68**	0.55*	-0.16	-0.12	-0.87**	0.87**
5 Seeds/pod						-0.66**	0.24	-0 58	-0.53*	-0.42	0.28	0.08	0.87**	-0.69**
6 Single plant yield							0.12	0.67**	0.79**	0.65**	-0.15	-0.19	0.35	0.96**
7 100 seed weight								0.20	0.22	-0.12	0.26	0.11	0.21	0.83**
8 Shelling %									0.43	0.51	-0.37	-0.29	-0.51*	0.63**
9 Total plant weight										-0.06	0.41	0.41	-0.51*	0.75**
10 Harvest index											-0.69**	-0.76**	-0.62**	0.66**
11 Days to flower												0.86**	0.32	-0.20
12 Days to maturity													0.49	-0.21
13 Pod length														0.79**
14 Plot yield														

* significant at 5% level

** significant at 1% level

negatively correlated with days to flower and maturity. In general, the correlation coefficients for the medium group were similar to that for the 21 hybrids.

5. DISCUSSION

Genetic information of various economic traits are of value to plant breeders because they help in determining the type of breeding procedures to be followed in self as well as cross pollinated crops. As pointed out by Dudley and Moll (1969), these estimates depend on many things including the populations sampled, mating and experimental design and environment.

The array means for females and males determine their respective general combining ability. In cases where the number of lines and testers are not equal, for example, if the lines are greater than the testers , the tester effects would be estimated with greater precision than the line effects (Arunachalam, 1974). Federer and Sprague (1947) stated that the greatest gain in total combining ability is expected when more than one tester is used and specific combining ability effects are, in part at least, averaged out. This ensures a more precise measure of GCA and leaves selection for SCA to the latter and more precise tests of single crosses.

Kempthorne (1956) has shown that ignoring epistacy in the estimation of genotypic components places,severe restrictions on the interpretation of any estimates obtained. The model used in the present study did not take epistasis into account, thus biasing the results presented to an unknown extent. Kempthorne (1956) also pointed out that estimates of the effects of genes from a diallel analysis have relevance only to the particular population from which the sample of inbred lines has been randomly drawn. The assumption of random selection of lines to be used in the set of crosses is most difficult to realize. The lines used in this study were not a random sample drawn from some specified population. Rather, they were selected to sample a wide range of pigeonpea genotypes.

Green et al., (1979a) observed that the maturity period of pigeonpea lines ranges from 120-270 days and that each specific maturity group is adapted to a specific environment. They found that early, medium and late maturing groups are suitable for areas with low, medium and high rainfall respectively. Therefore, studying the three groups at one location would favour the group most adapted to that location.

The medium maturity group (160-180 days) are best adapted to Hyderabad conditions where the present investigation was carried out. Therefore, the high seed yield per plant exhibited by MS-3A, MS-4A, C-11, crosses involving MS-3A and MS-4A with the 7 male parents excluding BDN-1, and crosses involving MS-Prabhat with C-11, ICP-7035, ICP-9150 and ICP-9180 which were medium in maturity was expected.

However, ICP-7035 which was medium in maturity gave low grain yield per plant. This could have resulted from low number of pods caused by high flower and pod drop which was realized for this line. Large seed size could be a factor for the pod drop.

The early maturing group which included MS-Prabhat, BDN-1, MS-Prabhat x BDN-1, MS-Prabhat x Royes and MS-Prabhat x C-322 had more number of pods per plant but less grain yield per plant which was unexpected. This group flowered and set pods when damage from insects were high (Figure 1). Although control measures were taken, the attack of the pest (Heliothis armigera) was more severe on the early than on the medium and late groups.

The late lines such as ICP-9150 and ICP-9180 had very low grain yield and total weight per plant. During the crop season, a total of 527 mm rainfall was recorded which was below the normal 690 mm. Under normal circumstances, the total dry weight per plant is usually high (Green et al., 1979a). However, in the present investigation it was low. The serious water-stress during both vegetative and reproductive phases may account for the low total dry weight and grain yield per plant.

The experiment was laid out with both the parents and the hybrids randomized within each replication. Arunachalam (1974) argues that the use of hybrid data from such a design for an analysis of combining ability would be equivalent to a field design with gaps, corresponding to the area occupied by the parental lines in each replication, and therefore would not conform to the basic requirements of a layout of a design for determining combining ability. However, Griffing (1956b) found it necessary to include parents in the same experimental area as the hybrids so that the hybrids can be compared directly with their parents grown in the same environment. Simmond (1980) recommended the use of data from such a design to determine combining ability. He concluded that results obtained though less reliable than when hybrids are grown without parents, can yield guidance on the choice of parents and crosses for economic exploitation. Therefore, it was found necessary to randomize both parents and hybrids with each replication in the present study.

The analysis of variance for parents and hybrids revealed the existance of highly significant differences for all the characters. This, with a high coefficient of variation (CV%) for number of branches, pods, yield and total weight per plant indicates enough variation on which selection can be effective.

The mean sums of square attributed to the male and female parents of the hybrids provide a measure of their general combining ability, while the interaction between male and female parents provides a measure of specific combining ability (Rojas, 1951).

In the present study, the mean squares for males, females and their interaction were highly significant for plant height, primary branches, secondary branches, seeds per pod, harvest index, days to flower and maturity and pod length. This indicated that additive as well as non-additive gene effects were important in conditioning these characters. For the characters such as pods per plant, single plant yield, 100-seed weight, shelling % and total weight per plant, the mean squares for females and males x female interaction were not significant. Therefore, one would expect that the performance of these characters in hybrids may be adequately predicted on the basis of general combining ability. This means that the best performing hybrid may be produced by crossing the two parents having the highest general combining abilities.

The percentage contribution of sum of squares arising from males, females and male x female interaction to the hybrids sum of squares may assist in knowing the source of variation. The contribution of males was found to be consistently larger than that of the females. This presumably was due to the fact that the number of male lines used in this study was greater than females and that they represented a wider range of genotypes than the female lines. Male plus females percentage contribution (i.e. GCA) was greater than males x female contribution (SCA) for most of the characters except primary branches, secondary branches and pod length. Such results may **also** suggest that a larger proportion of the total genetic variability associated with most of the characters may be as a result of additive gene action. However, the highly significant male x female mean squares for some of the traits indicated that non-additive gene effects should also be considered if maximum improvement of these characters is to be achieved. For primary and secondary branches and pod length, SCA contribution was greater than the GCA contribution suggesting that non-additive gene action is more important.

Estimates of the relative contribution of general and specific combining ability within the genetic variability present in a population are of interest to plant breeders. Breeding methods most appropriate for specific objectives may differ appreciably depending upon the type of gene action assumed. If the action of genes controlling a particular trait is primarily additive, lines to be used in a hybrid breeding program should be first selected on the basis of their general combining ability. Lines that survived a screening for general combining ability then would be evaluated on the basis of their performance in specific hybrid combination. If on the other hand, specific combining ability is determined to be of greatest importance in the population under test, the breeder will need to be concerned with making critical evaluations for specific crosses in the initial stages of selection.

The estimates for variance components for general and specific combining ability indicated the predominance of additive gene action for all characters except primary and secondary branches and pod length. The relative importance of additive and non-additive gene effects were obtained from the ratio $2\sigma^2GCA:2\sigma^2GCA+\sigma^2SCA$ as suggested by Griffing (1956b). The closer this ratio is to unity, the greater is the predictability based on additive gene action. This ratio further confirmed the predominance of additive gene action. It also revealed that plant height and seeds per pod may be determined by both types of gene action.

Negative estimates of variance components were encountered for secondary branches, single plant yield, total weight per plant, and pod length. These arises from random deviation of effects around zero, and may be interpreted as being equivalent to zero (Reddy et al., 1979, and Beil, 1967).

Previous studies by Sharma _et al._, (1973a, 1973b); Singh and Pandey, (1974); Dahiya and Brar (1977), Chaudhari (1980), Reddy _et al._, (1981), Saxena _et al._ (1981), Sindhu and Sandhu (1981) and Venkateswarlu and Singh (1982) indicated the predominance of additive gene action for most of the characters in pigeonpea. In contrast, Reddy _et al._, (1977b, 1979a, 1979b) reported the predominance of non-additive effects for all characters including phenology, plant height, and grain yield and its components. Pandey (1972) reported non-additive gene action for plant height while Dahiya and Brar (1977) and Singh and Sandhu (1981) observed non-additivity for grain yield per plant. This disagreement among different experiments on gene action may have resulted from the different methods employed by various authors for estimating genetic parameters, genotypic differences among the parents and high genotype environment interactions (Saxena _et al._, 1981, Reddy _et al._, 1981.)

For most of the characters, the array mean of MS-3A and MS-4A were found to be very close and significantly different from that array mean of MS-Prabhat. This indicates the similarity between MS-3A and MS-4A which was expected because of their related origin.

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For most of the characters, the array mean of MS-3A and MS-4A were found to be very close and significantly different from that array mean of MS-Prabhat. This indicates the similarity between MS-3A and MS-4A which was expected because of their related origin.

Among the females, MS-Prabhat, an early maturing short cultivar, was the best general combiner for short plant height, earliness and harvest index. It showed undesirable GCA effects for seed yield, number of primary branches, and pods per plant. Although it was a good combiner for short plant height, it may not be used to reduce tallness in F_1 generation. This is indicated by the fact that crosses involving MS-Prabhat with tall parents were tall. By improving grain yield, harvest index is also improved. Though MS-Prabhat was the best combiner for harvest index, its undesirable GCA effects for yield and yield components may argue against its use for improvement of yield in Hyderabad condition. MS-3A and MS-4A which are medium in maturity and adapted to Hyderabad conditions were found to be the best general combiners for yield and yield components, 100-seed weight, total plant weight and pod length. MS-4A was found to have high GCA effects for number of branches. However, both MS-3A and MS-4A had undesirable GCA effects for plant height, days to flower and maturity. But the means of most F_1 hybrids involving MS-3A and MS-4A for days to flower and maturity were lower than the better parent and in some cases the mid parental value. This indicated that both MS-3A and MS-4A can produce high yielding F_1 hybrids within the medium maturity group (110-140 days to flower).

Among the male parents C-11 proved to be the best general combiner for yield and yield components. It also showed desirable GCA effects for most of the characters. In fact, studies by Chaudhary et al., (1980), Venkateswarlu and Singh (1982) and at ICRISAT (ICRISAT Annual Report, 1979, 1980 and 1981) also indicated C-11 to be a good general combiner for yield.

For earliness, short plant height and long pods, C-322 was found to be the best general combiner among the males in this study. The male parent C-322 was earlier in maturity, shorter in height and had longer pods. Its crosses with MS-Prabhat resulted into early and short progenies indicating that early x early and short x short results into early maturing and short progenies respectively.

ICP-9150 and ICP-9180 which were tall and late in maturity were the best general combiners for tallness and lateness. These lines were similar for most of the characters because of their similar origin. The crosses involving these tall male parents with the three females were tall indicating the complete dominace of tallness over shortness. On the other hand, crosses involving the late male parents and early female parents resulted into F_1's which were earlier than their mid parental values indicating partial dominance towards earliness. Similar results were observed by Sharma et al., (1973b) and Dahiya and Satija (1978) for earliness while Sharma (1981) observed over-dominance for tallness.

For seeds per pod, 100-seed weight and pod length, the male parents ICP-7035, ICP-9150, ICP-9180, Royes and C-322 which had more seeds per pod, high 100-seed weight and long pods were good general combiners. The F_1's involving these male parents showed partial dominance toward the low parents. These characters were found to be negatively associated with yield and some of the yield components, therefore their improvement may result in reduction of yield. ICP-7035 was found to be the best general combiner for 100-seed weight. Similar result was observed by Venkateswarlu and Singh (1982).

An examination of the cross combinations revealed that the best crosses resulted from crosses between the best female and male general combiners. In general, it was observed that crosses showing the best SCA effects were derived from cross combinations with parents of low x medium, medium x high, low x high and high x high GCA effects. Similar results were reported by Reddy et al., (1979a), Saxena et al.,(1981) and Venkateswarlu and Singh (1982). It was observed in this investigation that crosses showing high SCA effects did not necessarily involve good general combiners as their parents.

For seed yield per plant, pods per plant and total weight per plant, no cross combination exhibited significant SCA effects. The cross combination MS-4A x C-11 had the best SCA effects for secondary branches which is highly associated with yield. MS-Prabhat x Royes and MS-Prabhat x C-322 were the next best crosses considering SCA effects for secondary branches. They also flowered early and had short plant height.

Large values for heterosis are expected when geographically diverse, and presumably genetically diverse, parents are crossed, because genetic diversity is the key to the expression of heterosis (Singh, 1974). Highly significant parents vs. crosses mean sum of squares and SCA variance components is an indication that some specific crosses performed better or worse than their parents and overall hybrid means respectively. Parents vs. crosses mean sum of square for primary and secondary branches and pods per plant was not significant indicating that the crosses did not perform better or worse than their parents. On the other hand, non-additive gene action was observed for primary and secondary branches which indicated better or worse performance of the hybrids compared to the overall hybrid mean. Though there was no significant difference between crosses and parents for primary and secondary branches, absolute values for some specific crosses such as MS-3A x BDN-1, MS-Prabhat x BDN-1, MS-4A x C-11, MS-3A x ICP-9150, MS-4A x ICP-9150, MS-Prabhat x ICP-9150, MS-Prabhat x ICP-9180, MS-4A x Royes and MS-3A x C-322 were significantly lower or higher compared to the overall hybrid mean. This may explain the non-additivity expressed by these characters.

The percentage heterosis and heterobeltiosis were higher in crosses involving MS-Prabhat as a female parent than in crosses involving MS-3A and MS-4A. This performance was expected because MS-Prabhat significantly differed with the male parents for most of the characters studied. It was observed that F_1 hybrids having an introduced line as male parent did no better than the F_1's that did not. However, the unfavourable growing conditions such as high insect population and water-stress could have had an impact on heterosis and heterobeltiosis values, particularly those for grain yield.

Previous studies involving MS-3A and MS-4A by Reddy (1980 unpublished data) has indicated that heterosis over the better parent for yield ranged from -24 to 15%. Green et al.,(1979) reported heterosis to the extent of 32 and 17% above the high yielding check in their trial for the combinations MS-3A x C-11 and MS-4A x BDN-1 respectively. In the present study, heterosis over mid-parent for yield ranged from -25 to 85%. Crosses involving MS-3A and MS-4A as females and C-11 as the male parent gave the highest absolute yield with reasonable heterosis of 27% for MS-3A x C-11 and 22% for MS-4A x C-11 over C-11, the better parent. Crosses involving BDN-1 as a male parent performed poorly, although reports from ICRISAT (ICRISAT Annual Report, 1979-80) indicated BDN-1 to perform well in combinations with MS-3A and MS-4A. Such poor performance of BDN-1 may be attributed to the differences in growing conditions.

Sharma et al., (1973a, 1973b), Venkateswarlu and Singh (1980) and Reddy et al.,(1980) observed high and significant positive correlation between the mean performance of the parents and their respective GCA effects. Singh and Joshi (1966) while working on linseed felt that the parental performance itself is not necessarily a guarantee of its usefulness in a breeding program especially for yield. When the means of the parents, used in this study were correlated with their respective GCA effects, the correlation coefficient for all characters were positive. However, this correlation was not significant for yield and yield components. This insignificant correlation could have resulted from the poor performance of the early and late maturity groups of parents which were not adapted to Hyderabad condition. Yield is a complex trait controlled by many genes. It also depends on the development stages of the plant (vegetative and reproductive). Environmental stress at any of these stages may affect yield tremendously. Therefore, the performance of the lines in this study may not be a good measure of their hybrids for yield and its components. However, high and significant correlation between the performance _per se_ and the GCA effects for plant height, seeds per pod, 100-seed weight, and days to flower and maturity which are controlled by fewer genes suggests that the _per se_ performance of the lines may be a good measure of their hybrids for these characters.

Phenotypic correlation coefficients were computed among different characters for the 21 hybrids. To determine whether correlations differs between the maturity groups, the 21 hyrbids were divided into early and medium groups with 7 and 14 hybrids respectively. Correlation between yield per plant and primary and secondary branches, pods per plant and harvest index were positive and significant for the 21 hybrids and the meddium group while positive but not significant for the early group. The medium group formed a dominant group of the 21 hybrids, therefore, a similar magnitude and direction of correlation was expected. Non-significant values for the early group may be due to low number of observations correlated. High correlation between yield and number of primary and secondary branches and pods per plant has also been reported by Sharma *et al.*, (1973); Kumar and Haque (1973); Awatade *et al.*, (1980); and Beohar *et al.*, (1981). It appears from the present study that, a pigeonpea breeder should be able to make significant progress in selecting for grain yield by screening segregating lines on the basis of number of branches and pods per plant. Screening for harvest index may be difficult because it involves indirect measurements.

Pods per plant was found to be negatively and significantly correlated with seeds per pod, 100-seed weight and pod length for both 21 hybrids and the medium group of hybrids. For early group these correlations were negative but not significant. Though 100-seed weight and seeds per pod are among the yield components, selection for their high values may result into low number of pods per plant followed by a reduction in seed yield. Since crosses with medium seeds per pod and 100-seed weight resulted into high absolute yield, high number of seeds per pod and 100-seed weight may be sacrificed for yield. In previous studies, Ganguli and Srivastava (1972) found that pod length, seeds per pod and 100-seed weight were negatively correlated with yield and pods per plant. While positive correlation between yield and seeds per pod and 100-seed weight was reported by Dahiya *et al.*, (1978).

Harvest index and pod length were positively and significantly correlated for the early group and negatively correlated for the medium group in this investigation.

The following general conclusions can be made from the discussion.

1. Since the parents used in this study were all selected for their particular traits and the experiment conducted for one season at one location, the inferences should only be restricted to these particular parents and location.

2. The parents under consideration have not been crossed in all possible combinations hence individual parent's contribution in a particular parental combination was not determinable.

3. The study clearly demonstrated that pigeonpea lines used exhibited hybrid vigour for most of the characters. From combining ability and heterosis analysis, a number of parents and crosses have been identified for future economic exploitation.

4. The data presented indicate that simple parameters like array mean and *per se* performance are good indicators of the combining

ability of the parents. Therefore, for selecting parents, array mean may be a more reliable parameter since it reflects the value of a parent in a number of cross combinations and therefore a more generalized expression of the potential of the parent.

6. SUMMARY

Seven geographically and genetically diversified lines of pigeonpea (*Cajanus cajan* (L.) Millsp.) were crossed to three male sterile testers (MS-3A, MS-4A and MS-Prabhat) to produce 21 F_1 hybrids. The 31 entries comprising 10 parents and 21 F_1 hybrids at ICRISAT, Patancheru during the 1982-83 rainy season. Data were collected from 10 randomly selected competitive plants from each plot for plant height, number of primary and secondary branches, and pods per plant, total weight per plant, harvest index, yield per plant and 100-seed weight. For characters such as seeds per pod, pod length and shelling percentage, the data were recorded from 10 matured, fully developed undamaged pods from each of the 10 plants. Data was collected on plot basis for days to flower and maturity and plant stand and yield. Analysis of variance was performed to test the genotypic variation and the differences between parents vs. hybrids for all these characters.

The components of genotypic variance were obtained under the assumption of no epistasis using half and full-sib relationships. Heterosis and heterobelteosis were determined for each hybrid. Phenotypic correlations were determined among the characters studied.

Comparisons between the means of hybrids and their parents which indicated that the hybrids bloomed earlier and were taller than the parents, also indicated better performance of hybrids compared to parents

for most of the characters except seeds per pod and 100-seed weight. The combination MS-3A x C-11 had the highest grain yield followed by MS-4A x C-11 hence should be directly used in a breeding program to produce F_1 hybrids. Heterosis and heterobeltiosis values for grain yield and other characters were much larger for crosses involving MS-Prabhat than for crosses involving MS-3A and MS-4A. The highest heterosis and heterobeltiosis was noted for grain yield from the crosses MS-Prabhat x ICP-7035 and MS-Prabhat x ICP-9180. Such crosses having only one parent as a good general combiner may be expected to throw some good segregants in further generations.

C-11 was found to be the male parent with the best general combining ability for grain yield and its components and therefore would be expected to perform well when included in most hybrid combination. The male parent ICP-7035 showed the highest GCA effects for 100-seed weight, harvest index and performed well for seeds per pod, therefore, should be considered for the improvement of these characters. For characters, such as plant height, days to flower and maturity, the male parent BDN-1, C-322 and Royes proved to be the best general combiners.

Additive genetic variance was larger than non-additive genetic variance for all traits except number of primary and secondary branches and pod length. Therefore, selection should be done on the basis of general combining ability and the lines which survived this selection should be tested for their specific combining ability.

Correlations between the means for each plant and the respective gca effects indicated that the hybrid performance for the characters days to flower and maturity, plant height, seeds per pod, 100-seed weight, shelling % and pod length can be predicted on the basis of the performance of their parents, whereas grain yield and its components and harvest index cannot.

Number of pods per plant, primary and secondary branches and harvest index were found to be positively correlated with grain yield. Negative correlations were observed between pods per plant and seeds per pod, 100-seed weight, and pod length.

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