“Heterosis and Combining Ability Studies in Short Duration Hybrids of Pigeonpea (*Cajanus cajan* (L.) Millsp.)”

BY

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B. Sc. (Horti.)

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(GENETICS AND PLANT BREEDING)

COLLEGE OF AGRICULTURE, BADNAPUR, JALNA

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“Heterosis and Combining Ability Studies in Short Duration Hybrids of Pigeonpea (*Cajanus cajan* (L.) Millsp.)”

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2017

CANDIDATE'S DECLARATION

I hereby declare that this dissertation or part there of

has not been previously submitted by me for

a degree of any other institution

or university.

Place: BADNAPUR

Date : 22 / 06 / 2017 **(JASTI. SRIVARSHA)**

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CERTIFICATE – I

This is to certify that the dissertation entitled "**Heterosis And Combining Ability Studies in Short Duration Hybrids of Pigeonpea (*Cajanus cajan* (L.) Millsp.)**" submitted by **Miss. JASTI.SRIVARSHA** to the College of Agriculture, Badnapur in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE (AGRICULTURE)** in the subject of **GENETICS AND PLANT BREEDING (AGRICULTURAL BOTANY)** is record of original and bonafide research work carried out by her under my guidance and supervision. It is of sufficiently high standard to warrant its presentation for the award of the said degree.

I also certify that the dissertation or part thereof has not been previously submitted by her for a degree of any university.

Place: Badnapur
Date : 22/06/2017

Dr. J. E. Jahagirdar
Research Guide and
Chairman of Advisory Committee

CERTIFICATE-II

This is to certify that the dissertation entitled "**Heterosis and Combining Ability Studies in Short Duration Hybrids of Pigeonpea (*Cajanus cajan* (L.) Millsp.)**" submitted by **Miss. JASTI SRIVARSHA (Reg. No. 08MB/2015A)** to the College of Agriculture, Badnapur, Jalna in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE (Agriculture)** in the subject of **GENETICS AND PLANT BREEDING (DIVISION OF AGRICULTURAL BOTANY)** has been approved by the student's Advisory Committee after *viva-voce* examination in collaboration with external examiner.

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CONTENTS

LIST OF TABLES

LIST OF PLATES

LIST OF GRAPHS

LIST OF PIE DIAGRAMS

ABBREVIATIONS

/	:	per
%	:	per cent
∑	:	Summation
σ^2	:	Variance
BP	:	Better parent
HB	:	Heterobeltiosis
cm	:	Centimeter (s)
CV	:	Coefficient of variation
d.f.	:	Degree of freedom
EMSS	:	Error mean sum of squares
et al.	:	*et alia* (and others)
etc.	:	Etceteras
Fig.	:	Figure
g	:	Gram (s)
G	:	Genotypic correlation
GM	:	General mean
GCA	:	General combining ability
i.e.	:	ld est (that is)
kg	:	Kilogram (s)
m	:	Meter
MSS	:	Mean sum of squares
P	:	Phenotypic correlation
No.	:	Number
R	:	Residual effect
RH	:	Relative Heterosis
r	:	Correlation coefficient
S.E.	:	Standard error
SC	:	Standard Check
SCA	:	Specific combining ability
viz.	:	Videlicet (namely)
SH	:	Standard Heterosis
FS	:	Full Sibs
HS	:	Half Sibs
CD at 5%	:	Critical difference at 5 per cent

CHAPTER-I

INTRODUCTION

Pulses are major sources of proteins among the vegetarians in India, and complement the staple cereals in the diets with proteins, essential amino acids, vitamins and minerals. They contain 22-24% protein, which is almost twice the protein in wheat and thrice that of rice. Though India is the world's largest producer of pulses, it imports a large amount of pulses to meet the growing domestic needs as it is the largest consumer too. It has been estimated that India's population would reach 1.68 billion by 2030 from the present level of 1.21 billion. Accordingly, the projected pulse requirement for the year 2030 is 32 million tonnes with an anticipated required growth rate of 4.2% (IIPR Vision 2030).

Pigeonpea *Cajanus cajan* (L.) Millsp., (2n=22) member of family Leguminosae (Fabaceae) is an important legume (pulse) crop of tropical and subtropical regions of Asia and Africa. India is considered as the center of origin of pigeonpea (Van der Maesen , 1980) because of its natural genetic variability available in the local germplasm and the presence of its wild relatives in the country. Pigeonpea [*Cajanus cajan* (L.) Millsp.] occupies an important place among rainfed resource poor farmers as it is with so many benefits at low cost. In addition to its main use as dehulled split dhals, its immature green seeds and pods are consumed as a green vegetable.

In India, pigeonpea is grown in an area of 5.21 million hectares with a production of 4.23 million tonnes (Anonymous 2017). The Indian sub-continent alone contributes nearly 92 per cent of the total pigeonpea production in the world. Although India leads the world both in area and production of pigeonpea, its productivity is lower (673 kg/ha) than the world average (762.4 kg/ha) (FAOSTAT 2015). In India, pigeonpea is important in the states of Maharashtra (1.1 m ha), Karnataka (0.58 m ha), Andhra Pradesh (0.51 m ha), Uttar Pradesh (0.41 m ha), Madhya Pradesh (0.32 m ha), and Gujarat (0.35 m ha). These six states account for over 70% of the total pigeonpea area in India.

In Maharashtra, pigeonpea having largest role in area, production and productivity. In the year 2016-17, pigeonpea covered the area of 15.33 lakh ha., with production of 11.70 lakh tonnes and productivity of 764 kg/ha. In Marathwada region in the year 2016-2017, pigeonpea covered the area of 5.95 lakh ha., with production of 4.47 lakh tonnes and productivity of 759 kg/ha.

Since 1976, pigeonpea has globally recorded a 56% increase in its area and production but the productivity of the crop has remained low at about 700 kg ha-1.This is a matter of concern since the majority of the Indian population is vegetarian and their protein source directly depends on pulses. In order to meet this requirement, the Indian Government annually imports about 0.5 to 0.6 m. tons of pigeonpea mainly from Myanmar and southern and eastern Africa (Saxena and Nadarajan, 2010).

Natural out-crossing in pigeonpea was first reported by Howard *et al*. (1919). The out-crossing in this crop is mediated by a variety of insects (Onim, 1981) and wind does not play any role in this event (Kumar and Saxena, 2001). Bhatia *et al*. (1981) reported 24% natural out-crossing in pigeonpea at Patancheru. The estimates of natural out-crossing vary greatly between 2 to 70% in different environmental conditions (Saxena *et al*., 1990). This level of out-crossing was found sufficient to maintain male-sterile lines and also to produce F_1 hybrid seeds.

To promote the pigeonpea production, genetic improvement of pigeonpea was emphasized by researchers for more than five decades and a number of cultivars were developed from hybridization programmes and selection of landraces. However, the progress in the genetic improvement of yield potential has been limited and the improved cultivars failed enhance the productivity of the crop.

Therefore, an alternative breeding approach such as hybrid technology, which has been profitably used in a number of cereals, fruits, and vegetable crops was attempted in pigeonpea to enhance the yield. The development of commercial hybrid pigeonpea programme was innovated at ICRISAT in collaboration with ICAR (Indian Council of Agricultural Research). In 1974, a source of genetic male-sterility (GMS) was identified. As a consequence, a genetic male-sterility based pigeonpea hybrid ICPH 8 was released in 1991 in India (Saxena *et al*., 1992). It is considered a milestone in the history of crop breeding as ICPH 8 is the first ever commercial hybrid released in any food legume in the world. This hybrid, however, could not be commercialized due to its high seed cost and difficulties in maintaining the genetic purity. This development provided the most important information on the role of partial natural out-crossing in large-scale hybrid seed production. This component is essential for commercial exploitation of hybrid vigour in pigeonpea (Saxena and Nadarajan, 2010).

Due to the limitation of large-scale hybrid seed production in GMS-based hybrids, the development of cytoplasmic male-sterility (CMS) became imperative. To develop a CMS system, pigeonpea genome was inserted in the cytoplasm of wild species through hybridization and backcrossing. It is believed that the interaction between wild cytoplasm and cultivated nuclear genome would produce male sterility effect. So far, seven such CMS systems have been bred in pigeonpea with varying degrees of success (Saxena and Nadarajan, 2010). Of these, A_2 and A_4 systems derived from crosses involving wild relatives of pigeonpea and cultivated types have shown promise because of their stability under various agro-climatic conditions and availability of good maintainers and fertility restorers (Saxena and Nadarajan, 2010).

One of the factors responsible for the poor productivity of pigeonpea are the lack of improved cultivars. Research for genetic improvement of this crop to raise yield levels effectively has to be strengthened countering biotic stresses, through widening genetic base. In pigeonpea, heterosis for grain yield and its component have not been reported for various quality parameters in pigeonpea hybrids by using CGMS lines and diverse restorers that will be expected to stable, good combiner across the environment. However, varieties good in *per se* performance may not necessarily produce desirable progenies when used in hybridization, proper understanding of underlying inheritance of quantitative traits and also in identifying the promising crosses for further use in breeding program. However, environmental effect greatly influence the combining ability estimates. In view of above consideration, the present study has been planned on heterosis, combining ability in CGMS-based short duration pigeonpea hybrids with the following objectives:

1) To study heterosis for yield and yield components.
2) To estimate combining ability effects of parents and hybrids for yield and yield contributing characters.

CHAPTER II

REVIEW OF LITERATURE

A brief review of related literature has been illustrated in this chapter, under the following headings.

2.1 Heterosis

2.2 Combining ability

2.1 Heterosis

Presence of heterosis is an important for development of hybrid varieties in breeding programme. Extent of heterosis decides the fate of the hybrid variety. Hybrid with high level of heterosis is always welcomed.

The term heterosis was first used by Shull (1914). Heterosis refers to the increased or decreased vigour exhibited by hybrids in F_1 generation over the mean of both parents or over better parent. The heterosis is the genetic expression of the beneficial effects of hybridization. In common usage, the terms heterosis and hybrid vigour are synonymous and it has been more precisely suggested by Whaley (1952) as the developed superiority of the hybrids as hybrid vigour and the mechanism by which the superiority is developed as heterosis.

Another definition of heterosis was given by Stebbins (1957) as greater adaptedness to human needs, which has obtained in particular environments through artificial selection followed by hybridization.

Jones (1917) postulated that heterosis is due to large number of linked favorable dominant genes.

East (1936) formulated the theory of allelic interaction and suggested that hybrid vigour is due to cumulative action of many loci.

Dobzhansky (1952) enlarged the scope of heterosis to include adaptive, selective and reproductive advantages of heterozygosity.

In a particular cross, heterosis is measured in terms of two parameters i.e. heterosis over mid parental value (Relative heterosis) and heterosis over better parent value (Heterobeltiosis). However, in plant breeding programme, heterosis is also estimated in terms of heterosis over check or standard variety/hybrid (Useful or Standard heterosis). In terms of combining ability for quantitative characters heterosis is highly associated with specific combining ability effects of the cross.

Heterosis may be positive or negative. Depending on the breeding objectives, both positive and negative heterosis are useful for crop improvement. In general positive heterosis is desirable for yield and negative heterosis for maturity. In pigeonpea there are many reports to present the possibility of good amount of heterosis for grain yield and its components in experimental hybrids. This information may be useful for exploitation of heterosis on commercial scale.

Soloman *et al.* (1957) gave first report on heterosis in pigeonpea by studying the extent of heterosis in ten hybrids in respect of fourteen morphological characters. Considerable heterosis was observed in several growth parameters and yield components. Fairly conspicuous vigour (24.5%) was noticed in few best hybrid combinations though it did not out yield the highest yielding variety.

Sharma *et al.* (1973) in diallel study comprising nine parents found that hybrids differed significantly for all characters studied. The hybrids also have higher mean values than the mid parent or superior parent, particularly for plant height and grain yield per plant indicating the presence of hybrid vigor to the extent of 80.5 and 72.2% respectively.

Veeraswamy *et al.* (1973) recorded that the intervarietal hybrids in red gram between CO 1 (a short duration high yielding strain) and 19 diverse varieties expressed heterosis for plant height, plant spread, number of branches, number of clusters, number of pods and days to 50 per cent flowering. The maximum heterosis was recorded for number of clusters (179.6 %) and number of pods (188.5 %) over the superior parent.

Shrivastava *et al.* (1975) studied the extent of heterosis in 17 F_1 hybrid combinations involving 14 genotypes for yield and observed 96 per cent heterosis for secondary branches and 80 per cent heterosis for number of pods per plant. In most of the crosses, low x medium and low x low parental combinations had maximum heterosis for individual characters. In case of secondary branches, heterosis was maximum in high x high as well as low x low crosses indicating the role of genetic diversity for obtaining high hybrid vigour.

Reddy *et al.* (1979b) observed high heterotic effects in crosses involving diverse parents of different maturity groups. Specifically, mid late x late and early x late cross combinations were of economic worth and negative heterosis was exhibited for traits *viz.,* plant height and protein content while positive heterosis was observed in respect of pod number and yield.

Venkateswarlu *et al.* (1981) observed the mean heterosis of 39 per cent for yield and about 16 per cent for days to flowering as well as pods per plant. In general early x late and 6midlate x late combinations resulted in high heterosis for yield.

Marekar (1982) observed overall heterosis of 17.85 and 6.75 per cent for yield over mid parent and better parent respectively. For other traits *viz.,* plant height, days to flower, number of primary branches, pod weight and hundred seed weight overall heterosis over mid-parent was 17.7, 0.4, 12.0, 6.6 and 5.6 per cent respectively. Negative heterobeltiosis over better parent was obtained for plant height, days to flower, number of primary branches, 100 pod weight and 100 seed weight.

Jadhav and Nerkar (1983) studied the magnitude of heterosis for seed yield in diallel crosses involving seven parents of pigeonpea under three cropping systems *viz.,* a rainy season sole crop, rainy season intercrop with sorghum hybrid and winter season sole crop. They found substantial heterosis over mid parent and better parent in all the three environments.

Singh *et al.* (1983) observed the maximum heterotic response up to 221 per cent for grain yield in line x tester studies of pigeonpea. The best heterotic cross, Mukta x Upas120 was identified as potential cross for early maturing hybrids.

Omanga (1985) studied the heterosis in seven fertile lines crossed in line x tester design and reported high heterosis per centage over mid parent for yield and other three related characters. High magnitude of heterosis was seen with MS-Prabhat than with MS 3A.

Saxena *et al.* (1986) observed the heterosis for yield and six yield contributing traits which ranged between 24 and 26 per cent.

Tuteja *et al.* (1989) reported high heterosis in a best cross A_2 x EE 76 for yield, number of clusters and pods among thirty hybrids.

Patel *et al.* (1991) using line x tester design including 3 male sterile lines, 10 medium and 10 early maturity pollinators recorded heterosis for seed yield per plant. Out of these 60 combinations, heterosis for seed yield over better parent was highest for crosses MS 3A x DL 781 (80%) and MS Prabhat x ICPL 684 (78%).

Tuteja *et al.* (1992) showed that a single cross Ageti x EE 76 and a three way cross (ICPL 87 x EE76) x UPAS 120 was significantly better for days to maturity in negative direction.

Khapre *et al.* (1996) studied 24 hybrids along with 11 parents and ICPH 8 and BDN 2 as standard hybrid and standard variety respectively as a check. They found that crosses with line MSHY 9 showed marked heterosis for height at first effective branches, number of primary branches, pods per plant and grain yield per plant followed by line MS Prabhat. Male parents BDN 2, Daithna local, ICPL 87 and BDN 7 gave marked heterosis for yield and its components.

Paul *et al.* (1996) studied heterosis for yield and yield components in hybrid pigeonpea in 28 late maturing pigeonpea experimental hybrids by crossing 28 lines with single male sterile lines MS 3783 and found that hybrids gave better heterotic response against T 7 as compared to Bahar which varied from – 27.7 to 91.2 per cent. They also concluded that pods per plant in association with number of secondary branches and dry matter at maturity were found to be the chief contributing characters.

Verulkar and Singh (1997) studied heterosis in pigeonpea and found that the standard heterosis for seed yield per plant ranged from 16.5 per cent in cross ICPL 151 x ICPL 84023 to 54.6 per cent in cross UPAS 120 x ICPL 84023. These crosses also exhibited significant desirable heterosis for days to flower, days to maturity, number of pods and 100 seed mass.

Kumar and Srivastava (1998) observed heterosis over better parent for seed yield which ranged from -77.91 to 110.97 per cent at IIPR, Kanpur using line x tester design involving three male sterile lines and twelve male fertile parents of longer duration.

Wanjari *et al.* (1998) studied selection of male sterile populations for development of parental lines for exploitation of heterosis in pigeonpea and found that MST 21 was better female line. Among the populations MS P_2 having positive gca has been identified for deriving MS Sibs. Among males, AK 22 and AK 30 had been good general combiners. The MS P_3 x AK 22 have been found to have high sca.

Wankhede (1998) studied heterosis for yield and yield components in pigeonpea involving male sterile lines i.e. three genetic male sterile lines (Females), eight testers (males) and their 24 possible crosses and revealed that the phenomenon of heterosis was of general occurrence for most of the traits, except plant height. The cross AKMA 11 x AKT 9221 showed highest seed yield per plant and exhibited high heterosis (63.19 %) and useful heterosis over BDN 2 (83.84 %). They concluded that the mean squares due to parents and crosses were highly significant for all the characters. AKMS 11 x AKT 9221 and AKML 11 x C 11 were the best crossed followed by AKMS 21 x C 11 for seed yield, number of clusters, number of pods and protein content and AKMS 21 x BDN 2 for number of clusters and pods per plant.

Hooda *et al.* (1999) reported heterosis in 40 crosses using line x tester design. Maximum heterosis for pods per plant over standard check Manak was obtained for crosses QMS 1 x TAT 10 (38.1 %), QMS 1 x H 88-43 (28%), heterosis for seed yield per plant was observed within range of 21.2 to 28.9 per cent.

Manivel *et al*. (1999) suggested the use of male sterile line Prabhat NDT as female parent for high yielding and early maturity hybrid in pigeonpea.

Singh *et al.* (1999) studied 16 inter specific hybrids involving four lines of *Cajanus sericeus* and four testers of *Cajanus cajan*. They observed average heterosis for branches per plant (85-96%), pods per primary branch (45.43%) and pods per plant (25.54%).

Srinivas *et al.* (2000) studied 22 experimental hybrids derived from two male sterile lines *viz.,* ICP MS 288 and MS 3783 as female and 11 medium to late genotypes as male in line x tester mating design. Out of these crosses, the crosses involving ICP MS 3783 line showed heterosis for seed yield and most of component characters. The cross ICP MS 3783 x LRG 30 was best hybrid combination.

Chandirakala and Raveendran (2002) studied 30 pigeonpea hybrids derived from three GMS lines i.e. MS Prabhat DT, MS Prabhat NDT, MS O-50 and ten tester lines (ICPL 87104, ICPL 85010, ICPL 88009, ICPL 89008, ICPL 89020, ICPL 84023, ICPL 88039, ICPL 90032, ICPL 90012 and ICPL 87). The cross with MS Prabhat DT showed marked heterosis for pods per plant, clusters per plant, 100 seed weight and grain yield per plant. Highest positive heterosis over mid, better and standard parents was observed in MS 0-5 x ICPL 88009 for number of branches per plant and in MS Prabhat NDT x ICPL 88009 and MS Prabhat DT x ICPL 84023 for grain yield per plant.

Pandey and Singh (2002) reported highly significant positive heterosis for seed yield per plant and number of primary and secondary branches per plant.

Kalaimagal and Ravikesavan (2003) reported heterosis for seed yield and its components in 63 crosses obtained by crossing 3 genetic male sterile lines with 21 testers in L×T fashion. ICPH 8 was used as check. The heterosis values ranged from 9.13 to 404.57 per cent, 10.11 to 57.92 per cent and 10.42 to 106.17 per cent over mid parent, better parent and standard check respectively.

Aher *et al.* (2006) studied the performance of three crosses *viz.,* BDN 2 x BDN 2010, BDN 2 x Nirmal 2 and BSMR 736 x Nirmal 2 and they observed maximum positive heterosis over mid parent for number of pods per plant (45.5%) and grain yield per plant (26.0%). Similar trend of heterosis over better parent was recorded for these traits and maximum positive inbreeding depression was observed for number of pods per plant (37.2 %) and grain yield per plant (21.0 %).

Saxena *et al.* (2006) studied the yield of new CMS-based pigeonpea hybrids and they found hybrids on A_1 cytoplasm i.e. ICPH 2319 (3017 kg/ha) was the best with standard heterosis of 61.3 per cent over the best check ICPL 360. On A_2 cytoplasm based hybrids, ICPH 3172 (2725 kg/ha) was found to be best with 33-36% superiority over controls and on A_4 cytoplasm based hybrids, ICPH 2438 (3414 kg/ha) was the best performing hybrids with 61 per cent superiority.

Anantha and Muthian (2007) undertaken studies on the combining ability and heterosis for seed yield and its components using line x tester mating design involving 12 crosses. A high degree of heterosis for seed yield per plant and other yield components over standard check (CO 5) was observed.

Wanjari *et al.* (2007) studied heterosis in CMS based 136 hybrids in pigeonpea. Out of which 11 expressed high pollen fertility (>80 %). They found maximum heterosis in hybrid No. 230407 (GT 288 A x 220751-5) with 212.26 per cent heterosis over check followed by hybrid No. 230466 (AKV 2 A x 22076-29) and hybrid No. 230405 (GT 288 A x 220682-55) with heterosis of 140.94 per cent and 131.92 per cent over check respectively.

Acharya *et al*. (2009) studied that out of 45 crosses, 30 and 19 crosses exhibited significant positive heterobeltiosis and standard heterosis for seed yield per plant. Ten best crosses GT 100 with ICP 12116, ICP 12161, Banas and ICP 11912, Banas with ICP 9140 and ICP 11488, GT 101 with ICP 12161 and ICP 12116, ICP 12161 with ICP 9135 and ICP 13555 with ICP 9135 exhibited significant desirable standard heterosis for seed yield per plant.

Sarode *et al*. (2009) studied the estimates of heterosis for yield and yield traits in long duration pigeonpea. Out of fifteen crosses, the maximum standard heterosis was recorded in a cross Pusa 9 x Bahar (55.32 %) followed by MAL 8 x ICPL 7035 (47.94 %) for yield per plant and pods per plant.

Chandirakala *et al*. (2010) reported that two hybrids *viz.,* MS Prabhat DT x ICPL 88009 and MS Prabhat DT x ICPL 84023 showed highly significant and positive heterosis over mid, better and standard parent. In general, the proportion of hybrids exhibiting significant heterotic effect for grain yield with genetic male sterile line MS Prabhat DT was greater as compared to lines, MS Prabhat NDT and CO 5.

Shoba and Balan (2010) reported the heterosis over standard parent for single plant yield varied from –25.0 % (CORG 990047 A x ICPL 87) to 325 % (MS CO 5 x PA 128).

For per se performance single plant yield varied from 15 g (CORG 990047 A x ICPL 87) to 85.0 g (MS CO5 x PA 128). While considering about mean performance, SCA effects and standard heterosis the promising hybrids namely CORG 990047 A x APK 1 and MS CO 5 X ICPL 83027 which was found to be superior for plant height(cm), number of pods/plant, single plant yield.

Gedam *et al*. (2013) studied heterosis for seed yield and its components in 40 crosses obtained by crossing 4 female lines with ten male testers in LxT fashion. Non-additive gene effects were predominant for all the characters, except for days to 50% flowering. The cross ICPL 20106 x ICPR 3477 showed high heterosis over mid parents and better parent with 144.98 % and 61.31 % over the standard check BSMR 736 and ICPH 2671 respectively for grain yield plant.

Pandey *et al.* (2013) studied heterosis for yield and its component traits on CGMS based hybrids and reported the best cross combinations NDACMS 1-6A x NDA 98-6. NDACMS 1-6A x NDA 5-14, NDACMS 1-4A x IPA 208, NDACMS 1-6A x ICP 870, NDACMS 1-6A x NDA 96-1, NDACMS 1-6A x NDA 8-6, NDACMS 1-6A x ICP 2309 and NDACMS1-4A x Bahar in order of merit seed yield and other yield components. The results indicated that the manifestation of heterobeltiosis for seed yield per plant was significantly superior for fourteen hybrids ranging from -85.06% to 33.74% and fifteen varieties over standard variety ranging from -82.57% to 26.28%.

Patel *et al*. (2013) studied diallel analysis in pigeonpea for estimation of heterosis including seed yield per plant and its component characters. Significant heterobeltosis and high per se performance with regards to seed yield per plant and its components were recorded by the crosses GT 102 x ICPL 87119 (33.80% and 95.00g), BSMR 853 x GT 102 (25.35% and 85.00 g) and ICPL 87119 x AGT 2 (25.23% and 92.67g) in positive direction.

Gite *et al.* (2014) reported standard heterosis for seed yield ranged from 53.31 to 77.94 per cent. On the basis of heterosis over standard check, first five hybrids *viz.,* (ICPA 2043 x ICPR 2671), (ICPA 2043 x ICPR 3473), (ICPA 2043 x ICPR 3477), (ICPA 2043 x ICPR 3514), (ICPA 2048 x ICPR 2671), out yielded BSMR 736 to the extent of 77.94%, 72.54%, 64.95%, 61.02% and 60.29%, respectively. Whereas, these five hybrids also had highest better parent heterosis to the extent of 53.81%, 58.92%, 42.58%, 48.64% and 31.58%, respectively.

Saroj *et al*. (2014b) studied the four hybrids *viz*., ICPA 2043 × Asha, ICPA 2092 × Asha, ICPA 2043 × Azad and ICPA 2043 × ICPR 4105 showed significant heterosis, MPH, BPH and EH, over commercial variety i.e. MAL 13 as well as inbreeding depression. Further, two hybrids (ICPA 2043 × Azad and ICPA 2043 × Asha) could manage to out yield the check MAL 13, significantly with the margin of > 20 % and thus may be exploited for heterosis breeding in pigeonpea.

Gadekar *et al.* (2015) Hybrids involving four diversified A_2 cytoplasm based male sterile (CMS) lines *viz*., oval leaf, sesamum leaf, obcordifoliate leaf and small leaf, were selected and crossed with twelve diverse fertility restorer lines of pigeon pea (*Cajanus cajan*) and these lines with hybrids were evaluated for the estimation of heterosis, GCA and SCA effects and variances in Lines x Tester analysis. Among the four CMS lines obcordifoliate leaf CMS line and three restorers AKPR- 178 (M), AKPR-364 and AKPR-192 were found good general combiners for yield and yield contributing traits. Hybrids *viz*., Obcordifoliate leaf × AKPR-178 (M), Obcordifoliate leaf × AKPR-344 and Obcordifoliate leaf × AKPR-210 exhibited highest significant economic heterosis and SCA effects over two checks PKV-TARA and AKT-8811. Obcordifoliate leaf was found best leaf type for hybrids.

Pandey *et al.* (2015) an attempt was made to assess relationship between heterosis and genetic diversity as well as forming heterotic groups for pigeonpea breeding. Three CMS lines were crossed with 20 elite genotypes/restorers in a line x tester mating system and the resultant 60 F1 hybrids along with their parents were evaluated for various morphological traits to predict the genetic relationship among parents and heterosis in their crosses. The crosses derived from high diversity group showed high positive significant heterosis for seed yield. However, some crosses give very high negative heterosis for seed yield although their parents belong to a high diversity group. The reason for this possibly will be linkage of alleles for complex genetic traits as biomass and yield.

Singh and Singh (2015) Twelve hybrids having diverse background were developed to understand the heterosis and inbreeding depression in late maturity groups of pigeonpea (*Cajanus cajan* L.). More than 100% significant economic heterosis were revealed in crosses, MAL-17 × NDA 4906 (266.32%), BHUA 96-13-3 × NDA 49-6 (249.98%), BHUA 96-13-3 × MAL-19 (190.41%), MAL-17 × NDA 99-1 (136.27%) and MAL-17 × MAL- 19 (103.46%) for seed yield per plant. The crosses, MAL-17 × NDA 49-6 and BHUA 96-13-3 × NDA 49-6, showed better performance in F1, low/even negative inbreeding depression in F2 and involved parents with high *per se* performance. Two crosses namely, BHUA 96-13-3 × MAL-19 and BHUA 96-21-4 × NDA 99-1 showing higher magnitude of heterosis were also associated with higher inbreeding depression. The cross, MAL-17 × NDA 49-6 (266.32%) showed maximum estimates of yield heterosis, also exhibited significant heterosis for days to 50% flowering, number of primary and secondary branches, pods per plant, pod length and harvest index.

Sudhir *et al*. (2016) synthesized manually twenty CGMS-based pigeonpea [*Cajanus cajan* (L.) Millspaugh] hybrids by crossing five CMS lines (A lines) with 11 male lines (R lines) and these hybrids were evaluated to study yield potential with the performance of their R lines. The results showed that the restoring capacities of restorer lines are very important to quality seed production and for yield potential. The study indicated that most of the R- line acts as good restorer and it ranged from 98.50% (ICPL 20108) to 59.22% (ICPL 2009.In present study most of the hybrids showed standard heterosis towards in desirable direction for yield and yield contributing characters over the checks so these cross combination of parent may be exploited to developed the hybrid in pigeonpea for obtaining higher grain yield. The range of standard heterosis over Asha for grain yield per plant was ranged from -13.06 (ICPA 2092 x ICPL 20123) to 40.91% (ICPA 2047 x ICPL 20126).

2.1 Combining ability

Combining ability can be defined as the relative ability of a genotype to transmit superiority to its crosses. The term general combining ability (gca) is defined as the average performance of a line in a series of crosses and specific combining ability (sca) of a cross is the performance of a cross combination to do relative better or worse than would be expected on the basis of average performance of the parents involved.

The concept of general and specific combining ability was first given by Sprague and Tatum (1942). They suggested that general combining ability is expected to be the result of genes which are largely additive in their effects and specific combining ability largely depends on genes with dominance or epistatic effects. On the other hand, Griffing (1956) suggested that general combining ability is due to both additive as well as additive x additive gene interactions.

Line x tester analysis is a precise approach to estimate the general and specific combining ability effects of parents and crosses respectively. It is also useful in estimating various types of gene effects. Kempthorne (1957) proposed line x tester analysis technique which is analogous to North Carolina mating design II of Comstock and Robinson (1952). In this analysis a random sample of 'S' sizes were taken and all of them were mated to each of ‘d’ dams. They also precisely expressed the variance due to general combining ability (σ^2gca) and variance due to specific combining ability (σ^2sca) in terms of the covariance of half-sibs (Cov (HS) and covariance of full-sibs (Cov (FS) respectively.

σ^2gca = Cov (HS)

σ^2sca = Cov (FS)-2 Cov (HS)

Plant breeders in India have recently been using a modified line x tester design by indicating the parental lines also in a bid to obtain a single degree of freedom for contrast 'Parents vs. hybrids' (Arunachalam, 1974).

The available literature pertaining to combining ability in pigeonpea has been reviewed here as under.

Dahiya and Barar (1977) reported low gca for flowering time and high gca for pod number, hundred seed weight and yield per plant.

Krishna Rao and Nagur (1979) observed a variety namely Jawahar 45 as consistently exhibiting good gca for grain yield.

Reddy *et al.* (1979a) reported the predominance of sca effects. The gca effect for most of the characters were generally negative for early and medium parents and positive for late parents. They also inferred that specific mid late x late and early x late combinations are likely to give recombination of economic worth.

Venkateshwarlu and Singh (1982) reported that variances due to both gca and sca were highly significant indicating the presence of both additive and dominance gene effects. The parent NP (WR)-15, T 7 and C 11 were the best general combiners for number of pods per plant, seeds per pod and 100 seed weight.

Singh *et al.* (1983) reported that UPAS 120, Mukta and S 103 were promising for use in breeding early maturing hybrids since they are best combiners for earliness and yield components.

Omanga (1985) found C 11 to be the best general combiner for seed yield while ICP 7035 and ICP 9150 showed highest gca effect for hundred seed weight.

Patel *et al.* (1987) analyzed 30 hybrids involving 3 genetic male sterile lines and reported significant positive sca mainly for number of pods and pod length.

Hazarika *et al.* (1988) observed significant gca and sca effects for yield components in pigeonpea. They reported 477, 219, ICPL 96 and ICPL 87 as good combiner for majority of characters. Determinate plants were generally good combiners for seeds per pod and seed size. Indeterminate plants were generally good for pods and yield per plant.

Patel *et al.* (1992) analyzed 10 hybrids involving three GMS lines and reported that hybrids showing significant positive sca effects mainly involved good and other poor combining parents. This was especially noted in respect of pod and branches per plant.

Ghodke *et al.* (1993) reported that the gca effect were highly significant for all characters. Whereas, sca effects were highly significant for days to maturity and 100 seed weight. They further reported 9 hybrids exhibiting good sca effects for yield and other characters. Two hybrids showing high sca effects involved both parents with low gca effects.

Khapre *et al*. (1993) studied combining ability for grain yield and it's components in diallel crosses involving seven diverse pigeonpea cultivars. This study revealed the predominance of additive gene effects for the yield and yield contributing characters. Parents BDN 2, ICP 6997, PBNA 54 and Daithna local were the best general combiners for all characters except days to maturity. Prabhat showed consistence desirable gca effects for days to maturity. The hybrids ICP 6997×PBNA 54 and ICP 6997× BDN 2 showed significant sca effects for grain yield.

Khapre *et al.* (1996) studied heterosis and combining ability analysis for grain yield and its components in pigeonpea and revealed a significant role of non-additive gene action for all the characters. The parent MS Hy 9, MS small leaf, lgithana local, BDN 2 and ICPL 87 were the best general combines. Seven hybrids showed significant positive sca effects and high per se performance for grain yield and other yield attributes.

Narladkar and Khapre (1997) studied combining ability in pigeonpea and found that out of 24 hybrids, 10 hybrids showed significant positive sca effects and high *per se* performance for grain yield and also showed significant sca effects for other related morpho-physiological traits.

Kumar and Srivastava (1998) reported KPMS 1050 and MSNP (WR) 15 among the lines and PR 5149, PDA 92-1, KPP 1034-1, KPP 1034-5 and KPP 1034-7 among the testers as good general combiners for seed yield. They also concluded that gene action was predominantly non-additive for the characters studied.

Wanjari *et al.* (1998) found that among males, AK 22 and AK 30 had been good general combiners. The MS P_3 x AK 22 has been found to have high sca. They also concluded that a hybrid MS P_9 x AK 31 is expected to be with complementary epistasis.

Singh and Srivastava (2001) studied combining ability variances and effects using four lines of the wild species *Cajanus sericeus* and four testers of cultivated species *Cajanus cajan* in a line x tester fashion and found that among the lines, *C. sericeus* (ICPW 160) proved to be a good general combiners for days to flowering, plant height, number of primary branches per plant, pod length, number of seed per pod, 100 seed weight and seed yield per plant. Among the testers *Cajanus cajan* proved to be a good general combiner.

Pandey and Singh (2002) evaluated three genetic male sterile lines (DAMS 1, ICPMS 3783 and KPMS 1050) and 12 diverse genotypes of the long duration group of pigeonpea (*Cajanus cajan* (L.) Millsp.) along with their hybrids for general and specific combining ability, variance components and standard heterosis. Among the lines, DA 32,

DA 34, DA 37, DA 46, DA 93-4, DA 93-2, DA 94-6 and Bahar mutant and among the testers DAMS 1 and ICPMS 3783 were found to be good general combiners for seed yield/plant and other yield contributing traits such as secondary branches/plant, clusters/plant and number of pods/plant. The tester DAMS 1 was also a good general combiner for primary branches/plant and per cent pod setting.

Pawar and Tikka (2003) studied 64 hybrids and revealed higher magnitude of sca variances over gca variances for all the traits which indicated preponderance of non-additive gene action. The parents MS 228, MS Pusa 33, SKNP 9256 and AL 15 were good general combiners for seed yield and its yield contributing traits.

Banu *et al*. (2006) studied the general (gca) and specific combining ability (sca) effects in 45 pigeonpea hybrids along with their parents for days to 50% flowering, days to maturity, plant height, primary branches per plant, clusters per plant, pods per plant, seeds per pod, pod length, 100-seed weight and single plant yield. The components of variance due to gca and sca revealed pre-dominance of non-additive gene action for most of the characters studied. The parents ICP 13201 and ICP 13207 were found to be the best general combiners for yield attributing traits. The hybrid ICP 11967 x CO 5 was identified as the best combination and could be exploited for improving seed yield in pigeon pea.

Baskaran and Muthiah (2007) studied in pigeonpea through line x tester analysis revealed that the parents CO 5, VBN 1 and ICPL 83027 were found to be good general combiners for majority of characters. The hybrids VBN 1 X ICPL 83027, ICPL 87 X ICPL 83024, CORG 9701 X APK I, CORG 9904 X ICPL 83027 had good SCA effects for most of the traits including seed yield and can be utilized in heterosis breeding programme.

Phad *et al.* (2007) evaluated five lines (females) and twelve testers and sixty crosses. The parents ICPL 87119, BDN 2004, AKT 8811, BSMR 736 and BSMR 853 had good general combining ability whereas among the crosses, BDN 2 x BDN 2010, BDN 2 x BSMR 853 and BSMR 736 x AKT 8811 were the best specific cross combinations for grain yield per plant, plant spread, number of primary branches per plant, number of secondary branches per plant and number of pods per plant.

Sameer Kumar *et al.* (2009) estimated the variances due to gca and sca effect and found the predominance of non-additive gene action for most of the characters in the present study. Among female parents, PRG 100 and LRG 30 and among the testers, ICP 8863 and ICPL 87119 were found to be good combiners for most of the characters studied. The cross combinations *viz*., LRG 30 x ICP 8863, PRG 100 x ICP 8863, LRG 30 x ICP 87119, ICPL 85063 x ICP 87119 and PRG 100 x ICP 87119 exhibited significant sca effects coupled with appreciable amounts of relative heterosis, heterobeltiosis and standard heterosis for yield and its attributes.

Singh and Singh *et al.* (2009) crossed ten pod fly resistant lines namely, PDA 93-1E, PDA 89-2E, PDA 88-2E, SL 12-3-1, SL 21-1-3, SL 21-6-2, SL 21-9-3, SL 22-2-3 and ICP 8102-5-S1 with each of three pod fly susceptible varieties *viz*., Bahar, ICP 5036 and T 7 in a line x tester mating design. MA2, PDA 93-1E, SL 21-9-3, Bahar and T 7 were identified as good general combiners for seed yield per plant. Heterosis to the extent of 73.77% and 168.42% over the standard check (Bahar) and better parent, respectively, were recorded for seed yield per plant. Five hybrids i.e., MA 2 x Bahar, PDA 93-lE x T 7, PDA 93-lE x Bahar, SL 219-3 x T7 and ICP 8102-5-S1 x T 7 exceeding above 45% standard yield heterosis were spotted out as promising heterotic crosses.

Shoba *et al.* (2010) developed twenty seven hybrids utilizing three lines (two CMS and one GMS) and nine testers and their hybrids were evaluated for ten characters in order to understand the gene action in pigeonpea. The combining ability analysis revealed that variances due to dominance was higher than variances due to additive for all characters indicating the preponderance of non additive gene action governing these traits. Among the lines, MS CO5 and among the testers, CORG 9060, PA 128, CORG 7 and ICPL 83027 were the best general combiners for seed yield. Most of the crosses showing significant *sca* effects involved one good and one poor or even negative general combiners. The crosses MS CO 5 x CORG 9060, MS CO 5 x PA 128, MS CO5 x CORG 7 , MS CO5 x ICPL 83027 and CORG 990047 A x APK 1 would be suitable for exploiting heterosis for increased pod in pigeonpea.

Gupta *et al.* (2011) studied combining ability and found that the lines CMSGT 33A, CMSGT 100A, CMSGT 288A, CMSGT 301A and CMSGT 311A among females

(A lines) and GTR 27 and GTR 29 among males (R lines) were good general combiners for seed yield and one or more other characters. CMSGT 311A × GTR 29, CMSGT 310A × GTR 27, CMSGT 288A × GTR 26, CMSGT 301A × GTR 27, CMSGT 301A × GTR 30 and CMSGT 100A × GTR 28 showed desired higher sca effects for seed yield per plant.

Thiruvengadam and Muthiah (2012) studied combining ability in pigeonpea using genetic male sterile lines and estimated the nature of gene action for yield and its component traits. Based on overall GCA effects, the lines MS CO 9701, MS CO 5 and the testers ICPL 87, CORG 9302 and TAT 93-47 were identified as potential parents as they exhibited significant GCA effects for most of the traits. Among the number of crosses with high SCA values, the hybrids MS CO 9701 x ICPL 87, MS CO 9701 x CORG 9302, MS CO 5 x CORG 9302, MS CO 5 x TAT 93-47 were the most promising as they were early, dwarf and high yielding.

Arbad *et al.* (2013*)* studied the combining ability and genetic variance for nine quantitative traits in pigeonpea nonadditive gene effects were pre dominant for all characters. Two crosses exhibiting high sca effects for grain yield per plants and some parents were good combiner for grain yield and pod per plants.

Meshram *et al*. (2013) developed forty eight hybrids by using 6 CGMS lines and 8 restorers. He reported none of the parents exhibit significant GCA effects for all the characters under study, however among the lines AKCMS 10A, AKCMS 13A and AKCMS 09A and among the testers AKPR 8, AKPR 359 and AKPR 292 were identified as potential parents as they exhibited significant GCA effects for most of the important traits. Among the hybrid combinations AKCMS 09A x AKPR 8, AKCMS 10A x ICPR 2740, AKCMS 11A x AKPR 319, AKCMS 09A x AKPR 374 and AKCMS 06A x AKPR 359 might be exploited for the improvement of respective traits as found to possess desirable genes for most of the important characters including seed yield.

Saroj *et al*. (2014a) evaluated 26 F_1 hybrids involving two CMS lines and 13 restorers/testers in line × tester fashion and revealed first four cross combinations *viz*., ICPA 2043 × Azad, ICPA 2043 × ICPR 4105, ICPA 2092 × ICPR 3760 and ICPA 2092 × MA 6 exhibited significantly high SCA effects for seed yield and the parents involved having high × high and low × low GCA effects.

Yamamura *et al.* (2014) studied the gca effects of parents ICPA 2078, GT 308A, PKV TARA, ARCCV 2 and GPHR 08-11 were good general combiners for seed yield and its direct components. The estimates of sca effects revealed that nine experimental hybrids had significant, desirable and positive sca effects for seed yield. The cross combination ICPA 2092 x Vipula, ICPA 2078 x BSMR 856 and ICPA 2078 x ARCCV 2 were good specific combiners for number of secondary branches, number of pods per plant and seed yield per plant.

Patil *et al*. (2015) crossed seven obcordate A-lines with four known fertility restorers in line x tester mating design to study their general and specific combining ability. Higher magnitude of SCA effect showed that, hybrid yield was under the control of non-additive genes. Among A-lines, ICPA 2204 was the best general combiner. Among testers, ICPL 20116 was the best general combiner. Among hybrids, ICPA 2208 x ICPL 20108 a cross between high GCA parents was the best with positive significant SCA effect and higher mean performance for grain yield, 100-seed mass, number of seeds per pod and resistance to fusarium wilt disease.

Mhasal *et al.* (2015) conducted experiment with 11 new genotypes; six females (CMS lines viz., AKCMS-81A, AKCMS-82-2A, AKCMS-83A, AKCMS-12A, AKCMS-93A and ICPA-2047A) and five males (testers) viz., AKPR-303, AKPR-324, AKPR-364, AKPR-372, AKPR-057 and their 30 crosses along with two checks PKV-TARA and ASHA. Layout used was RCBD with three replications. Among female parents, ICPA-2047A recorded significant general combining ability (GCA) effect for maximum six characters such as grain yield per plant, plant height, number of clusters, number of seeds per pod, 100 seed weight and days to 50 per cent flowering. The male parent AKPR-324 achieved the highest GCA effect for plant height, number of clusters, 100 seed weight and grain yield per plant. The cross ICPA-2047A × AKPR-324 depicted high mean performance (33.67), high magnitude of useful heterosis, positive specific combining ability (SCA) effect and both the parents involved revealed high GCA effects. Another cross ICPA-2047A × AKPR-372 revealed highest mean performance along with highest magnitude of useful heterosis and highest SCA effects while the significant variances for male and female parents were observed for days to 50 per cent flowering, days to maturity, plant height, number of branches and 100 seed weight. One of the parents i.e.

AKPR-372; although low combiner for grain yield yet it exhibited good combining ability for number of branches, number of pods, number of seeds/ pod and days to 50% flowering.

Sudhir *et al*. (2017) conducted trial to ascertain combining ability of 30 hybrids which were made from 13 parents in a line X tester mating design during kharif, 2012-13 and tested in a Randomized Block Design with two replications during kharif, 2013-14. Analysis of variance for quantitative traits revealed that all accessions were significantly different and a wide range of variability exists for most of the traits studied. Most promising combinations for seed yield per plant were ICPA 2047 x ICPL 20126, ICPA 2048 x ICPL 20106, ICPA 2047 x ICPL 20108 and ICPA 2047 x ICPL 20098. The general combining ability revealed that among the testers, ICPL 20126 and ICPL 20108 were good general combiners for seed yield/plant. The results also revealed that some crosses exhibited high order significant and desirable SCA effects for different characters involved parents having different GCA effects.

CHAPTER – III

MATERIAL AND METHODS

The present investigation was undertaken to study the "Heterosis and Combining Ability Studies in Short Duration Hybrids of Pigeonpea (*Cajanus cajan* (L.) Millsp.)".The experiment was conducted at ICRISAT, Patancheru.

3.1 Experimental materials

3.1.1 Description of Breeding Materials The experiment consisted of 27 crosses developed by using 3 female and 9 male parents along with VL Arhar1, ICPL 161, ICPH2433 as check.

The details of the female and male parents are given in table below

Table 3.1. Details of female parents (lines) and male parents (testers).

LINES	CHARACTERS
ICPA2039	Determinate growth, male sterile source
ICPA2089	Indeterminate, male sterile source
ICPA2156	Indeterminate, male sterile source
TESTERS	**CHARACTERS**
ICPL 88034	Earliness
ICPL 88039	Good restoring capacity
ICPL 149	Non determinate
ICPL 161	Short duration
ICPL 81-3	Good restorer

Table 3.1 contd..

TESTERS	CHARACTERS
ICPL 89	Earliness
ICPL 90048	Non determinate
ICPL 86022	Early maturity
ICPL 92047	Short duration

3.2 Crossing programme

The set of 27 hybrids were developed during monsoon season of 2015-2016 by crossing three female lines with nine male parents.

3.3 Experimental methods

3.3.1 Study of crosses and its parents

27 pigeonpea hybrids along with 12 parents and checks were studied during *Kharif* of 2016-17 at the ICRISAT, Patancheru.

3.3.2 Details of experiment.

1) Design : RBD
2) No. of Replication : Three
3) Treatments : 42 (27 hybrids+3 lines+9 testers+3 checks)
4) Plot size : 4.0 x 3.0m^2
5) Spacing : 75x25cm^2
6) Fertilizer dose : 25:50:0 NPK (kg/ha)
7) Season : *Kharif* 2016-17
8) Location : International Crops Research Institute For Semi Arid Tropics, Patancheru.

Cultural practices

The crop was given a uniform basal dose of 25 kg N and 50 kg P_2O_5/ha. Cultural practices like weeding and plant protection measures were followed as and when required. Crop was irrigated once during vegetative growing stage because of long dry spell and the rest of the time it was rainfed.

3.4 Observations

3.4.1 Observations on yield and yield contributing characters

Five competitive plants were selected randomly from each row in each replication for recording the observations. Average value of the line for each character was computed from these plants for the characters given below.

3.4.1.1. Plant height (cm)

At maturity, plant height was measured in cm from base of the plant to tip of the main stem.

3.4.1.2. Days to 50% flowering

Number of days from sowing to 50% flowering in a plot was recorded and average number of days to flowering was worked out.

3.4.1.3 Pollen fertility (%)

For testing the pollen fertility in the hybrids 2 percent aceto-carmine solutions was used to stain and differentiate the fertile and sterile pollen grains. Three plants were selected randomly from each hybrid and five buds from each plant were collected to record its pollen fertility. Anthers from each flower bud were squashed on a slide and the count of fertile and sterile pollen grains in three microscopic fields was noted.

Percent pollen fertility of hybrids was calculated on mean of all the observations from a hybrid.

$$\text{Pollen fertility (\%)} = \frac{\text{Number of fertile pollens}}{\text{Total number of pollens}} \times 100$$

3.4.1.4 Days to maturity

Days required from sowing to maturity of 80 per cent of plants in a plot were recorded as days to maturity.

3.4.1.5 Number of primary branches per plant

The total effective pod bearing branches per plant on the main stem were recorded.

3.4.1.6 Number of secondary branches per plant

Total effective pod bearing branches per plant on primary branches were noted.

3.4.1.7 Number of pods per plant

The numbers of pods without any damage on plant were counted. Total number of pods bearing seeds were counted per plant at maturity.

3.4.1.8 Number of seeds per pod

The number of seeds in each of 10 pods of selected five plants were recorded and average was worked out as number of seeds per pods on each plant.

3.4.1.9 100 seeds weight (g)

Healthy 100 seeds were counted and weight recorded in grams.

3.4.1.10 Grain yield per plant (g)

The grain yield was recorded in grams (g) per plant.

3.4.1.11 Harvest Index (%)

The total harvested grain and the total dry shoot matter of randomly selected five plants was recorded and harvest index is worked out by dividing total harvested grain upon the total dry matter.

3.5 Statistical method

Data in each experiment of all entries was subjected to analysis of variance (Panse and Sukhatme, 1967) for testing the significance of treatments.

3.6 Estimation of heterosis

The heterosis was calculated as per the procedure suggested by Fonseca and Patterson (1968).

3.6.1 Heterobeltiosis

Heterobeltiosis can be defined as the superiority of the F_1 over better parent. The heterosis effects in terms of per cent increase or decrease were measured for 11 characters.

$$\text{Heterobeltiosis} = \frac{\overline{F_1} - \overline{BP}}{\overline{BP}} \times 100$$

Where,

$\overline{F_1}$ = Mean of F_1 hybrid

$\overline{BP}$ = Mean value of better parent

3.6.2 Standard heterosis

The heterosis effects in terms of per cent increase or decrease over standard check (useful heterosis) were measured for all the eleven characters.

$$\text{Per cent heterosis over standard check} = \frac{\overline{F_1} - \overline{SC}}{\overline{SC}} \times 100$$

Where,

$\overline{F1}$ = Mean of F1 hybrid

$\overline{SC}$ = Mean value of standard check

Heterosis was tested by least significance difference (LSD) as below:

$$\text{L.S.D. for standard check} = \left[\frac{2 \times \text{pooled error mean square of the RBD}}{\text{Number of replication}}\right]^{1/2}$$

at p = 0.05 and 0.01

3.7 Line x tester analysis

The genetic analysis was carried out for line x tester mating design as suggested by Kempthorne (1957) and modified by Arunachalam (1974).

The treatment SS was partitioned to source attributed to parents, crosses and parent vs crosses.

Table 3.2 ANOVA for line x tester mating design

Sr. No.	Sources of variation	DF	SS	MSS
1.	Replication	(r - 1)	-	-
2.	Genotype/treatments	(g - 1)		
3.	Lines (females)	(l - 1)		
4.	Testers (Males)	(t - 1)		
5.	Lines x Testers	(l - 1) (t - 1)		
6.	Error	(r - 1) (lt - 1)		

The standard error and critical difference between two means were calculated as follows

$$\text{S.E. of mean} = \sqrt{\text{EMSS / No. of replications}}$$

S.E. difference = S.E. of mean x $\sqrt{2}$

Critical difference (C.D.) = S.E. difference x ‘t’ value

(‘t’ value at 5 and 1 per cent level of probability for error degrees of freedom)

3.7.1 Analysis of variance for combining ability in line x tester

The line x tester analysis to estimate general and specific combining ability in respect of the character in F_1 under the study was carried out according to the procedure given by Kempthorne (1957). The analysis of variance will take the following form.

Table 3.3 ANOVA for combining ability analysis.

Sr. No.	Source of variation	Degree of freedom (d.f.)	Mean square	Expectations
1.	Lines (l)	(l-1)	M_1	$\sigma^2 e$+ (CovFS-2CovHS) + (tr CovHS)
2.	Tester (t)	(t-1)	M_2	$\sigma^2 e$+ r (CovFS-2CovHS) + (tr CovHS)
3.	Line x tester	(l-1) (t-1)	M_3	$\sigma^2 e$+ r (CovFS-2CovHS)
4.	Error	(r-1) (tl-1)	M_4	$\sigma^2 e$

Where,

lr	=	Line x Replication
tr	=	Tester x Replication
Cov HS	=	Covariance half sibs
Cov FS	=	Covariance of full Sibs

3.7.2 Estimation of general and specific combining ability effects

One of the major objectives of the present study was to estimate the general combining ability effect of the lines and the testers and the specific combining ability effect between the lines and the testers. The combining ability effects and their standard errors were estimated as follows.

The mean used to estimate the general and specific combining ability effects of the ijk observations was

$$X_{ijx} = m + g_i + g_j + s_{ij} + r_k + e_{ijk}$$

Where,

X_{ijx}	=	Any character measured on cross i x j in k^{th} replication
m	=	Population mean
g_i	=	gca effect of i^{th} female parent
g_j	=	gca effects of j^{th} male parent
s_{ij}	=	sca effects of ij^{th} combination
e_{ijk}	=	Error associated with the observation xijk

i = Number of female parents

j = Number of male parents

k = Number of replications

The individual effects were estimated as indicated below

i) $$m = \frac{X\ldots}{mfr}$$

Where

x = The total of all hybrids

m = Number of males

f = Number of females

r = Number of replications

ii) $$g_i = \frac{X_{i}..}{fr} - \frac{X\ldots}{mfr}$$

Where

$X_{i}.$ = Total of i^{th} male parent over all female parents and réplications.

iii) $$g_j = \frac{X_{j}..}{mr} - \frac{X\ldots}{mfr}$$

Where

X_j = Total of j[th] female parent over all male parents and réplications.

iii) $$S_{ijgj} = \frac{X_{(ij)}}{r} - \frac{X_{j..}}{fr} - \frac{X_{j..}}{mr} + \frac{X_{...}}{fmr}$$

Where

$x_{(ij)}$ = (ij)[th] combination total over all replication.

The restriction $g_i = 0$, $s_{ij} = 0$ is imposed on the elements of model

The covariance for half sib and full sib were obtained by following relation.

i) $$\text{Cov HS} = (\sigma^2 \text{gca line}) = \frac{M_l - M_{l \times t}}{r \times t}$$

ii) $$\text{Cov HS} = (\sigma^2 \text{ gca tester}) = \frac{M_t - M_{l \times t}}{r \times l}$$

iii) $$\text{Cov HS} = (\sigma^2 \text{ gca ave.}) = \frac{M_l + M_t - 2\, M_{l \times t}}{r\,(l + t)}$$

Where,

M_l = MSS of lines

M_t = MSS of testers

$M_{l \times t}$ = MSS of line x tester

r = Replication

l = Lines

t = Testers

$$\text{iv) Cov FS} = \frac{(M_l - M_e) + (M_t - M_e) + (M_{lxt} - M_e)\ 6r\ (\text{Cov HS ave.}) - r\ (l \times t)\ \text{Cov HS ave}}{3r}$$

v) σ^2 sca = Cov. FS

vi) σ^2 sca = Cov. FS - 2 Cov. HS

$$\text{vii) } \sigma^2 sca = \frac{M_{l \times t} - Me}{r}$$

Where,

M_e = Error mean sum square

The standard error for GCA and SCA effects were calculated as follows

$$\text{i) S.E. (GCA line) gi} = \left(\frac{M_e}{r \times t} \right)^{1/2}$$

ii) S.E. (GCA tester) gj = $\left(\dfrac{M_e}{r \times l}\right)^{1/2}$

iii) S.E. (sij - skl) = $\left(\dfrac{2M_e}{r}\right)^{1/2}$

Where,

Me = Error mean sum of squares

r = Replications

t = Testers

l = Lines

Per cent contribution of lines, testers and crosses

The proportional contribution of lines, testers and their interactions were determined by following formulae

i) Contribution of males = $\dfrac{SS\ (m)}{SS\ (crosses)} \times 100$

ii) Contribution of females = $\dfrac{SS\ (f)}{SS\ (crosses)} \times 100$

iii) Contribution of females x males = $\frac{SS\ (m \times f)}{SS\ (crosses)} \times 100$

CHAPTER- IV

RESULTS

In this study three CMS lines (ICPA 2039, ICPA 2089 and ICPA 2156) were crossed with nine testers (ICPL 88034, ICPL88039, ICPL 149, ICPL 161, ICPL 81-3, ICPL 89, ICPL 90048, ICPL 86022 and ICPL 92047) and twenty seven hybrids were developed following line x tester mating design. These twenty seven hybrids along with their parental lines and checks *viz*. VL Arhar1, ICPL 161, ICPH 2433 were grown during *Kharif* season of 2016 at International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Hyderabad. Observations were recorded on different quantitative characters and genotypes were analyzed as per line x tester mating design, while mean data on genotypes (3 lines, 9 testers, 27 hybrids, three checks) was used for estimation of heterosis.

The results of the present investigation are presented under the following major heading.

1. **Analysis of variance**
2. **Mean performance of genotypes for yield and yield components**
3. **Estimation of Heterosis**
4. **Line x tester analysis**
5. **Combining ability of parents and crosses for yield and yield components**

4.1 Analysis of variance

The analysis of variance showed significant differences among the genotypes for all the characters studied. (Table 4.1)

4.2 Mean performance yield contributing characters

Mean performance of different characters studied along with checks is presented in (Table 4.2).

4.2.1 Plant height (cm)

The range of plant height was 106.20 to 182 cm with general mean of 143 cm.

Among the lines, ICPA 2156 (133.67 cm) was very tall. Among the testers ICPL161 (152 cm) was the tallest tester. Among the crosses, ICPA 2039 x ICPL 149 (182 cm), recorded highest plant height followed by ICPA 2039 x ICPL 161 (171 cm).The standard checks *viz.,* VL Arhar1, ICPL 161 and ICPH 2433 recorded plant height of 137.13 cm, 143.33 cm and 165.67 cm respectively.

4.2.2 Days to 50 per cent flowering

The range of days to 50 per cent flowering was 62 to 84 days with general mean of 75.00 days.

Among the lines, ICPA 2156 (67 days) was earliest to flower. Among the testers, ICPL 88039 (62 days) was earliest in flowering. Among the crosses, ICPA 2089 x ICPL88039 (70 days) and ICPA 2156 x ICPL 86022 (70 days) took minimum days to flower. The standard checks *viz.,* VL Arhar1, ICPL 161 and ICPH 2433 recorded 50% flowering at 63, 84 and 84 days respectively.

4.2.3 Pollen fertility (%)

The range of pollen fertility recorded was 0.08 to 99.83 % with the general mean of 54.00 %.

The lines were male sterile. Maximum pollen fertility among the testers was recorded by ICPL92047 (99.83%). Among the crosses, ICPA 2156 x ICPL89 (99.32%) recorded highest pollen fertility followed by ICPA 2039 x ICPL 92047 (99.30%). The standard checks *viz.,* VL Arhar1, ICPL161 and ICPH 2433 recorded pollen fertility of 98.43%, 99.30% and 96.60% respectively.

4.2.4 Days to maturity

Days to maturity ranged from 105.00 to 135.00 days with general mean 124 days.

The line ICPA 2156 (109 days) and the tester ICPL 88039 (105 days) were early to mature among lines and testers respectively. The cross ICPA 2089 x ICPL 86022 (118 days) was earliest followed by ICPA 2039 x ICPL 88039 (119 days). The standard checks *viz.,* VL Arhar1, ICPL161 and ICPH 2433 recorded maturity at 105, 134 and 134 respectively.

4.2.5 Number of primary branches per plant

Number of primary branches per plant ranged from 7.75 to 12.10 with general mean of 10.11.

Maximum number of primary branches per plant was observed in line ICPA 2089 (10.63) and tester ICPL88034 (12.10) among the lines and testers. The crosses, ICPA2039 x ICPL81-3 (11.97) had relatively maximum number of primary branches per plant followed by ICPA2039 x ICPL90048 (11.27). The standard checks *viz.,* VL Arhar1, ICPL161 and ICPH 2433 recorded 10.60, 9.83 and 10.33 primary branches per plant respectively.

4.2.6 Number of secondary branches per plant

The range of number of secondary branches per plant was 16.30 to 22.77 with general mean of 19.85.

Among the lines ICPA 2156 (18.87) recorded highest number of secondary branches per plant and among testers ICPL 92047 (21.50) had highest number of secondary branches per plant. Among the crosses, ICPA 2156 x ICPL 88034 (22.77) recorded highest number of secondary branches per plant followed by ICPA 2039 x ICPL 90048 (22.38), ICPA 2039 x ICPL 88039 (22.23). The standard checks *viz.,* VL Arhar1, ICPL161 and ICPH 2433 recorded 20.03, 19.53 and 21.33 secondary branches per plant respectively.

Table 4.1 ANOVA for different characters in Pigeonpea.

Sources of Variation	d. f.	Mean sum of squares										
		Plant height (cm)	Days to 50 % flowering	Pollen fertility (%)	Days to maturity	No. of pri. branches per plant	No. of sec. branches per plant	No. of pods per plant	No. of seeds per pod	100 seed weight (g)	Grain yield per plant (g)	Harvest Index
Replications	2	123.1	15.58	1.69	47.65	1.88	2.57	354.19	0.02	0.07	3.83	1.36
Genotypes	41	632.72**	96.65**	1916.03**	157.87**	1.49**	6.52**	20313.40**	0.08**	1.05**	1498.07**	112.32**
Error	82	43.5	5.2	3.88	18.25	0.8	2.02	130.49	0.04	0.19	29.72	14.68

* - Significant at 5 % level of significance

** - Significant at 1 % level of significance

Table 4.2 Mean values of parents, hybrids and checks for yield and yield contributing characters.

Sr. No	Parents/crosses	Plant height (cm)	Days to 50 per cent flowering	Pollen fertility (%)	Days to maturity	No. of primary branches per plant	No. of secondary branches per plant	No. of pods per plant	No. of seeds per pod	100 seed wt. (g)	Grain yield Per Plant (g)	Harvest Index
	LINES											
1	ICPA 2039	106.20	77.00	0.08	125.00	9.20	16.30	216.50	3.73	7.97	63.67	34.13
2	ICPA 2089	131.33	68.00	0.08	113.33	10.63	18.33	118.43	4.33	7.53	37.67	23.58
3	ICPA 2156	133.67	67.00	0.86	108.67	10.07	18.87	114.00	3.73	7.60	36.67	36.76
	TESTERS											
4	ICPL 88034	134.67	82.67	99.63	131.67	12.10	18.97	183.43	3.63	8.07	54.33	33.47
5	ICPL 88039	131.67	62.33	98.30	105.00	10.30	19.87	198.33	3.73	9.83	70.33	29.70
6	ICPL 149	136.33	79.67	98.47	125.00	7.75	18.70	314.23	3.73	7.37	84.50	31.08
7	ICPL 161	152.00	81.00	99.23	126.67	9.80	19.27	347.73	3.73	7.93	100.43	41.14
8	ICPL 81-3	147.33	78.67	99.47	125.33	10.00	19.27	288.27	3.77	7.80	81.37	39.75
9	ICPL 89	126.20	71.67	99.27	117.33	9.67	19.43	136.90	3.67	7.80	38.67	40.18
10	ICPL 90048	129.67	72.33	99.73	122.00	9.07	19.67	138.93	4.00	8.63	53.00	22.06
11	ICPL 86022	116.67	66.33	99.60	110.67	9.23	19.31	162.33	3.77	8.07	40.00	34.81
12	ICPL 92047	141.00	77.67	99.83	126.67	10.40	21.50	212.73	3.73	8.27	58.33	37.12
	CROSSES											
13	ICPA 2039 X ICPL 88034	152.00	77.00	97.26	121.00	10.07	20.13	314.73	3.80	8.10	89.67	27.25
14	ICPA 2039 X ICPL 88039	144.67	72.67	99.20	118.67	10.03	22.23	203.67	3.80	8.00	63.67	34.15
15	ICPA 2039 X ICPL 149	182.00	84.00	98.57	135.00	10.13	19.80	352.00	3.73	8.33	102.33	35.29

Note: A lines and B lines are isogenic except for pollen fertility. The observations of yield and yield contributing characters except pollen fertility were recorded on B-lines (ICPB 2039, ICPB 2089 and ICPB 2156)

Table 4.2 cont.......

Sr. No	Parents/crosses	Plant height (cm)	Days to 50 per cent flowering	Pollen fertility (%)	Days to maturity	No. of primary branches per plant	No. of secondary branches per plant	No. of pods per plant	No. of seeds per pod	100 seed wt. (g)	Grain yield Per Plant (g)	Harvest Index (%)
16	ICPA 2039 X ICPL 161	171.00	83.00	94.19	132.00	10.33	21.50	454.17	3.77	8.17	133.33	34.62
17	ICPA 2039 X ICPL 81-3	169.33	84.33	99.00	133.33	11.97	20.90	251.67	3.70	8.43	73.67	30.64
18	ICPA 2039 X ICPL 89	150.00	80.00	85.90	129.67	10.30	21.60	189.30	3.73	7.77	49.67	25.59
19	ICPA 2039 X ICPL 90048	145.87	83.00	96.20	133.67	11.27	22.38	356.53	3.73	9.03	116.67	31.69
20	ICPA 2039 X ICPL 86022	142.00	75.67	97.40	126.67	9.85	20.20	185.87	3.80	7.83	47.83	40.67
21	ICPA 2039 X ICPL 92047	166.67	80.00	99.30	126.67	10.03	19.83	294.60	3.77	7.37	77.33	26.75
22	ICPA 2089 X ICPL 88034	139.33	72.33	95.59	121.33	9.89	20.93	222.87	3.50	8.30	63.67	31.99
23	ICPA 2089 X ICPL 88039	131.20	69.67	94.65	120.67	9.76	19.98	182.33	4.13	8.10	60.00	40.68
24	ICPA 2089 X ICPL 149	163.33	75.33	94.08	120.67	10.02	20.27	245.33	4.00	7.40	63.00	33.98
25	ICPA 2089 X ICPL 161	139.33	76.33	86.16	128.00	10.01	21.83	206.12	3.77	7.27	57.00	37.31
26	ICPA 2089 X ICPL 81-3	146.33	73.67	86.58	123.33	10.00	21.35	243.87	3.80	8.13	74.00	35.23
27	ICPA 2089 X ICPL 89	129.67	73.33	88.30	122.00	10.70	20.85	166.30	3.77	8.33	54.00	43.77
28	ICPA 2089 X ICPL 90048	140.33	72.00	94.47	127.00	9.85	20.67	139.80	3.83	8.97	49.83	22.54
29	ICPA 2089 X ICPL 86022	136.00	72.00	98.33	118.33	10.02	18.13	123.43	3.70	8.20	37.33	34.72
30	ICPA 2089 X ICPL 92047	132.67	72.67	86.93	126.67	9.87	19.33	197.00	3.77	8.50	51.00	37.96
31	ICPA 2156 X ICPL 88034	151.67	75.33	93.37	125.33	10.09	22.77	160.33	3.77	8.27	46.33	27.90
32	ICPA 2156 X ICPL 88039	133.33	77.00	86.04	129.00	9.82	18.23	165.93	4.00	9.00	57.00	37.97
33	ICPA 2156 X ICPL 149	143.00	76.33	98.43	127.67	9.76	17.17	213.53	3.73	8.03	57.00	42.09

Note: A lines and B lines are isogenic except for pollen fertility. The observations of yield and yield contributing characters except pollen fertility were recorded on B-lines (ICPB 2039, ICPB 2089 and ICPB 2156).

Table 4.2 cont.......

Sr. No	Parents/crosses	Plant height (cm)	Days to 50 per cent flowering	Pollen fertility (%)	Days to maturity	No. of primary branches per plant	No. of secondary branches per plant	No. of pods per plant	No. of seeds per pod	100 seed wt. (g)	Grain yield Per Plant (g)	Harvest Index (%)
34	ICPA 2156 X ICPL 161	146.00	75.67	98.87	124.67	10.57	20.37	170.07	3.73	7.67	44.67	40.35
35	ICPA 2156 X ICPL 81-3	151.67	76.00	96.60	124.00	10.10	19.70	161.33	3.80	8.90	52.63	39.53
36	ICPA 2156 X ICPL 89	134.67	70.67	99.32	123.33	10.67	19.40	150.33	3.83	9.07	47.00	23.90
37	ICPA 2156 X ICPL 90048	138.00	70.67	95.00	123.00	10.87	17.07	161.63	4.20	9.00	53.33	45.34
38	ICPA 2156 X ICPL 86022	143.33	69.67	98.43	125.33	9.90	17.30	203.93	3.60	8.13	59.00	33.65
39	ICPA 2156 X ICPL 92047	149.53	72.00	94.39	123.33	9.81	19.43	205.33	3.57	7.87	58.57	42.63
	CHECKS											
40	ICPL 88039	137.13	63.33	98.43	105.00	10.60	20.03	200.67	4.00	9.77	70.44	28.15
41	ICPL 161	143.33	84.33	99.30	133.67	9.83	19.53	332.10	3.67	7.93	95.83	41.05
42	ICPH 2433	165.67	84.33	96.60	134.00	10.33	21.33	426.67	3.83	8.13	99.94	37.41
	Parental Mean	132.22	73.69	74.54	119.77	9.85	19.12	202.65	3.80	8.07	59.91	33.64
	Mean of crosses	147.14	75.56	94.55	125.56	10.21	20.12	219.33	3.79	8.22	64.42	33.74
	General Mean	**143.00**	**75.16**	**54.00**	**123.82**	**10.11**	**19.85**	**221.74**	**3.80**	**8.21**	**64.87**	**34.49**
	S.E. ±	3.81	1.32	1.61	2.47	0.52	0.82	6.60	0.12	0.25	3.15	2.21
	C.D. 5%	10.71	3.71	3.20	6.94	1.45	2.31	18.55	0.33	0.70	8.86	6.22
	C.V.	4.61	3.04	3.25	3.45	8.83	7.17	5.15	5.29	5.27	8.40	11.11

Note: A lines and B lines are isogenic except for pollen fertility. The observations of yield and yield contributing characters except pollen fertility were recorded on B-lines (ICPB 2039, ICPB 2089 and ICPB 2156).

4.2.7 Number of pods per plant

Number of pods per plant ranged from 114.00 to 454.17 with general mean of 221.74.

Maximum number of pods per plant was recorded by ICPA 2039 (216.50) among the lines and ICPL 161 (347.73) recorded maximum number of pods per plant among testers. Among the crosses, ICPA 2039 x ICPL 161 (454.17) has recorded highest number of pods per plant followed by ICPA2039 x ICPL 90048 (356.53). The standard checks *viz.,* VL Arhar1, ICPL161 and ICPH 2433 recorded 200.67, 332.10 and 426.67 pods per plant respectively.

4.2.8 Number of seeds per pod

Number of seeds per pod ranged from 3.50 to 4.33 with general mean 3.79.

Among the lines, ICPA 2089 (4.33) recorded maximum number of seeds per pod and among the testers ICPL90048 (4.00) recorded maximum number of seeds per pod. Among the crosses, ICPA 2156 x ICPL 90048 (4.2) recorded highest number of seeds per pod. The standard checks *viz.,* VL Arhar1, ICPL161 and ICPH 2433 recorded 4.00, 3.67 and 3.83 seeds per pod respectively.

4.2.9 100 seed weight (g)

100 seed weight ranged from 7.27 to 9.83 g with general mean of 8.21 (g).

Among the lines ICPA 2039 (7.97 g) and among testers ICPL 88039 (9.83 g) had highest 100 seed weight. In the crosses, ICPA 2156 x ICPL 89 (9.07 g) recorded highest test weight followed by ICPA 2039 x ICPL 90048 (9.03 g). The standard checks *viz.,* VL Arhar1, ICPL161 and ICPH 2433 recorded 9.77 g, 7.93 g and 8.13 g test weight respectively.

4.2.10 Grain yield per plant (g)

The range of yield per plant was 36.67 to 133.33 g with general mean of 64.87 (g).

Out of three lines ICPA 2039 (63.67 g) yielded highest grain per plant while among the testers ICPL 161(100.43 g) recorded highest grain yield per plant. In the crosses, ICPA 2039 x ICPL 161 (133.33 g) had highest grain yield per plant followed by ICPA 2039 x ICPL 90048 (116.67 g). The standard checks *viz.,* VL Arhar1, ICPL161 and ICPH 2433 recorded 70.44 g, 95.83 g and 99.94 g grain yield per plant respectively.

4.2.11 Harvest Index (%):

The range of harvest index was 22.06 to 45.34 % with general mean of 34.49.

The line ICPA 2156 (36.76%) had highest harvest index out of the three. Among testers, ICPL161 (41.14%) recorded highest harvest index. Among the crosses, ICPA 2156 x ICPL 90048 (45.34%) recorded highest harvest index followed by ICPA 2156 x ICPL 92047 (42.63%). The standard checks *viz.,* VL Arhar1, ICPL161 and ICPH 2433 recorded 28.15%, 41.05% and 37.41% harvest index respectively.

4.3 Heterosis

In the present investigation, heterosis is estimated for all the twenty seven crosses for eleven yield and yield contributing characters and expressed as per cent increase or decrease over better parent (BP) and over standard checks VL Arhar1, ICPL 161 and ICPH 2433.

4.3.1 Estimation of Heterobeltiosis (%)

Heterobeltiosis can be defined as the superiority of the F_1 over better parent. The percentage of heterobeltiosis for the characters studied is presented in table 4.3.1. The character wise result of heterobeltiosis was observed in 27 crosses tested as presented below.

4.3.1.1 Plant height (cm)

For this trait, heterobeltiosis ranged from -8.33 to 33.50 per cent. Out of the 27 crosses, the crosses ICPA 2039 x ICPL 149 (33.50%), ICPA 2039 x ICPL 86022 (21.71%), ICPA 2089 x ICPL 149 (19.80%), ICPA 2039 x ICPL 89 (18.86%), ICPA 2039 x ICPL 92047 (18.20%), ICPA 2039 x ICPL 81-3 (14.93%), ICPA 2039 x ICPL 88034 (12.87%), ICPA 2156 x ICPL 88034 (12.62%), ICPA 2039 x ICPL 161 (12.50%), ICPA 2039 XICPL 90048 (12.49%) and ICPA 2039 x ICPL 88039 (9.87%) recorded positive significant heterobeltiosis for this trait. The significant negative heterobeltiosis was exhibited by ICPA 2089 x ICPL 161 (-8.33%) for the trait plant height.

4.3.1.2 Days to 50 per cent flowering

For the trait days to 50% flowering, negative heterobeltiosis is desirable. The heterobeltiosis ranged from -12.50 to 14.93 per cent. Out of the 27 crosses, the crosses ICPA 2089 x ICPL 88034 (-12.50%), ICPA 2156 x ICPL 88034 (-8.87%), ICPA 2156 x ICPL 92047 (-7.30%), ICPA 2039 x ICPL 88034 (-6.85%), ICPA 2156 x ICPL 161 (-6.58%), ICPA 2089 x ICPL 92047 (-6.44%), ICPA 2089 x ICPL 81-3 (-6.36%), ICPA 2089 x ICPL 161 (-5.76%), ICPA 2039 x ICPL 88039 (-5.63%) and ICPA 2089 x ICPL 149 (-5.44%) showed highest significant negative heterobeltiosis. Maximum significant positive heterobeltiosis is manifested by ICPA 2156 x ICPL 88039 (14.93%) followed by ICPA 2039 x ICPL 90048 (7.79%) for the trait days to 50% flowering.

4.3.1.3 Pollen fertility (%)

The heterobeltiosis range of -13.43 to 0.92 per cent was observed for this character. Out of 27 crosses, none of the crosses showed significant positive heterobeltiosis for this character. For this trait, maximum significant negative heterobeltiosis was recorded by ICPA 2039 x ICPL 89 (-13.43%) followed by ICPA 2089 x ICPL 161 (-13.13%).

4.3.1.4 Days to maturity

Heterosis over better parent ranged from -8.10 to 18.71 per cent. Out of the 27 crosses, ICPA 2039 x ICPL 88034 (-8.10%) and ICPA 2089 x ICPL 88034 (-7.85%) showed highest negative significant heterobeltiosis for days to maturity. Maximum significant positive heterobeltiosis was shown by ICPA 2156 x ICPL 88039 (18.71%) followed by ICPA 2156 x ICPL 86022 (13.25%) for the trait days to maturity.

4.3.1.5 Number of primary branches per plant

Heterobeltiosis for number of primary branches per plant ranged from -18.26 to 22.50 per cent. Out of 27 crosses, the crosses ICPA 2039 x ICPL 90048 (22.50%) and ICPA 2039 x ICPL 81-3 (19.67%) recorded positive significant heterobeltiosis for this trait. Maximum significant negative heterobeltiosis was observed for ICPA 2089 x ICPL 88034 (-18.26%) followed by ICPA 2039 x ICPL 88034 (-16.80%) and ICPA 2156 x ICPL 88034 (-16.61%) for the character number of primary branches per plant.

4.3.1.6 Number of secondary branches per plant

For the trait number of secondary branches, heterobeltiosis ranged from -13.22 to 20.04 per cent. Out of 27 crosses, the crosses ICPA 2156 x ICPL 88034 (20.04%), ICPA 2039 x ICPL 90048 (13.81%) and ICPA 2089 x ICPL 161 (13.32%) have recorded maximum positive significant heterobeltiosis for this trait. The significant negative heterobeltiosis is shown by the cross ICPA 2156 x ICPL 90048 (-13.22%) for the trait number of secondary branches per plant.

Table 4.3.1 contd….

Sr.No	Crosses	Plant height (cm)	Days to 50 per cent flowering	Pollen fertility (%)	Days to maturity	No. of primary branches per plant	No. of secondary branches per plant	No. of pods per plant	No. of seeds per pod	100 seed wt. (g)	Grain yield Per Plant (g)	Harvest Index
17	ICPA 2089 x ICPL 86022	3.55	5.88*	-1.27	4.41	-5.77	-6.08	-23.96**	-14.62**	1.65	-6.67	-0.24
18	ICPA 2089 x ICPL 92047	-5.91	-6.44*	-12.92**	0	-7.18	-10.08	-7.4	-13.08**	2.82	-12.57	2.27
19	ICPA 2156 x ICPL 88034	12.62**	-8.87*	-6.26**	-4.81	-16.61**	20.04**	-12.59*	0.89	2.48	-14.72	-24.10**
20	ICPA 2156 x ICPL 88039	-0.25	14.93**	-12.44**	18.71**	-4.69	-8.22	-16.34**	7.14	-8.47*	-18.96**	3.31
21	ICPA 2156 x ICPL 149	4.89	-4.18	-0.03	2.13	-3.08	-9.01	-32.05**	0	5.7	-32.54**	14.5
22	ICPA 2156 x ICPL 161	-3.95	-6.58**	-0.37	-1.58	5.03	5.71	-51.09**	0	-3.36	-55.53**	-1.91
23	ICPA 2156 x ICPL 81-3	2.94	-3.39	-2.88	-1.06	0.33	2.25	-44.03**	0.88	14.10**	-35.31**	-0.57
24	ICPA 2156 x ICPL 89	0.75	-1.4	0.05	5.11	5.96	-0.17	9.81	2.68	16.24**	21.55*	-40.52**
25	ICPA 2156 x ICPL 90048	3.24	-2.3	-4.75**	0.82	8.01	-13.22*	16.34*	5	4.25	0.63	23.36**
26	ICPA 2156 x ICPL 86022	7.23	3.98	-1.17	13.25**	-1.69	-10.39	25.63*	-4.42	0.83	47.50**	-8.44
27	ICPA 2156 x ICPL 92047	6.05	-7.30**	-5.44**	-2.63	-5.71	-9.61	-3.48	-4.46	-4.84	0.4	14.85
	SE (d) ±	5.49	1.92	1.67	3.61	0.76	1.21	9.58	0.16	0.37	4.53	3.15
	CD at 5 %	11.01	3.84	3.35	7.25	1.51	2.42	19.22	0.32	0.74	9.08	6.31
	CD at 1 %	14.67	5.12	4.46	9.66	2.02	3.22	25.6	0.43	0.98	12.1	8.41

* - Significant at 5 % level of significance ** - Significant at 1 % level of significance

4.3.1.7 Number of pods per plant

The heterobeltiosis range of -51.09 to 64.68 per cent was observed for this character. Out of 27 crosses, the crosses ICPA 2039 x ICPL 90048 (64.68%), ICPA 2039 x ICPL 88034 (45.37%), ICPA 2039 x ICPL 92047 (36.07%), ICPA 2039 x ICPL 161 (30.61%), ICPA 2156 x ICPL 86022 (25.63%), ICPA 2089 x ICPL88034 (21.50%), ICPA 2089 x ICPL 89 (21.48%), ICPA 2156 x ICPL 90048 (16.34%) and ICPA 2039 x ICPL 149(12.02%) exhibited positive significant heterobeltiosis. Maximum significant negative heterobeltiosis is manifested by ICPA 2156 x ICPL 161 (-51.09%) followed by ICPA 2156 x ICPL 81-3 (-44.03%) for the trait number of pods per plant.

4.3.1.8 Number of seeds per pod

The heterobeltiosis range of -19.23 to 7.14 per cent was observed for this character. Out of 27 crosses, none of the crosses showed significant positive heterobeltiosis for this character. Maximum significant negative heterobeltiosis is exhibited by ICPA 2089 x ICPL 88034 (-19.23%) followed by ICPA 2089 x ICPL 86022 (-14.62%) for the trait number of seeds per pod.

4.3.1.9 100 seed weight (g)

For 100 seed weight trait, heterobeltiosis ranged from -18.64 to 16.24 per cent. The crosses ICPA 2156 x ICPL 89 (16.24%) and ICPA 2156 x ICPL 81-3 (14.10%) exhibited significant positive heterobeltiosis out of twenty seven crosses. Maximum significant negative heterobeltiosis was recorded by ICPA 2039 x ICPL 88039 (-18.64%) followed by ICPA 2089 x ICPL 88039 (-17.63%) for the trait 100 seed weight.

4.3.1.10 Grain yield per plant (g)

Yield is a complex trait and end product of a number of components most of which are under polygenic control. Heterobeltiosis for the important character like grain yield per plant ranged from -55.53 to 83.25 per cent. Out of 27 crosses, nine crosses expressed significant and positive heterobeltiosis. Significant positive heterobeltiosis was observed in crosses ICPA 2039 x ICPL 90048 (83.25%), ICPA 2156 x ICPL86022 (47.50%), ICPA 2039 x ICPL88034 (40.84%), ICPA 2089 x ICPL 89 (39.66%), ICPA 2039 x ICPL 161 (32.76%), ICPA 2156 x ICPL 89 (21.55%), ICPA 2039 x ICPL 92047

(21.47%), ICPA 2039 x ICPL 149 (21.10%) and ICPA 2089 x ICPL 88034 (17.18%). Maximum significant negative heterobeltiosis is exhibited by the cross ICPA 2156 x ICPL 161 (-55.53%) followed by ICPA 2089 x ICPL 161 (-43.25%) for the trait grain yield per plant.

4.3.1.11 Harvest Index (%)

For harvest index (%), heterobeltiosis ranged from -40.52 to 36.99 per cent. Among 27 crosses, the crosses ICPA 2089 x ICPL 88039 (36.99%), ICPA 2156 x ICPL 90048 (23.36%) manifested significant positive heterobeltiosis. Maximum significant negative heterobeltiosis is exhibited by ICPA 2156 x ICPL 89 (-40.52%) followed by ICPA 2039 x ICPL 89 (-36.33%) for the trait harvest index.

4.3.2 Standard heterosis estimated over the checks VL Arhar1, ICPL 161 and ICPH 2433:

The percentage of standard heterosis over the checks VL Arhar1, ICPL 161 and ICPH 2433 for the characters studied is presented in Table 4.3.2

4.3.2.1 Plant height (cm)

The standard heterosis range over VL Arhar1 is -5.44 to 32.72 per cent for the trait plant height. Out of 27 crosses, the crosses ICPA 2039 x ICPL 149 (32.72%), ICPA 2039 x ICPL 161 (24.70%), ICPA 2039 x ICPL 81-3 (23.48%), ICPA 2039 x ICPL 92047 (21.54%), ICPA 2089 x ICPL 149 (19.11%), ICPA 2039 x ICPL 88034 (10.84%), ICPA 2156 x ICPL 88034 (10.60%), ICPA 2156 x ICPL 81-3 (10.60%), ICPA 2039 x ICPL 89 (9.38%) and ICPA 2156 x ICPL 92047 (9.04%) showed significant positive heterosis over VL Arhar1 for plant height trait . None of the crosses exhibited significant negative heterosis over the check VL Arhar1 for plant height.

The range of standard heterosis over ICPL 161 is -9.53 to 26.98 per cent for the trait plant height. Out of 27 crosses, the crosses ICPA 2039 x ICPL 149 (26.98%), ICPA 2039 x ICPL 161 (19.30%), ICPA 2039 x ICPL 81-3 (18.14%), ICPA 2039 x ICPL 92047 (16.28%) and ICPA 2089 x ICPL 88039 (13.95%) recorded significant positive heterosis over ICPL 161 for plant height trait. The cross ICPA 2089 x ICPL 89 (-9.53%) exhibited maximum significant negative heterosis over ICPL 161 for plant height trait.

For the trait plant height (cm) standard heterosis over ICPH 2433 ranged from -21.73 to 9.86 per cent for the trait plant height. Out of 27 crosses, the cross ICPA 2039 x ICPL 149 (9.86%) manifested significant positive heterosis over ICPH 2433 for plant height trait. The cross ICPA 2089 x ICPL 89 (-21.73%) showed maximum significant negative heterosis over ICPH 2433 for plant height trait.

4.3.2.2 Days to 50 % flowering

For this trait negative heterosis is desirable. The standard heterosis range over VL Arhar1 is 10 to 33.16 per cent for the trait days to 50 per cent flowering. Out of 27 crosses, the crosses ICPA 2039 x ICPL 81-3 (33.16%) and ICPA 2039 x ICPL 149 (32.63%) manifested significant positive heterosis over VL Arhar1 for days to 50 per cent flowering trait. None of the crosses exhibited significant negative heterosis over VL Arhar1 for days to 50 per cent flowering trait.

The standard heterosis range over ICPL 161 is -17.39 to 0 per cent for the trait days to 50 per cent flowering. Out of 27 crosses, none of the crosses showed significant positive heterosis over ICPL 161 for days to 50 per cent flowering trait. The crosses ICPA 2089 x ICPL 88039 (-17.39%), ICPA 2156 x ICPL 86022 (-17.39%), ICPA 2156 x ICPL 89 (-16.21%) and ICPA 2156 x ICPL 90048 (-16.21%) registered maximum significant negative heterosis over ICPL 161 for days to 50 per cent flowering trait.

The range of standard heterosis over ICPH 2433 is -17.39 to 0 per cent for the trait days to 50 per cent flowering. Out of 27 crosses, none of the crosses recorded significant positive heterosis over ICPH 2433 for days to 50 per cent flowering trait. The crosses ICPA 2089 x ICPL 88039 (-17.39%), ICPA 2156 x ICPL 86022 (-17.39%), ICPA 2156 x ICPL 89 (-16.21%) and ICPA 2156 x ICPL 90048 (-16.21%) showed maximum significant negative heterosis over ICPH 2433 for days to 50 per cent flowering trait.

Table 4.3.2. Estimation of standard heterosis over VL Arhar1, ICPL 161, ICPH2433

Sr. No.	Crosses	Plant height (cm)			Days to 50 % flowering			Pollen fertility (%)			Days to maturity		
		SC1	SC2	SC3	SC1	SC2	SC3	SC1	SC2	SC3	SC1	SC2	SC3
1	ICPA2039 x ICPL88034	10.84**	6.05	-8.25*	21.58**	-8.70**	-8.70**	-1.19	-2.05	0.69	15.24**	-9.48**	-9.70**
2	ICPA2039 x ICPL88039	5.49	0.93	-12.68**	14.74**	-13.83**	-13.83**	0.78	-0.10	2.69	13.02**	-11.22**	-11.44**
3	ICPA2039 x ICPL149	32.72**	26.98**	9.86**	32.63**	-0.40	-0.40	0.14	-0.74	2.04	28.57**	1.00	0.75
4	ICPA2039 x ICPL161	24.70**	19.30**	3.22	31.05**	-1.58	-1.58	-4.30*	-5.14**	-2.48	25.71**	-1.25	-1.49
5	ICPA2039 x ICPL81-3	23.48**	18.14**	2.21	33.16**	0.00	0.00	0.58	-0.30	2.48	26.98**	-0.25	-0.50
6	ICPA2039 x ICPL89	9.38*	4.65	-9.46**	26.32**	-5.14*	-5.14*	-12.70**	-13.46**	-11.04**	23.49**	-2.99	-3.23
7	ICPA2039 x ICPL90048	6.37	1.77	-11.95**	31.05**	-1.58	-1.58	-2.27	-3.12	-0.41	27.30**	0.00	-0.25
8	ICPA2039 x ICPL86022	3.55	-0.93	-14.29**	19.47**	-10.28**	-10.28**	-1.05	-1.91	0.83	20.63**	-5.24	-5.47*
9	ICPA2039 x ICPL92047	21.54**	16.28**	0.60	26.32**	-5.14*	-5.14*	0.88	0.00	2.80	20.63**	-5.24	-5.47*
10	ICPA2089 x ICPL88034	1.60	-2.79	-15.90**	14.21**	-14.23**	-14.23**	-2.88	-3.73*	-1.04	15.56**	-9.23**	-9.45**
11	ICPA2089 x ICPL88039	-4.33	-8.47*	-20.80**	10.00**	-17.39**	-17.39**	-3.79*	-4.63**	-1.97	14.92**	-9.73**	-9.95**
12	ICPA2089 x ICPL149	19.11**	13.95**	-1.41	18.95**	-10.67**	-10.67**	-4.40*	-5.24**	-2.59	14.92**	-9.73**	-9.95**
13	ICPA2089 x ICPL161	1.60	-2.79	-15.90**	20.53**	-9.49**	-9.49**	-12.43**	-13.19**	-10.77**	21.90**	-4.24	-4.48
14	ICPA2089 x ICPL81-3	6.71	2.09	-11.67**	16.32**	-12.65**	-12.65**	-12.02**	-12.79**	-10.35**	17.46**	-7.73**	-7.96**
15	ICPA2089 x ICPL89	-5.44	-9.53*	-21.73**	15.79**	-13.04**	-13.04**	-10.23**	-11.01**	-8.52**	16.19**	-8.73**	-8.96**
16	ICPA2089 x ICPL90048	2.33	-2.09	-15.29**	13.68**	-14.62**	-14.62**	-4.03*	-4.87**	-2.21	20.95**	-4.99	-5.22
17	ICPA2089 x ICPL86022	-0.83	-5.12	-17.91**	13.68**	-14.62**	-14.62**	-0.10	-0.97	1.79	12.70**	-11.47**	-11.69**
18	ICPA2089 x ICPL92047	-3.26	-7.44	-19.92**	14.74**	-13.83**	-13.83**	-11.68**	-12.45**	-10.01**	20.63**	-5.24	-5.47*
19	ICPA2156 x ICPL88034	10.60*	5.81	-8.45*	18.95**	-10.67**	-10.67**	-5.15**	-5.98**	-3.35	19.37**	-6.23*	-6.47*
20	ICPA2156 x ICPL88039	-2.77	-6.98	-19.52**	21.58**	-8.70**	-8.70**	-12.56**	-13.33**	-10.90**	22.86**	-3.49	-3.73
21	ICPA2156 x ICPL149	4.28	-0.23	-13.68**	20.53**	-9.49**	-9.49**	0.00	-0.87	1.90	21.59**	-4.49	-4.73
22	ICPA2156 x ICPL161	6.47	1.86	-11.87**	19.47**	-10.28**	-10.28**	0.44	-0.44	2.35	18.73**	-6.73*	-6.97*
23	ICPA2156 x ICPL81-3	10.60*	5.81	-8.45*	20.00**	-9.88**	-9.88**	-1.86	-2.72	0.00	18.10**	-7.23**	-7.46**
24	ICPA2156 x ICPL89	-1.80	-6.05	-18.71**	11.58**	-16.21**	-16.21**	0.90	0.02	2.82	17.46**	-7.73**	-7.96**
25	ICPA2156 x ICPL90048	0.63	-3.72	-16.70**	11.58**	-16.21**	-16.21**	-3.49*	-4.33*	-1.66	17.14**	-7.98**	-8.21**
26	ICPA2156 x ICPL86022	4.52	0.00	-13.48**	10.00**	-17.39**	-17.39**	0.00	-0.87	1.90	19.37**	-6.23*	-6.47*
27	ICPA2156 x ICPL92047	9.04*	4.33	-9.74**	13.68**	-14.62**	-14.62**	-4.10*	-4.93**	-2.28	17.46**	-7.73**	-7.96**
	SE (d) ±	5.48	5.48	5.48	1.91	1.91	1.91	1.67	1.67	1.67	3.61	3.61	3.61
	CD at 5 %	11.01	11.01	11.01	3.84	3.84	3.84	3.35	3.35	3.35	7.25	7.25	7.25
	CD at 1 %	14.68	14.68	14.68	5.12	5.12	5.12	4.45	4.45	4.45	9.65	9.65	9.65

Table 4.3.2. contd…

Sr. No.	Crosses	No.of primary branches per plant			No.of secondary branches per plant			No. of pods per plant			No. of seeds per pod		
		SC1	SC2	SC3	SC1	SC2	SC3	SC1	SC2	SC3	SC1	SC2	SC3
1	ICPA2039 x ICPL88034	-5.03	2.37	-2.58	0.50	3.07	-5.63	56.84**	-5.23	-26.23**	-5.00	3.64	-0.87
2	ICPA2039 x ICPL88039	-5.35	2.03	-2.90	10.98	13.82*	4.22	1.50	-38.67**	-52.27**	-5.00	3.64	-0.87
3	ICPA2039 x ICPL149	-4.40	3.05	-1.94	-1.16	1.37	-7.19	75.42**	5.99*	-17.50**	-6.67	1.82	-2.61
4	ICPA2039 x ICPL161	-2.52	5.08	0.00	7.32	10.07	0.78	126.33**	36.76**	6.45**	-5.83	2.73	-1.74
5	ICPA2039 x ICPL81-3	12.89	21.69**	15.81*	4.33	7.00	-2.03	25.42**	-24.22**	-41.02**	-7.50	0.91	-3.48
6	ICPA2039 x ICPL89	-2.83	4.75	-0.32	7.82	10.58	1.25	-5.66	-43.00**	-55.63**	-6.67	1.82	-2.61
7	ICPA2039 x ICPL90048	6.32	14.61	9.06	11.73	14.59*	4.92	77.67**	7.36*	-16.44**	-6.67	1.82	-2.61
8	ICPA2039 x ICPL86022	-7.08	0.17	-4.68	0.83	3.41	-5.31	-7.38	-44.03**	-56.44**	-5.00	3.64	-0.87
9	ICPA2039 x ICPL92047	-5.35	2.03	-2.90	-1.00	1.54	-7.03	46.81**	-11.29**	-30.95**	-5.83	2.73	-1.74
10	ICPA2089 x ICPL88034	-6.70	0.58	-4.29	4.49	7.17	-1.88	11.06*	-32.89**	-47.77**	-12.50**	-4.55	-8.70*
11	ICPA2089 x ICPL88039	-7.89	-0.71	-5.52	-0.25	2.30	-6.33	-9.14	-45.10**	-57.27**	3.33	12.73**	7.83
12	ICPA2089 x ICPL149	-5.50	1.86	-3.06	1.16	3.75	-5.00	22.26**	-26.13**	-42.50**	0.00	9.09*	4.35
13	ICPA2089 x ICPL161	-5.57	1.80	-3.13	8.99	11.77	2.34	2.72	-37.94**	-51.69**	-5.83	2.73	-1.74
14	ICPA2089 x ICPL81-3	-5.63	1.73	-3.19	6.57	9.30	0.08	21.53**	-26.57**	-42.84**	-5.00	3.64	-0.87
15	ICPA2089 x ICPL89	0.94	8.81	3.55	4.08	6.74	-2.27	-17.13**	-49.92**	-61.02**	-5.83	2.73	-1.74
16	ICPA2089 x ICPL90048	-7.04	0.20	-4.65	3.19	5.84	-3.09	-30.33**	-57.90**	-67.23**	-4.17	4.55	0.00
17	ICPA2089 x ICPL86022	-5.47	1.90	-3.03	-9.48	-7.17	-15.00*	-38.49**	-62.83**	-71.07**	-7.50	0.91	-3.48
18	ICPA2089 x ICPL92047	-6.89	0.37	-4.48	-3.49	-1.02	-9.38	-1.83	-40.68**	-53.83**	-5.83	2.73	-1.74
19	ICPA2156 x ICPL88034	-4.81	2.61	-2.35	13.64*	16.55**	6.72	-20.10**	-51.72**	-62.42**	-5.83	2.73	-1.74
20	ICPA2156 x ICPL88039	-7.39	-0.17	-5.00	-8.99	-6.66	-14.53*	-17.31**	-50.04**	-61.11**	0.00	9.09*	4.35
21	ICPA2156 x ICPL149	-7.96	-0.78	-5.58	-14.31*	-12.12	-19.53**	6.41	-35.70**	-49.95**	-6.67	1.82	-2.61
22	ICPA2156 x ICPL161	-0.25	7.53	2.32	1.66	4.27	-4.53	-15.25**	-48.79**	-60.14**	-6.67	1.82	-2.61
23	ICPA2156 x ICPL81-3	-4.72	2.71	-2.26	-1.66	0.85	-7.66	-19.60**	-51.42**	-62.19**	-5.00	3.64	-0.87
24	ICPA2156 x ICPL89	0.63	8.47	3.23	-3.16	-0.68	-9.06	-25.08**	-54.73**	-64.77**	-4.17	4.55	0.00
25	ICPA2156 x ICPL90048	2.58	10.58	5.23	-14.81*	-12.63*	-20.00**	-19.45**	-51.33**	-62.12**	5.00	14.55**	9.57*
26	ICPA2156 x ICPL86022	-6.64	0.64	-4.23	-13.64*	-11.43	-18.91**	1.63	-38.59**	-52.20**	-10.00*	-1.82	-6.09
27	ICPA2156 x ICPL92047	-7.48	-0.27	-5.10	-3.00	-0.51	-8.91	2.33	-38.17**	-51.88**	-10.83**	-2.73	-6.96
	SE (d) ±	0.75	0.75	0.75	1.21	1.21	1.21	9.57	9.57	9.57	0.16	0.16	0.16
	CD at 5 %	1.51	1.51	1.51	2.41	2.41	2.41	19.21	19.21	19.21	0.32	0.32	0.32
	CD at 1 %	2.02	2.02	2.02	3.22	3.22	3.22	25.60	25.60	25.60	0.43	0.43	0.43

Table 4.3.2. contd…

Sr. No.	Crosses	100 Seed weight			Grain yield per plant (g)			Harvest Index (%)		
		SC1	SC2	SC3	SC1	SC2	SC3	SC1	SC2	SC3
1	ICPA 2039 x ICPL 88034	-17.06**	2.10	-0.41	27.29**	-6.43	-10.28*	-3.20	-33.61**	-27.15**
2	ICPA 2039 x ICPL 88039	-18.09**	0.84	-1.64	-9.62	-33.57**	-36.3	21.30	-16.81*	-8.72
3	ICPA 2039 x ICPL 149	-14.68**	5.04	2.46	45.27**	6.78	2.39	25.36*	-14.02	-5.66
4	ICPA 2039 x ICPL 161	-16.38**	2.94	0.41	89.28**	39.13**	33.41**	22.97*	-15.67*	-7.46
5	ICPA 2039 x ICPL 81-3	-13.65**	6.30	3.69	4.58	-23.13**	-26.29**	8.83	-25.36**	-18.10*
6	ICPA 2039 x ICPL 89	-20.48**	-2.10	-4.51	-29.49**	-48.17**	-50.31**	-9.11	-37.66**	-31.60**
7	ICPA 2039 x ICPL 90048	-7.51	13.87**	11.07*	65.62**	21.74**	16.73**	12.59	-22.79**	-15.27
8	ICPA 2039 x ICPL 86022	-19.80**	-1.26	-3.69	-32.10**	-50.09**	-52.14**	44.49**	-0.91	8.73
9	ICPA 2039 x ICPL 92047	-24.57**	-7.14	-9.43*	9.78	-19.30**	-22.62**	-4.96	-34.82**	-28.48**
10	ICPA 2089 x ICPL 88034	-15.02**	4.62	2.05	-9.62	-33.57**	-36.30**	13.63	-22.07**	-14.49
11	ICPA 2089 x ICPL 88039	-17.06**	2.10	-0.41	-14.83*	-37.39**	-39.97**	44.51**	-0.89	8.75
12	ICPA 2089 x ICPL 149	-24.23**	-6.72	-9.02	-10.57	-34.26**	-36.96**	20.72	-17.21*	-9.15
13	ICPA 2089 x ICPL 161	-25.60**	-8.40	-10.66*	-19.08**	-40.52**	-42.97**	32.55**	-9.10	-0.25
14	ICPA 2089 x ICPL 81-3	-16.72**	2.52	0.00	5.05	-22.78**	-25.96**	25.16*	-14.16	-5.81
15	ICPA 2089 x ICPL 89	-14.68**	5.04	2.46	-23.34**	-43.65**	-45.97**	55.48**	6.63	17.00*
16	ICPA 2089 x ICPL 90048	-8.19*	13.03**	10.25*	-29.26**	-48.00**	-50.14**	-19.92	-45.08**	-39.73**
17	ICPA 2089 x ICPL 86022	-16.04**	3.36	0.82	-47.00**	-61.04**	-62.65**	23.35*	-15.41*	-7.17
18	ICPA 2089 x ICPL 92047	-12.97**	7.14	4.51	-27.60**	-46.78**	-48.97**	34.86**	-7.51	1.49
19	ICPA 2156 x ICPL 88034	-15.36**	4.20	1.64	-34.23**	-51.65**	-53.64**	-0.89	-32.03**	-25.41**
20	ICPA 2156 x ICPL 88039	-7.85*	13.45**	10.66*	-19.08**	-40.52**	-42.97**	34.90**	-7.49	1.51
21	ICPA 2156 x ICPL 149	-17.75**	1.26	-1.23	-19.08**	-40.52**	-42.97**	49.51**	2.53	12.51
22	ICPA 2156 x ICPL 161	-21.50**	-3.36	-5.74	-36.59**	-53.39**	-55.31**	43.35**	-1.69	7.88
23	ICPA 2156 x ICPL 81-3	-8.87*	12.18*	9.43*	-25.28**	-45.08**	-47.34**	40.41**	-3.70	5.67
24	ICPA 2156 x ICPL 89	-7.17	14.29**	11.48*	-33.28**	-50.96**	-52.97**	-15.1	-41.77**	-36.11**
25	ICPA 2156 x ICPL 90048	-7.85*	13.45**	10.66*	-24.29**	-44.35**	-46.64**	61.08**	10.47	21.22*
26	ICPA 2156 x ICPL 86022	-16.72**	2.52	0.00	-16.24*	-38.43**	-40.97**	19.55	-18.01*	-10.03
27	ICPA 2156 x ICPL 92047	-19.45**	-0.84	-3.28	-16.86*	-38.89**	-41.40**	51.45**	3.87	13.97
	SE (d) ±	0.37	0.37	0.37	4.52	4.52	4.52	3.14	3.14	3.14
	CD at 5 %	0.73	0.73	0.73	9.08	9.08	9.08	6.31	6.31	6.31
	CD at 1 %	0.98	0.98	0.98	12.1	12.1	12.1	8.41	8.41	8.41

4.3.2.3 Pollen fertility (%)

For the trait pollen fertility (%) the standard heterosis over VL Arhar1 ranged from -12.70 to 0.90 per cent for the trait pollen fertility. Out of 27 crosses, none of the crosses exhibited significant positive heterosis over this check. The cross ICPA 2039 x ICPL 89 (-12.70%) showed significant negative heterosis over the check VL Arhar1 for the trait pollen fertility (%).

Over ICPL 161, the standard heterosis ranged from -13.46 to 0.02 per cent for the trait pollen fertility. Out of 27 crosses, none of the crosses had shown significant positive heterosis over this check. The cross ICPA 2039 x ICPL 89 (-13.46%) registered significant negative heterosis over the check ICPL 161 for the trait pollen fertility (%).

The standard heterosis range over ICPH 2433 is -11.04 to 2.82 per cent for the trait pollen fertility. Out of 27 crosses, none of the crosses recorded significant positive heterosis over this check. The cross ICPA 2039 x ICPL 89 (-11.04%) exhibited significant negative heterosis over the check ICPH 2433 for the trait pollen fertility (%).

4.3.2.4 Days to maturity

For this trait negative heterosis is desirable. The standard heterosis range over VL Arhar1 is 12.70 to 28.57 per cent for the trait days to maturity. Out of 27 crosses, the crosses ICPA 2039 x ICPL 149 (28.57%) and ICPA 2039 x ICPL 81-3 (26.98%) showed significant positive heterosis over VL Arhar1 for days to maturity trait. No crosses exhibited significant negative heterosis over VL Arhar1 for days to maturity trait.

The range of standard heterosis is -11.47 to 1 per cent over ICPL 161 for the trait days to maturity. Out of 27 crosses, none of the crosses exhibited significant positive heterosis over ICPL 161 for days to maturity trait. The crosses ICPA 2089 x ICPL 86022 (-11.47%), ICPA 2039 x ICPL 88039(-11.22%), ICPA 2089 x ICPL 88039 (-9.73%), ICPA 2089 x ICPL 149 (-9.73%), ICPA 2039 x ICPL 88034 (-9.48%), ICPA 2089 x ICPL 88034 (-9.23%), ICPA 2089 x ICPL 89 (-8.73%), ICPA 2156 x ICPL 90048 (-7.98%), ICPA 2156 x ICPL 92047 (-7.73%), ICPA 2156 x ICPL 89 (-7.73%), ICPA 2089 x ICPL 81-3 (-7.73%), ICPA 2156 x ICPL 81-3 (-7.23%), ICPA 2156 x ICPL 161

(-6.73%), ICPA 2156 x ICPL 88034 (-6.23%) and ICPA 2156 x ICPL 86022 (-6.23%) registered significant negative heterosis over ICPL 161 for days to maturity trait.

Over ICPH 2433 the range of standard heterosis is -11.69 to 0.75 per cent for the trait days to maturity. Out of 27 crosses, none of the crosses showed significant positive heterosis over ICPH 2433 for days to maturity trait. The crosses ICPA 2089 x ICPL 86022 (-11.69%), ICPA 2039 x ICPL 88039(-11.44%), ICPA 2089 x ICPL 88039 (-9.95%), ICPA 2089 x ICPL 149 (-9.95%), ICPA 2039 x ICPL 88034 (-9.70%), ICPA 2089 x ICPL 88034 (-9.45%), ICPA 2089 x ICPL 89 (-8.96%), ICPA 2156 x ICPL 90048 (-8.21%), ICPA 2156 x ICPL 92047 (-7.96%), ICPA 2156 x ICPL 89 (-7.96%), ICPA 2089 x ICPL 81-3 (-7.96%), ICPA 2156 x ICPL 81-3 (-7.46%), ICPA 2156 x ICPL 161 (-6.97%), ICPA 2156 x ICPL 88034 (-6.47%), ICPA 2156 x ICPL 86022 (-6.47%), ICPA 2039 x ICPL 86022 (-5.47%), ICPA 2039 x ICPL 92047 (-5.47%) and ICPA 2089 x ICPL 92047 (-5.47%) exhibited significant negative heterosis over ICPH 2433 for days to maturity trait.

4.3.2.5 Number of primary branches per plant

The standard heterosis over high yielding standard checks VL Arhar1, ICPL 161 and ICPH 2433 ranged from -7.96 to 12.89 per cent, -0.78 to 21.69 per cent and -5.58 to 15.81 per cent respectively. None of the crosses recorded significant positive heterosis over check VL Arhar1. Over ICPL 161, the cross ICPA 2039 x ICPL 81-3 (21.69%) showed significant positive heterosis for the trait number of primary branches per plant. Over ICPH 2433, the cross ICPA 2039 x ICPL 81-3 (15.81%) exhibited significant positive heterosis for the trait number of primary branches per plant.

4.3.2.6 Number of secondary branches per plant

For the trait number of secondary branches per plant, standard heterosis range over VL Arhar1 is -14.81 to 13.64 per cent. Out of 27 crosses, the cross ICPA 2156 x ICPL 88034 (13.64%) exhibited significant positive heterosis over this check. The crosses ICPA 2156 x ICPL 90048 (-14.81%), ICPA 2156 x ICPL 149 (-14.31%), ICPA 2156 x ICPL 86022 (-13.64%) and ICPA 2156 x ICPL 88034 (-13.64%) exhibited significant negative heterosis over the check VL Arhar1 for the trait number of secondary branches per plant.

Over ICPL 161, the standard heterosis range is -12.63 to 16.55 per cent for the trait number of secondary branches per plant. Out of 27 crosses, the crosses ICPA 2156 x ICPL 88034 (16.55%), ICPA 2039 x ICPL 90048 (14.59%) and ICPA 2039 x ICPL 88039 (13.82%) manifested significant positive heterosis over this check. The cross ICPA 2156 x ICPL 90048 (-12.63%) registered significant negative heterosis over the check ICPL 161 for the trait number of secondary branches per plant.

The range of standard heterosis over ICPH 2433 is -20.00 to 6.72 per cent for the trait number of secondary branches per plant. Out of 27 crosses, none of the crosses exhibited significant positive heterosis over this check. The crosses ICPA 2156 x ICPL 90048 (-20.00), ICPA 2156 x ICPL 149 (-19.53%), ICPA 2156 x ICPL 86022 (-18.91%), ICPA 2089 x ICPL 86022 (-15.00%) and ICPA 2156 x ICPL 88039 (-14.53%) showed significant negative heterosis over the check ICPH 2433 for the trait number of secondary branches per plant.

4.3.2.7 Number of pods per plant

For the important trait number of pods per plant the standard heterosis range over VL Arhar1 is -38.49 to 126.33 per cent. Out of 27 crosses, the cross ICPA 2039 x ICPL 161 (126.33%), ICPA 2039 x ICPL 90048 (77.67%), ICPA 2039 x ICPL 149 (75.42%), ICPA 2039 x ICPL 88034 (56.84%), ICPA 2039 x ICPL 92047 (46.81%), ICPA 2039 x ICPL 81-3 (25.42%), ICPA 2089 x ICPL 149 (22.26%), ICPA 2089 x ICPL 81-3 (21.53%) and ICPA 2089 x ICPL 88034 (11.06%) exhibited significant positive heterosis over this check.The crosses ICPA 2089 x ICPL 86022 (-38.49%), ICPA 2089 x ICPL 90048 (-30.33%), ICPA 2156 x ICPL 89 (-25.08%), ICPA 2156 x ICPL 88034 (-20.10%), ICPA 2156 x ICPL 81-3 (-19.60%), ICPA 2156 x ICPL 90048 (-19.45%), ICPA 2156 x ICPL 88039 (-17.31%), ICPA 2089 x ICPL 89 (-17.13%) and ICPA 2156 x ICPL 161 (-15.25%) were with significant negative heterosis over the check VL Arhar1 for the trait number of pods per plant.

The heterosis range of -62.83 to 36.76 per cent is shown by the crosses for the trait number of pods per plant over ICPL 161. Out of 27 crosses, the crosses ICPA 2039 x ICPL 161 (36.76%), ICPA 2039 x ICPL 90048 (7.36%) and ICPA 2039 x ICPL 149 (5.99%) recorded significant positive heterosis over this check. Maximum significant negative heterosis over the check ICPL 161 for the trait number of secondary branches per plant is exhibited by ICPA 2089 x ICPL 86022 (-62.83%).

The standard heterosis range over ICPH 2433 is -71.07 to 6.45 per cent for the trait number of pods per plant. Out of 27 crosses, only one cross ICPA 2039 x ICPL 161 (6.45%) registered significant positive heterosis over this check. The rest of the crosses exhibited negative heterosis. The cross ICPA 2089 x ICPL 86022 (-71.07%) showed maximum significant negative heterosis over the check ICPH 2433 for the trait number of pods per plant.

4.3.2.8 Number of seeds per pod

Over VL Arhar1, the standard heterosis range is -12.50 to 5.00 per cent for the trait number of seeds per pod. Out of 27 crosses, no crosses exhibited significant positive heterosis over this check. The crosses ICPA 2089 x ICPL 88034 (-12.50%), ICPA 2156 x ICPL 92047 (-10.83%), ICPA 2156 x ICPL 86022 (-10.00%) recorded significant negative heterosis over the check VL Arhar1 for the trait number of seeds per pod.

For the trait number of seeds per pod the standard heterosis ranges from -4.55 to 14.55 per cent over ICPL 161. Out of 27 crosses, the crosses ICPA 2156 x ICPL 90048 (14.55%), ICPA 2089 x ICPL 88039 (12.73%), ICPA 2089 x ICPL 149 (9.09%) and ICPA 2156 x ICPL 88039 (9.09%) manifested significant positive heterosis over this check. None of the crosses exhibited significant negative heterosis over the check ICPL 161 for the trait number of seeds per pod.

The standard heterosis range over ICPH 2433 is -8.70 to 9.57 per cent for the trait number of seeds per pod. Out of 27 crosses, the cross ICPA 2156 x ICPL 90048 (9.57%) showed significant positive heterosis over this check. The cross ICPA 2089 x ICPL 88034 (-8.70%) exhibited significant negative heterosis over the check ICPH 2433 for the trait number of seeds per pod.

4.3.2.9 100 seed weight (g)

The standard heterosis over VL Arhar1 ranged from -25.60 to -7.17 per cent for the trait 100 seed weight. Out of 27 crosses, all the crosses showed significant negative heterosis over the check VL Arhar1 for the trait 100 seed weight. Maximum significant negative heterosis over VL Arhar1 for this trait is exhibited by ICPA 2089 x ICPL 161 (-25.60%).

For the trait 100 seed weight, standard heterosis range over ICPL 161 is -8.40 to 14.29 per cent. Out of 27 crosses, the crosses ICPA 2156 x ICPL 89 (14.29%), ICPA 2039 x ICPL 90048 (13.87%), ICPA 2156 x ICPL 88039 (13.45%), ICPA 2156 x ICPL 90048 (13.45%), ICPA 2089 x ICPL 90048 (13.03%) and ICPA2156 x ICPL 81-3 (12.18%) recorded significant positive heterosis over this check. None of the crosses had significant negative heterosis over the check ICPL 161 for the trait 100 seed weight.

Over ICPH 2433, the standard heterosis range is -10.66 to 11.48 per cent for the trait 100 seed weight. Out of 27 crosses, the crosses ICPA 2156 x ICPL 89 (11.48%), ICPA 2039 x ICPL 90048 (11.07%), ICPA 2156 x ICPL 88039 (10.66%), ICPA 2156 x ICPL 90048 (10.66%), ICPA 2089 x ICPL 90048 (10.25%) and ICPA 2156 x ICPL 81-3 (9.43%) manifested significant positive heterosis over this check. The crosses ICPA 2089 x ICPL 161 (-10.66%), ICPA 2039 x ICPL 92047 (-9.43%) exhibited significant negative heterosis over the check ICPH 2433 for the trait 100 seed weight.

4.3.2.10 Grain yield per plant (g)

Improvement in the grain yield per plant is the important breeding objective in any breeding programme. The standard heterosis range over VL Arhar1 is -47.00 to 89.28 per cent for the trait grain yield per plant. Out of 27 crosses, maximum significant positive heterosis over this check is exhibited by ICPA 2039 x ICPL 161 (89.28%), ICPA 2039 x ICPL 90048 (65.62%), ICPA 2039 x ICPL 149 (45.27%) and ICPA 2039 x ICPL 88034 (27.29%).The crosses ICPA 2089 x ICPL 86022 (-47.00%) recorded maximum significant negative heterosis over the check VL Arhar1 for the trait grain yield per plant followed by the cross ICPA 2156 x ICPL 161 (-36.59%).

Over ICPL 161, the standard heterosis ranged from -61.04 to 39.13 per cent for the trait grain yield per plant. Out of 27 crosses, the crosses ICPA 2039 x ICPL 161 (39.13%) manifested maximum significant positive heterosis over this check followed by ICPA 2039 x ICPL 90048 (21.74%).Maximum significant negative heterosis over the check ICPL 161 for this trait is showed by ICPA 2089 x ICPL 86022 (-61.04%) followed by ICPA 2156 x ICPL 161 (-53.39%).

For the trait grain yield per plant, standard heterosis range over ICPH 2433 is -62.65 to 33.41 per cent. Out of 27 crosses, maximum significant positive heterosis over this check is registered by ICPA 2039 x ICPL 161 (33.41%) followed by ICPA 2039 x ICPL 90048 (16.73%). Maximum significant negative heterosis over the check ICPH 2433 for the trait grain yield per plant is recorded by ICPA 2089 x ICPL 86022 (-62.25%) followed by ICPA 2156 x ICPL 161 (-55.31%).

4.3.2.11 Harvest Index (%)

The standard heterosis range over VL Arhar1 is -19.92 to 61.08 per cent for the trait harvest index. Out of 27 crosses, the crosses ICPA 2156 x ICPL 90048 (61.08%), ICPA 2089 x ICPL 89 (55.48%), ICPA 2156 x ICPL 92047 (51.45%), ICPA 2156 x ICPL 149 (49.51%), ICPA 2089 x ICPL 88039 (44.51%), ICPA 2039 x ICPL 86022 (44.49%), ICPA 2156 x ICPL 161 (43.35%), ICPA 2156 x ICPL 81-3 (40.41%), ICPA 2156 x ICPL 88039 (34.90%), ICPA 2089 x ICPL 92047 (34.86%), ICPA 2089 x ICPL 161 (32.55%), ICPA 2039 x ICPL 149 (25.36%), ICPA 2089 x ICPL 81-3 (25.16%), ICPA 2089 x ICPL 86022 (23.35%) and ICPA 2039 x ICPL 161 (22.97%) exhibited significant positive heterosis over this check. None of the crosses showed significant negative heterosis over the check VL Arhar1 for the trait harvest index.

The range of standard heterosis over ICPL 161 is -45.08 to 10.47 per cent for the trait harvest index. Out of 27 crosses, none of the crosses recorded significant positive heterosis over this check. Maximum significant negative heterosis over the check ICPL 161 for the trait harvest index is exhibited by ICPA 2089 x ICPL 90048 (-45.08%) followed by ICPA 2156 x ICPL 89 (-41.77%).

For the trait harvest index, standard heterosis range over ICPH 2433 is -39.73 to 21.22 per cent. Out of 27 crosses, none of the crosses registered significant positive heterosis over this check. All the crosses showed negative heterosis. The cross ICPA 2089 x ICPL 90048 (-39.73%) recorded maximum significant negative heterosis over the check ICPH 2433 for the trait harvest index followed by ICPA 2156 x ICPL 89 (-36.11%).

4.4 Line x tester analysis

Total of twenty seven crosses were developed by crossing three lines with nine testers. These twenty seven crosses were grown along with their parents. Data were collected for eleven characters. The data was analyzed following the line x tester design. The results obtained for eleven characters are presented in Table 4.4.1 below.

4.4.1 Analysis of variance for line x tester analysis

The analysis of variance (Line x tester) due to different sources for eleven characters is summarized in Table 4.4.1. The analysis of variance indicated that the differences due to crosses were significant for all of the characters except number of primary branches per plant and number of seeds per pod. The analysis of variance due to lines were significant for all the characters except pollen fertility, number of primary branches per plant , number of seeds per pod , 100 seed weight and harvest index. The analysis of variance due to testers were significant for the characters plant height and 100 seed weight. The analysis of variance due to line x tester were significant for all the characters except number of primary branches per plant, number of secondary branches per plant and number of seeds per pod.

Table 4.4.1 ANOVA for line x tester analysis

Sources of variation	d. f.	Mean sum of squares										
		Plant height (cm)	Days to 50 % flowering	Pollen fertility (%)	Days to maturity	Number of primary branches per plant	Number of secondary branches per plant	Number of pods per plant	Number of seeds per pod	100 seed weight (g)	Grain yield per plant (g)	Harvest Index
Replications	2	72.99	15.46	2.41	24.98	0.6	4.82	301.46	0.06	0.16	11.08	1.56
Crosses	26	525.90**	57.12**	65.41**	60.61**	0.79	7.25**	17538.31**	0.07	0.81**	1518.42**	117.19**
Parents (Line)	2	2552.01**	394.16**	168.1	202.31*	1.27	25.76*	100271.93**	0.02	0.88	7695.10**	189.37
Parents (Tester)	8	703.07*	45.15	40.18	45.85	1.07	7.91	13939.54	0.09	1.36*	975.95	82.22
Line x Tester	16	184.05**	20.98**	65.19**	50.28**	0.58	4.61	8996.00**	0.06	0.52*	1017.57**	125.65**
Error	52	45.03	6.53	6.04	18.19	0.83	2.69	142.91	0.05	0.24	29.74	15.97

* - Significant at 5 % level of significance ** - Significant at 1 % level of significance

Note: A lines and B lines are isogenic except for pollen fertility. The observations of yield and yield contributing characters except pollen fertility were recorded on B-lines (ICPB 2039, ICPB 2089 and ICPB 2156).

4.4.2 Proportional contribution of lines, testers and line x testers

The proportional contribution of lines, testers, and line x testers for various characters are presented in Table 4.4.2. The data revealed that contribution of line x tester was higher than both lines and testers for characters pollen fertility (64.44%), days to maturity (51.05%), number of primary branches per plant (45.64%), number of seeds per pod (55.62%), grain yield per plant (41.23%) and harvest index (65.98%). The contribution of tester was highest for plant height (41.13%) and 100 seed weight (51.94%) than line and line x tester. The contribution of lines was more than testers and line x tester for the character days to 50% flowering (53.07%) and number of pods per plant (43.97%).

Table 4.4.2 Proportional contribution of lines, testers and line x tester

Sr. No.	Characters	Line (%)	Tester (%)	Line x tester (%)
1.	Plant height (cm)	37.32	41.13	21.53
2.	Days to 50% flowering	53.07	24.32	22.06
3.	Pollen fertility (%)	21.14	14.40	64.44
4.	Days to maturity	25.67	23.27	51.05
5.	Number of primary branches per plant	12.38	41.96	45.64
6.	Number of secondary branches per plant	27.33	33.55	39.11
7.	Number of pods/ plant	43.97	24.45	31.56
8	Number of seeds / pod	2.21	42.16	55.62
9.	100 seed weight (g)	8.42	51.94	39.63
10.	Grain yield per plant (g)	38.98	19.77	41.23
11.	Harvest Index	12.42	21.58	65.98

Note: A lines and B lines are isogenic except for pollen fertility. The observations of yield and yield contributing characters except pollen fertility were recorded on B-lines (ICPB 2039, ICPB 2089 and ICPB 2156).

4.5 Analysis of variance for combining ability

Line x tester analysis of 27 crosses obtained by crossing 3 lines with 9 testers was carried out and the total variance due to crosses was partitioned into portions attributable to GCA, SCA and error. Analysis of variance for combining ability is presented in Table 4.5.

The mean squares of GCA effect were significant for all characters. The mean square of SCA effect were significant for all the characters except days to 50% flowering, days to maturity, number of primary branches per plant and number of seeds per pod. This indicated the presence of significant differences between males and females for these traits.

4.5.1 General Combining Ability (GCA) effect

General combining ability (GCA) effect for parents is presented in Table 4.5.1 and described character wise as below.

4.5.1.1 Plant height (cm)

Of the three lines evaluated ICPA 2039 (11.02) exhibited significant positive GCA effect while maximum significant negative GCA effect is exhibited by ICPA 2089 (-7.35). Among the male parents significant positive GCA effect is recorded by ICPL 149 (15.63), ICPL 81-3 (8.63) and ICPL 161 (4.97). Maximum significant negative GCA effect among testers is observed for ICPL 88039 (-10.75) for the trait plant height.

4.5.1.2 Days to 50 per cent flowering

For this trait, the lines ICPA 2089 (-2.53), ICPA 2156 (-1.86) exhibited significant negative GCA effect while ICPA 2039 (4.40) exhibited significant positive GCA effect. Of the nine testers ICPL 86022 (-3.12) and ICPL 88039 (-2.46) recorded significant negative GCA effect while ICPL 49 (2.99) exhibited significant positive GCA effect among testers for the trait days to 50% flowering.

4.5.1.3 Pollen fertility (%)

Among the lines, ICPA 2039 (1.79) and ICPA 2156 (1.06) exhibited significant positive GCA effect. Whereas, line ICPA 2089 (-2.85) recorded significant negative GCA effect. Among testers, ICPL 86022 (3.50) and ICPL 149 (2.48) recorded significant positive GCA effect. Whereas, tester ICPL 89 (-3.34) recorded significant negative GCA effect.

4.5.1.4 Days to maturity

Highly significant negative GCA effects were recorded by the lines ICPA 2089 (-2.46) and ICPA 2156 (-0.49) while ICPA 2039 (2.95) exhibited significant positive GCA effect. Among the testers, ICPL 88034 (-3.01) and ICPL 88039 (-2.79) exhibited significant negative GCA effect for the trait days to maturity. None of the testers exhibited significant positive GCA effect.

4.5.1.5 Number of primary branches per plant

None of the lines and testers showed significant positive and negative GCA effects.

4.5.1.6 Number of secondary branches per plant

Among the lines, ICPA 2039 (0.83) expressed significant positive GCA effect while ICPA 2156 (-1.08) recorded significant negative GCA effect. Among testers, ICPL 88034 (1.15) and ICPL 161 (1.11) showed significant positive GCA effect while significant GCA effect is exhibited by ICPL 86022 (-1.58) for the trait number of secondary branches per plant.

4.5.1.7 Number of pods per plant

The line ICPA 2039 (69.84) manifested significant positive GCA effect, whereas, lines ICPA 2156 (-42.40) and ICPA 2089 (-27.44) recorded significant negative GCA effect. Among testers, ICPL 161 (57.45), ICPL 149 (50.95), ICPL 88034 (13.31) and ICPL 92047 (12.98) exhibited significant positive GCA effect. The testers

ICPL 89 (-50.69) recorded highest significant negative GCA effect followed by ICPL 86022 (-48.26).

4.5.1.8 Number of seeds per pod

Of the three lines, none of them showed significant positive and negative GCA effects. Among testers, highest significant positive GCA effect was observed for ICPL 88039 (0.19) followed by ICPL 90048 (0.13). None of the testers recorded significant negative GCA effect.

4.5.1.9 100 seed weight (g)

For this trait, ICPA 2156 (0.21) recorded highest significant positive GCA effect among the lines. Out of nine testers, ICPL 90048 (0.77) recorded significant positive GCA effect while ICPL 161 (-0.53) recorded significant negative GCA effect for the trait 100 seed weight.

4.5.1.10 Grain yield per plant (g)

Among the lines, ICPA 2039 (19.37) manifested significant positive GCA effect, whereas, line ICPA 2156 (-11.59) and ICPA 2089 (-7.78) exhibited highest significant negative GCA effect.

Among testers, ICPL 161 (13.91), ICPL 149 (9.68) and ICPL 90048 (8.85) showed significant positive GCA effect while testers ICPL 86022 (-16.37) and ICPL 89 (-14.20) had significant negative GCA effect.

Table 4.5 ANOVA for Combining Ability analysis

Sources of variation	d. f.	Mean sum of squares										
		Plant height (cm)	Days to 50 % flowering	Pollen fertility (%)	Days to maturity	Number of primary branches per plant	Number of secondary branches per plant	Number of pods per plant	Number of seeds per pod	100 seed weight (g)	Grain yield per plant (g)	Harvest Index
GCA	11	459.42**	132.94**	6007.32**	217.90**	3.30**	4.24*	18128.51**	0.11**	1.27**	1307.45**	113.83**
SCA	16	185.04*	20.98	65.18**	45.85	0.58	4.60*	8995.99**	0.06	0.52**	1017.57**	125.65**
Error	76	45.19	30.03	4.17	18.19	0.85	2.17	137.55	0.04	0.2	30.72	14.85

* - Significant at 5 % level of significance ** - Significant at 1 % level of significance

Note: A lines and B lines are isogenic except for pollen fertility. The observations of yield and yield contributing characters except pollen fertility were recorded on B-lines (ICPB 2039, ICPB 2089 and ICPB 2156).

Table 4.5.1 General combining ability of parents in pigeonpea

Sr. No	Parents	Plant height (cm)	Days to 50 % flowering	Pollen fertility	Days to maturity	No. of primary branches per plant	No. of secondary branches per plant	No. of pods per plant	No. of seeds per pod	100 seed wt. (g)	Grain yield per plant (g)	Harvest Index
	Female parents											
1	ICPB2039	11.02**	4.40**	1.79**	2.95**	0.23	0.83**	69.84**	-0.03	-0.11	19.37**	-2.90**
2	ICPB2089	-7.35**	-2.53**	-2.85**	-2.46**	-0.2	0.25	-27.44**	0.02	-0.1	-7.78**	0.61
3	ICPB2156	-3.68**	-1.86**	1.06**	-0.49	-0.04	-1.08**	-42.40**	0.01	0.21*	-11.59**	2.29**
	Male parents											
4	ICPL 88034	0.52	-0.68	0.86	-3.01*	-0.2	1.15*	13.31**	-0.1	-0.01	2.13	-5.70**
5	ICPL88039	-10.75**	-2.46**	-1.22	-2.79*	-0.34	0.03	-35.36**	0.19*	0.14	-4.20*	2.85*
6	ICPL149	15.63**	2.99**	2.48**	2.21	-0.24	-1.05	50.95**	0.03	-0.31	9.68**	2.37*
7	ICPL161	4.97*	2.77**	-1.46*	2.65	0.09	1.11*	57.45**	-0.03	-0.53**	13.91**	2.68*
8	ICPL81-3	8.63**	2.43**	-0.48	1.32	0.48	0.53	-0.38	-0.02	0.26	2.34	0.38
9	ICPL89	-9.03**	-0.9	-3.34**	-0.57	0.34	0.49	-50.69**	-0.01	0.16	-14.20**	-3.66**
10	ICPL90048	-5.75*	-0.35	0.67	2.32	0.45	-0.08	-0.01	0.13*	0.77**	8.85**	-1.56
11	ICPL86022	-6.70**	-3.12**	3.50**	-2.12	-0.29	-1.58**	-48.26**	-0.09	-0.17	-16.37**	1.6
12	ICPL92047	2.48	-0.68	-1	-0.01	-0.31	-0.59	12.98**	-0.09	-0.32*	-2.13	1.03
	SE ± Gi (line)	1.29	0.49	0.009	0.82	0.17	0.31	2.3	0.04	0.09	1.04	0.68
	SE ± Gj (tester)	2.23	0.85	0.016	1.42	0.3	0.54	3.98	0.07	0.16	1.81	1.18

* - Significant at 5 % level of significance ** - Significant at 1 % level of significance

4.5.1.11 Harvest Index (%)

Out of three lines, only ICPA 2156 (2.29) expressed significant positive GCA effect, while, line ICPA 2039 (-2.90) recorded highest significant negative GCA effect.

Among nine testers, ICPL 88039 (2.85), ICPL 161 (2.68) and ICPL 149 (2.37) recorded significant positive GCA effect while tester ICPL 89 (-3.66) recorded significant negative GCA effect.

4.5.2 Specific Combining Ability (SCA) effects

Specific combining ability (SCA) effect is generally considered as the best criterion for selection of superior hybrid combination. Specific combining ability (SCA) effects were estimated for eleven characters in 27 hybrids. Estimates of specific combining ability effects are presented in Table 4.5.2 and described characters wise as below.

4.5.2.1 Plant height (cm)

Out of twenty seven crosses evaluated, three crosses *viz*., ICPA 2089 x ICPL 149 (7.90), ICPA 2039 x ICPL 149 (8.20), ICPA 2089 x ICPL 149 (7.90) and ICPA 2039 x ICPL 161 (7.86) registered significant positive SCA effect for plant height. Three crosses showed significant negative SCA effects for plant height while ICPA 2156 x ICPL 149 (-16.10) exhibited maximum significant negative SCA effect.

4.5.2.2 Days to 50 per cent flowering

Among twenty seven crosses, one cross showed significant negative SCA effect for days to 50 % flowering *viz.,* ICPA 2039 x ICPL 88039 (-4.84).The crosses ICPA 2156 x ICPL 88039 (5.75) and ICPA 2039 x ICPL 90048 (3.38) significant positive SCA effect.

4.5.2.3 Pollen fertility (%)

Eight crosses out of twenty seven crosses exhibited significant positive SCA effect for pollen fertility. The crosses ICPA 2156 x ICPL 89 (7.05), ICPA 2156 x ICPL 161 (4.72), ICPA 2089 x ICPL 88039 (4.23), ICPA 2039 x ICPL 88039 (4.09), ICPA

2039 x ICPL 92047 (3.96), ICPA 2039 x ICPL 81-3 (3.14), ICPA 2089 x ICPL 86022 (3.13) and ICPA 2089 x ICPL 88034 (3.04) showed significant positive SCA effects for pollen fertility. Eight crosses recorded significant negative SCA effects for pollen fertility. Out of which maximum significant negative SCA effect was shown by ICPA 2156 x ICPL 88039 (-8.31) for the trait pollen fertility (%).

4.5.2.4 Days to maturity

For this trait, only one cross ICPA 2039 x ICPL 88039 (-7.06) showed significant negative SCA effects. On the contrary, the cross ICPA 2156 x ICPL 88039 (6.72) recorded significant positive SCA effect.

4.5.2.5 Number of primary branches per plant

None of the crosses exhibited significant negative SCA effects among twenty seven crosses. Out of the twenty seven crosses evaluated, the cross ICPA 2039 x ICPL 81-3 (1.04) exhibited significant positive SCA effects.

4.5.2.6 Number of secondary branches per plant

Only one cross showed significant positive SCA effect for number of secondary branches per plant *viz.,* ICPA 2156 x ICPL 88034 (2.57). Two crosses recorded significant negative SCA effect for number of secondary branches per plant, among which ICPA 2039 x ICPL 88034 (-1.97) exhibited highest significant negative SCA effect followed by ICPA 2156 x ICPL 90048 (-1.90).

Table 4.5.2 Specific combining ability of crosses in pigeonpea

Sr. No	Crosses	Plant height (cm)	Days to 50 % flowering	Pollen fertility (%)	Days to maturity	No. of primary branches per plant	No. of secondary branches per plant	No. of pods per plant	No. of seeds per pod	100 seed wt. (g)	Grain yield per plant (g)	Harvest Index (%)
1	ICPA2039 x ICPL88034	-6.69	-2.28	0.06	-4.51	-0.18	-1.97*	12.25	0.14	-0.01	3.74	1.10
2	ICPA2039 x ICPL88039	-2.76	-4.84**	4.09**	-7.06**	-0.07	1.25	50.15**	-0.15	-0.25	-15.92**	-0.55
3	ICPA2039 x ICPL149	8.20*	1.05	-0.26	4.27	-0.07	-0.11	11.87	-0.06	0.52	8.85**	1.07
4	ICPA2039 x ICPL161	7.86*	0.27	-0.68	0.83	-0.20	-0.56	107.55**	0.04	0.58*	35.63**	0.09
5	ICPA2039 x ICPL81-3	2.53	1.94	3.14*	3.49	1.04*	-0.58	-37.13**	-0.04	0.06	-12.47**	-1.60
6	ICPA2039 x ICPL89	0.86	0.94	-7.06**	1.72	-0.49	0.15	-49.18**	-0.01	-0.51	-19.92**	-2.60
7	ICPA2039 x ICPL90048	-6.56	3.38*	-0.81	2.83	0.37	1.51	67.37**	-0.16	0.15	24.02**	1.40
8	ICPA2039 x ICPL86022	-9.47*	-1.17	-2.45*	0.27	-0.30	0.83	-55.05**	0.13	-0.11	-19.59**	7.22**
9	ICPA2039 x ICPL92047	6.02	0.72	3.96**	-1.84	-0.10	-0.53	-7.55	0.10	-0.43	-4.34	-6.13**
10	ICPA2089 x ICPL88034	-0.99	-0.02	3.04*	1.23	0.07	-0.59	17.66*	-0.21	0.17	4.89	2.33
11	ICPA2089 x ICPL88039	2.15	-0.91	4.23**	0.35	0.09	-0.41	25.80**	0.14	-0.17	7.56*	2.47
12	ICPA2089 x ICPL149	7.90*	-0.69	-0.08	-4.65	0.24	0.94	2.48	0.16	-0.43	-3.33	-3.74
13	ICPA2089 x ICPL161	-5.43	0.53	-4.04**	2.23	-0.10	0.35	-43.23**	-0.01	-0.34	-13.55**	-0.72
14	ICPA2089 x ICPL81-3	-2.10	-1.80	-4.62**	-1.10	-0.49	0.45	52.35**	0.02	-0.26	15.01**	-0.51
15	ICPA2089 x ICPL89	-1.10	1.20	0.01	-0.54	0.34	-0.01	25.10**	-0.03	0.04	11.56**	12.08**
16	ICPA2089 x ICPL90048	6.28	-0.69	2.09	1.57	-0.62	0.38	52.08**	-0.11	0.06	-15.67**	-11.26**
17	ICPA2089 x ICPL86022	2.90	2.09	3.13*	-2.65	0.29	-0.66	-20.20**	-0.02	0.24	-2.94	-2.23

* - Significant at 5 % level of significance ** - Significant at 1 % level of significance

4.5.2.7 Number of pods per plant

Significant positive SCA effect for number of pods per plant were observed in ten crosses and the cross ICPA 2039 x ICPL 161 (107.55) topped the list followed by the other crosses ICPA 2156 x ICPL 86022 (75.25), ICPA 2039 x ICPL 90048 (67.37), ICPA 2089 x ICPL 81-3 (52.35), ICPA 2089 x ICPL 88039 (25.80), ICPA 2089 x ICPL 89 (25.10), ICPA 2156 x ICPL 88039 (24.35), ICPA 2156 x ICPL 89 (24.09), ICPA 2089 x ICPL 88034 (17.66) and ICPA 2156 x ICPL 92047 (15.42). Twelve crosses showed significant negative SCA effect for number of pods per plant among which maximum was exhibited by ICPA 2156 x ICPL 161 (-64.32).

4.5.2.8 Number of seeds per pod

Out of twenty seven crosses evaluated, only one cross had relatively significant positive SCA effect for number of seeds per pod. The cross ICPA 2156 x ICPL 90048 (0.26) showed significant positive SCA effect for number of seeds per pod.

4.5.2.9 100 Seed weight (g)

Three crosses *viz.,* ICPA 2089 x ICPL 92047 (0.68) followed by ICPA 2039 x ICPL 161 (0.58), ICPA 2039 x ICPL 149 (0.53) exhibited significant highest positive SCA effect for 100 seed weight and none of the crosses manifested significant negative SCA effects.

4.5.2.10 Grain yield per plant (g)

Significant positive SCA effects for this important trait were recorded by nine crosses out of twenty seven crosses. The crosses that exhibited significant positive SCA effect are ICPA 2039 x ICPL 161 (35.63), ICPA 2039 x ICPL 90048 (24.02), ICPA 2156 x ICPL 86022 (22.53), ICPA 2089 x ICPL 81-3 (15.01), ICPA 2089 x ICPL 89 (11.56), ICPA 2039 x ICPL 149 (8.85), ICPA 2156 x ICPL 88039 (8.37), ICPA 2156 x ICPL 89 (8.37) and ICPA 2156 x ICPL 92047 (7.86). Three crosses showed significant negative SCA effect for this character. Among them, ICPA 2156 x ICPL 161 (-22.08) had highest significant negative SCA effect.

4.5.2.11 Harvest Index (%)

Four crosses out of 27 crosses exhibited significant positive SCA effect for harvest index (%).The crosses that showed significant positive SCA effect for harvest index are ICPA 2089 x ICPL 89 (12.08), ICPA 2156 x ICPL 90048 (9.86), ICPA 2039 x ICPL 86022 (7.22) and ICPA 2156 x ICPL 92047 (4.56). Out of 27 crosses, four crosses recorded significant negative SCA effects. The cross ICPA 2089 x ICPL 90048 (-11.26) exhibited highest significant negative SCA effects.

CHAPTER-V

DISCUSSION

Heterosis breeding aims to exploit the phenomenon of hybrid vigour to increase yield potential and yield stability. It assembles genes that perform well under heterozygous condition (F_1). The model of breeding procedure is based on use of cytoplasmic male sterility, the most effective genetic tool developing hybrids in pigeonpea. Successful development of hybrid pigeonpea is possible, only if the effective fertility restorers to cytoplasmic genetic male sterile (CGMS) lines are identified. Further, isolation of new maintainers for CGMS lines is necessary for the development of new CGMS lines. Since pigeonpea is predominantly self-pollinated crop heterosis breeding must have a stable male sterility and an effective fertility restorer system to produce enough quantity of hybrid seeds.

In the present investigation, hybrids were derived by crossing 3 CMS lines with 9 testers. The hybrids were studied to estimate the magnitude of heterosis [Fonesca and Paterson, 1968]. The combining ability parameters for yield and yield components were also estimated in this study. The results of the present findings are discussed in the following sub-headings.

1. Analysis of variance

2. Mean performance of parents and crosses in yield contributing characters

3. Estimation of heterosis

4. Line x tester analysis

5. Combining ability analysis

5.1 Analysis of variance

The analysis of variance showed significant differences among the genotypes for all the eleven yield and yield contributing characters under study. The significant differences among genotypes indicated worth of genetic variability for the yield and yield contributing characters, which are important in hybrid pigeonpea yield.

5.2 Mean performance of parents and crosses for yield contributing characters.

The mean performance of twelve parents and twenty seven crosses studied is presented in Table 4.2. For plant height, the line ICPA 2156 (133.67 cm) and the tester ICPL 161 (152 cm) recorded highest plant height. Among the crosses ICPA 2039 x ICPL 149 (182 cm) showed highest plant height followed by ICPA 2039 x ICPL 161 (171 cm).

In the present investigation, ICPA 2089 (68 days) was earlier in flowering among lines while in testers it was ICPL 88039 (62 days). The cross ICPA 2089 x ICPL 88039 (70 days) and ICPA 2156 x ICPL 86022 (70 days) was earlier to flower among the cross combinations.

The lines were male sterile and among the testers ICPL 92047 (99.84%) recorded highest pollen fertility. Among the crosses, ICPA 2156 x ICPL89 (99.32%) exhibited highest pollen fertility followed by ICPA 2039 x ICPL 92047 (99.30%).

Maturity duration is a very important factor that determines the adaptation. In the present investigation, line ICPA 2156 (109 days) and tester ICPL 88039 (105 days) were early in maturing among the lines and testers respectively. Out of twenty seven crosses, the cross ICPA 2089 x ICPL 86022 (118 days) recorded early maturity.

Of the twelve parents, line ICPA 2089 (10.63) and tester ICPL 88034 (12.10) recorded maximum number of primary branches per plant when compared to the three controls. The crosses, ICPA2039 x ICPL81-3 (11.97) had maximum number of primary branches per plant followed by ICPA2039 x ICPL90048 (11.27).

The highest number of secondary branches were registered by ICPA 2156 (18.87) and ICPL 92047 (21.50) among lines and testers respectively. Among the crosses, ICPA 2039 x ICPL 90048 (22.38) was with highest number of secondary branches per plant followed by ICPA 2039 x ICPL 88039 (22.23).

In the present investigation, among the lines and testers highest number of pods per plant is recorded by ICPA 2039 (216.50) and ICPL 161 (347.73) respectively. Out of the twenty seven crosses, ICPA 2039 x ICPL 161 (451.67) had highest number of pods followed by ICPA 2039 x ICPL 90048 (356.53).

ICPA 2089 (4.33) and ICPL 90048 (4.2) recorded maximum number of seeds per pod among the lines and testers respectively. The cross ICPA 2156 x ICPL 90048 (4.2) was with maximum number of seeds per pod among the twenty seven crosses.

Maximum 100 seed weight was recorded by ICPA 2039 (7.96), ICPL 88039 (9.83) and ICPA 2156 x ICPL 89 (9.06) among lines, testers and crosses respectively.

In the present investigation, among the lines ICPA 2039 (63.67 g) has manifested highest grain yield per plant while among the testers, ICPL 161 (100.43 g) has shown highest grain yield per plant. Out of the twenty seven crosses evaluated, highest grain yield was recorded by ICPA 2039 x ICPL 161 (133.33) followed by ICPA 2039 x ICPL 90048 (116.67).

Highest Harvest Index has been recorded by ICPA 2156 (36.75), ICPL 161 (41.14) and ICPA 2156 x ICPL 90048 (45.34) among the lines, testers and crosses respectively.

5.3 Estimation of Heterosis

The success of hybrid breeding depends on the amount of heterosis and the availability of cost-effective hybrid seed production system. In the present investigation, per centheterosis was calculated over better parent (heterobeltiosis) and standard checks *viz.,*VL Arhar1, ICPL 161, ICPH 2433 (standard heterosis) in twenty seven crosses developed by crossing three lines with nine testers. The magnitude of heterosis varied from trait to trait and cross to cross.

In pigeonpea plant height is desirable character for achieving high yield as vigour in plant height may lead to increase biomass as well as source-sink capacity for obtaining optimum yield. For plant height, the heterobeltiosis ranged from -8.33 to 33.50 percent. Eleven crosses exhibited significant positive heterobeltiosis. Out of 27 crosses maximum significant heterobeltiosis is manifested by ICPA 2039 x ICPL 149 (33.50%) followed by ICPA 2039 x ICPL 86022 (21.71%). The range of standard heterosis is -5.44 to 32.72, -9.53 to 26.98 and -21.73 to 9.86 per cent for VL Arhar1, ICPL 161 and ICPH 2433 respectively. Ten crosses exhibited significant positive heterosis over the check VL Arhar1, of which the cross ICPA 2039 x ICPL 149 (32.72%) recorded maximum significant positive heterosis. Five crosses exhibited significant positive heterosis over ICPL 161, of which ICPA 2039 x ICPL 149 (26.98%) recorded maximum significant positive heterosis. Only one cross showed ICPA 2039 x ICPL 149 (9.86%) significant positive heterosis over the check ICPH 2433.Similar results were also reported earlier by Kumar and Srivastva (1998), Wankhade *et al.* (2005), Baskaran and Muthiah ,(2006), Patel and Tikka, (2008), Sarode *et al.* (2009), Chandrikala *et al.* (2010), Vaghela *et al.* (2011), Pandey *et al.* (2013), Gite *et.al.* (2014).

Early maturing hybrids are generally preferred therefore, negative heterosis for days to 50% flowering is considered as useful parameter. For days to 50% flowering, the heterobeltiosis range from -12.50 to 14.93 percent. Ten crosses exhibited significant negative heterobeltiosis. Maximum significant negative heterobeltiosis is recorded by ICPA 2089 x ICPL 88034 (-12.50%). The standard heterosis range is 10 to 33.16, -17.39 to 0, -17.39 to 0 per centfor VL Arhar1, ICPL 161 and ICPH 2433 respectively. No significant negative heterosis is exhibited over the check VL Arhar1. Out of 27 crosses, 23 crosses manifested significant negative heterosis over the checks ICPL 161 and ICPH 2433. Maximum significant negative heterosis is recorded by ICPA 2089 x ICPL 88039 (-17.39%) and ICPA 2156 x ICPL 86022 (-17.39%) over the checks ICPL 161 and ICPH 2433. Heterosis in both negative and positive directions for days to 50% flowering have also been reported by Kumar and Srivastva (1998), Wankhade *et al.* (2005), Baskaran and Muthiah (2006), Wanjari *et al.* (2007), Patel and Tikka (2008), Sarode *et al.* (2009), Chandrikala *et al.* (2010), Vaghela *et al.* (2011), Pandey *et al.* (2013), Gite *et.al.* (2014) and Patil *et al.* (2015)

The range of heterobeltiosis for the trait pollen fertility is -13.43 to 0.92 percent. None of the crosses exhibited positive significant heterobeltiosis. The range of standard heterosis is -12.70 to 0.90, -13.46 to 0.02 and -11.04 to 2.82 for VL Arhar1, ICPL 161 and ICPH 2433 respectively. None of the crosses showed significant positive heterosis over all the checks.

For days to maturity, the range of negative heterobeltiosis is -8.10 to 18.71 percent. Two crosses recorded significant negative heterobeltiosis *viz.,* ICPA 2039 x ICPL 88034 (-8.10%) and ICPA 2089 x ICPL 88034 (-7.85%). The range of standard heterosis ranged from 12.70 to 28.57, -11.47 to 1, -11.69 to 0.75 per cent for VL Arhar1, ICPL 161 and ICPH 2433 respectively. None of the crosses exhibited significant negative heterosis over VL Arhar1 for this trait. Out of the twenty seven crosses, the maximum significant negative heterosis was manifested by ICPA 2089 x ICPL 86022 followed by ICPA 2039 x ICPL 88039 over both checks ICPL 161 and ICPH 2433. The desirable combinations were common for both the heterosis for days to maturity are not cross specific. Solanki *et al.* (2008) reported that most of the hybrids depicted significant negative heterosis for days to 50% flowering and days to maturity, thereby suggesting that high yield in hybrids can be achieved along with early flowering and maturity. These results are in agreement with earlier results reported by Veeraswamy *et al.* (1973), Hooda *et al.*(1999), Kalimagal and Ravikesavan (2003), Aher *et al.* (2006), Sarode *et al.* (2009), Gupta *et al.* (2011), Pandey *et al.* (2013), Gite *et al.*(2014) and Patil *et al.*(2015).

More primary branches per plant are believed to be closely associated with high seed yield per plant resulting high productivity. Therefore, the cross combinations with more primary branches per plant were to be identified. The range of heterobeltiosis for the trait number of primary branches per plant is -18.26 to 22.50 percent. Two crosses exhibited significant positive heterobeltiosis for this trait *viz.,* ICPA 2039 x ICPL 90048 (22.50%) and ICPA 2039 x ICPL 81-3 (19.67%). The range of standard heterosis is -7.96 to 12.89, -0.78 to 21.69 and -5.58 to 15.81 per cent for VL Arhar1, ICPL 161 and ICPH 2433 respectively. None of the crosses registered significant negative heterosis over VL Arhar1 for this trait. Over ICPL 161, the cross ICPA 2039 x ICPL 81-3 (21.69%) showed significant positive heterosis. The cross ICPA 2039 x ICPL 81-3 (15.81) manifested significant positive heterosis over the check ICPH 2433. Similar results were earlier reported by Pandey and Singh (2002), Aher *et al.* (2006) and Pandey *et al.* (2013).

For the trait number of secondary branches per plant, heterobeltiosis ranged from -13.22 to 20.04 percent. Maximum significant positive heterobeltiosis is exhibited by ICPA 2156 x ICPL 88034 (20.04%) followed by ICPA 2039 x ICPL 90048 (13.81%). The range of standard heterosis is -14.31 to 13.64, -12.63 to 16.55 and -20 to 6.72 per cent for VL Arhar1, ICPL 161 and ICPH 2433 respectively. The cross ICPA 2156 x ICPL 88034 (13.64%) recorded significant positive heterosis over the check VL Arhar1. Three crosses exhibited significant positive heterosis over the check ICPL 161. Maximum significant positive heterosis was shown by ICPA 2156 x ICPL 88034 (16.55%) followed by ICPA 2039 x ICPL 90048 (14.59%) over the check ICPL 161. None of the crosses recorded significant positive heterosis over the check ICPH 2433. Results were in conformity with those obtained by Pandey and Singh (2002), Wankhade *et al.* (2005), Aher *et al.* (2006), Baskaran and Muthiah (2006), Patel and Tikka (2008), Sarode *et al.* (2009), Chandrikala *et al.* (2010), Vaghela *et al.* (2011), Pandey *et al.* (2013), Gite *et al.*(2014) and Patil *et al.*(2015).

The hybrids with positive heterosis for number of pods per plant are desirable to increase the yield. The range of heterobeltiosis for the trait number of pods per plant is -51.09 to 64.68 percent. Out of twenty seven crosses, nine crosses manifested significant positive heterobeltiosis. Maximum significant positive heterobeltiosis is exhibited by ICPA 2039 x ICPL 90048 (64.68%) followed by ICPA 2039 x ICPL 88034 (45.37%). The range of standard heterosis was -38.49 to 126.33, -62.83 to 36.76 and -71.07 to 6.45 per cent for VL Arhar1, ICPL 161 and ICPH 2433 respectively. Maximum significant positive heterosis was recorded by ICPA 2039 x ICPL 161 over all the three checks VL Arhar1, ICPL 161 and ICPH 2433. These results are in agreement with the finding of Hooda *et al* (1999), Aher *et al.* (2006), Baskaran and Muthiah (2006), Patel and Tikka (2008), Sarode *et al.* (2009), Chandrikala *et al.* (2010), Gupta *et al.* (2011), Vaghela *et al.* (2011), Pandey *et al.* (2013), Gite *et al.* (2014) and Patil *et al.* (2015).

The hybrids with positive heterosis for number of seeds per pod are desirable to increase the yield. For the trait number of seeds per pod, heterobeltiosis ranged from -19.23 to 7.14 percent. None of the crosses exhibited significant positive heterobeltiosis. The range of standard heterosis was -12.50 to 5, -4.55 to 14.55 and -8.70 to 9.57 over the check VL Arhar1, ICPL 161 and ICPH 2433 respectively. None of the crosses recorded significant positive heterosis over the check VL Arhar1. Over ICPL 161 maximum significant positive heterosis was registered by ICPA 2156 x ICPL 90048 (14.55%) followed by ICPA 2089 x ICPL 88039 (12.73%). The cross ICPA 2156 x ICPL 90048 (9.5%) manifested significant positive heterosis over ICPH 2433. These findings were in agreement with the findings of Aher *et al.* (2006), Banu *et al.* (2006), Patel and Tikka (2008), Sarode *et al.* (2009), Kumar *et al.* (2012), Pandey *et al.* (2013), Patil *et al.* (2015), Mhasal *et al.* (2015).

The hundred seed weight is one of the important common traits which influence the yield. The range of heterobeltiosis for the trait 100 seed weight is -18.64 to 16.24 percent. Maximum significant positive heterobeltiosis is exhibited by ICPA 2156 x ICPL 89 (-16.24%) followed by ICPA 2156 x ICPL 81-3 (-14.10%). The range of standard heterosis for the trait 100 seed weight was -25.60 to -7.17, -8.40 to 14.29 and -10.66 to 11.48 per cent over the check VL Arhar1, ICPL 161 and ICPH 2433 respectively. None of the crosses showed significant positive heterosis over the check VL Arhar1. Six crosses recorded significant positive heterosis over the checks ICPL161 and ICPH 2433. Maximum significant positive heterosis is manifested by ICPA 2156 x ICPL 89 followed by ICPA 2039 x ICPL 90048 over the checks ICPL 161 and ICPH 2433. Heterosis with respect to 100 seed weight in positive and negative direction have also been repoted by Kumar and Srivasatva (1998), Wankhade *et al.* (2005), Baskaran and Muthiah (2006), Patel and Tikka (2008), Sarode *et al.* (2009), Vaghela *et al.* (2011), Kumar *et al.* (2012), Pandey *et al.* (2013), Gite *et al.* (2014) and Patil *et al.* (2015).

Ultimate aim of breeding is to gain the heterotic yield associated with other heterotic characters. Grain Yield is the complex character of all other yield contributing characters. All changes in yield must be accompanied by changes in one or more characters have been pointed out by Grafius (1959). A wide range of variation in the estimates of heterobeltiosis and standard heterosis in positive and negative direction was observed for grain yield per plant. For the trait, heterobeltiosis ranged from -55.53 to 83.25%. Nine crosses manifested significant positive heterobeltiosis for this trait. Maximum significant positive heterobeltiosis is manifested by ICPA 2039 x ICPL 90048 (83.25%) followed by ICPA 2156 x ICPL 86022 (47.50%). The range of standard heterosis was -47.00 to 89.28, -61.04 to 39.13 and -62.65 to 33.41 per cent over the checks VL Arhar1, ICPL 161 and ICPH 2433 respectively. The cross ICPA 2039 x ICPL 161 (89.28%) exhibited significant positive heterosis over the check VL Arhar1 followed by ICPA 2039 x ICPL 90048 (65.62%). Maximum significant positive heterosis is recorded by ICPA 2039 x ICPL 161 (39.17%) over the check ICPL 161 followed by ICPA 2039 x ICPL 90048 (21.74%). Over the check ICPH 2433, the crosses ICPA 2039 x ICPL 161 (33.41%) and ICPA 2039 x ICPL 90048 (16.73%) exhibited significant positive heterosis. These findings were in close agreement with the results of earlier workers Kumar and Srivasatva (1998), Hooda *et al.* (1999), Pandey and Singh (2002), Wankhade *et al.* (2005), Baskaran and Muthiah, (2006), Wanjari *et al.* (2007), Solanki *et al.* (2008), Patel and Tikka, (2008), Sarode *et al.* (2009), Singh and Singh, (2009),Dheva *et al.* (2009), Bharate *et al.* (2010), Chandrikala *et al.* (2010), Vaghela *et al.* (2011), Gupta *et al.* (2011), Kumar *et al.* (2012), Pandey *et al.* (2013), Patil *et al.* (2015) and Mhasal *et al.*(2015).

Harvest index indirectly influences the seed yield through partitioning photosynthates in source and sink. The range of heterobeltiosis ranged from -40.52 to 36.99 per cent for the trait harvest index. Maximum significant positive heterobeltiosis is recorded by ICPA 2089 x ICPL 88039 (36.99%) followed by ICPA 2156 x ICPL 90048 (23.36%). The range of standard heterosis was -19.92 to 61.08, -45.08 to 10.47 and -39.73 to 21.22 per cent over the checks VL Arhar1, ICPL 161 and ICPH 2433 respectively. Out of 27 crosses, 15 crosses exhibited significant positive heterosis over the check VL Arhar1. Maximum significant positive heterosis manifested by ICPA 2156 x ICPL 90048 (61.08%) followed by ICPA 2089 x ICPL 89 (55.48%) over the check VL Arhar1. None of the crosses showed significant positive heterosis over the checks ICPL 161 and ICPH 2433. The significant positive and negative heterosis for harvest index was also reported by Singh and Singh (2009), Dheva *et al.* (2009), Bharate *et al.* (2010), Gupta *et al.* (2011) and Pandey *et al.* (2013).

Table 5.1 Crosses showing high desirable heterobeltiosis and standard heterosis

Sr. No	Characters	Heterobeltiosis	Standard heterosis		
			Over VL Arhar1	Over ICPL 161	Over ICPH 2433
1	Plant height (cm)	ICPA 2039 x ICPL 149 ICPA 2039 x ICPL 86022 ICPA 2089 x ICPL 149	ICPA 2039 x ICPL 149 ICPA 2039 x ICPL 161 ICPA 2039 x ICPL 81-3	ICPA 2039 x ICPL 149 ICPA 2039 x ICPL 161 ICPA2039 x ICPL 81-3	ICPA 2039 x ICPL 149
2	Days to 50 per cent flowering	ICPA 2089 x ICPL 88034 ICPA 2156 x ICPL 88034 ICPA 2156 x ICPL 92047	------------------------------	------------------------------	------------------------------
3	Pollen fertility (%)	----------------------------	------------------------------	------------------------------	-----------------------
4	Days to maturity	ICPA 2039 x ICPL 88034 ICPA 2089 x ICPL 88034	------------------------------	ICPA 2089 x ICPL 86022 ICPA 2039 x ICPL 88039 ICPA 2089 x ICPL 88039	ICPA 2089 x ICPL 86022 ICPA 2039 x ICPL 88039 ICPA 2089 x ICPL 88039
5	Number of primary branches per plant	ICPA 2039 x ICPL 90048 ICPA 2039 x ICPL 81-3	------------------------------	ICPA 2039 x ICPL 81-3	ICPA 2089 x ICPL 81-3
6	Number of secondary branches per plant	ICPA 2156 x ICPL 88034 ICPA 2039 x ICPL 90048 ICPA 2089 x ICPL 161	ICPA 2156 x ICPL 88034	ICPA 2156 x ICPL 88034 ICPA 2039 x ICPL 90048 ICPA 2039 x ICPL 88039	------------------------------
7	Number of pods per plant	ICPA 2039 x ICPL 90048 ICPA 2039 x ICPL 88034 ICPA 2039 x ICPL 92047	ICPA 2039 x ICPL 161 ICPA 2039 x ICPL 90048 ICPA 2039 x ICPL 149	ICPA 2039 x ICPL 161 ICPA 2039 x ICPL 90048 ICPA 2039 x ICPL 149	ICPA 2039 x ICPL 161

Table 5.1 contd…..

Sr. No	Characters	Heterobeltiosis	Standard heterosis		
			Over VL Arhar1	Over ICPL 161	Over ICPH 2433
8	Number of seeds per pod	----------------------------	------------------------------	ICPA 2156 x ICPL 90048 ICPA 2089 x ICPL 88039	ICPA 2156 x ICPL 90048
9	100 Seed weight	ICPA 2156 x ICPL 89 ICPA 2156 x ICPL 81-3	----------------------------	ICPA 2156 x ICPL 89 ICPA 2039 x ICPL 90048 ICPA 2156 x ICPL 88039	ICPA 2156 x ICPL 89 ICPA 2039 x ICPL 90048 ICPA 2156 x ICPL 88039
10	Grain yield per plant (g)	ICPA 2039 x ICPL 90048 ICPA 2156 x ICPL 86022 ICPA 2039 x ICPL 88034 ICPA 2089 x ICPL 89 ICPA 2039 x ICPL 161 ICPA 2156 x ICPL 89 ICPA 2039 x ICPL 92047 ICPA 2039 x ICPL 149 ICPA 2089 x ICPL 88034	ICPA 2039 x ICPL 161 ICPA 2039 x ICPL 90048 ICPA 2039 x ICPL 149 ICPA 2039 x ICPL 88034	ICPA 2039 x ICPL 161 ICPA 2039 x ICPL 90048	ICPA 2039 x ICPL 161 ICPA 2039 x ICPL 90048
11	Harvest Index (%)	ICPA 2089 x ICPL 88039 ICPA 2156 x ICPL 90048	ICPA 2156 x ICPL 90048 ICPA 2089 x ICPL 89 ICPA2156 x ICPL 92047	-------------------------------	-------------------------------

5.4 Line x Tester Analysis

5.4.1 Analysis of variance for line x tester analysis

The analysis of variance indicated that the differences due to crosses were significant for all of the characters except number of primary branches per plant and number of seeds per pod. The analysis of variance due to lines were significant for all the characters except pollen fertility, number of primary branches per plant , number of seeds per pod , 100 seed weight and harvest index. The analysis of variance due to testers were significant for the characters plant height and 100 seed weight. The analysis of variance due to line x tester were significant for all the characters except number of primary branches per plant, number of secondary branches per plant and number of seeds per pod.

5.5. Combining Ability Analysis

Combining ability is the capacity of an individual to transmit superior performance to its offspring. Combining ability analysis on one hand is useful in the identification of potential parents for developing commercial hybrids while on other side it helps to select parents to develop base population for further crop improvement programmes. There were significant differences among the genotypes for characters, which led to the combining ability analysis. Thus were partitioned genetic effects between genotypes into General combining ability and Specific combining ability. Regarding to the significance of g_i in two directions in traits, we can declare that parents have potential of transfer of high and low values for each trait. Hence in cases, which increasing and decreasing the value of traits are desired, we should consider positive and negative values of g_i respectively. Therefore for days to 50% flowering and days to maturity negative GCA and SCA effects were desirable, while in case of other characters, positive GCA and SCA effects were desirable.

The mean squares of GCA effects were significant for all the eleven yield and yield contributing characters. The mean squares of SCA effects were significant for characters plant height, pollen fertility, number of secondary branches per plant, number of pods per plant, 100 seed weight, grain yield per plant and harvest index.

5.5.1 General combining ability (GCA effects):

The parental lines showing high GCA effects for yield and yield contributing characters are presented in table 5.2.

Table 5.2: Parents showing high desirable GCA effects.

Sr. No.	Character	Parents
1.	**Plant height (cm)**	ICPA 2039, ICPL 149, ICPL 81-3, ICPL 161
2.	**Days to 50% flowering**	ICPA 2089, ICPA 2156, ICPL 86022, ICPL 88039
3.	**Pollen fertility (%)**	ICPA 2039, ICPA 2156, ICPL 86022, ICPL 149
4.	**Days to maturity**	ICPA 2089, ICPA 2156, ICPL 88034, ICPL 88039
5.	**Number of primary branches per plant**	---
6.	**Number of secondary branches per plant**	ICPA 2039, ICPL 88034, ICPL 161
7.	**Number of pods per plant**	ICPA 2039, ICPL 161, ICPL 149, ICPL 88034
8.	**Number of seeds per pod**	ICPL 88039, ICPL 90048
9.	**100 seed weight (g)**	ICPA 2156, ICPL 90048
10.	**Grain yield per plant (g)**	ICPA 2039, ICPL 161, ICPL 149, ICPL 90048
11.	**Harvest Index (%)**	ICPA 2156, ICPL 88039, ICPL 161, ICPL 149

None of the CMS lines or pollinators was found to be a good general combiner for all the characters studied. Investigation of GCA effects revealed that the parents

ICPA 2039 among lines, ICPL 161, ICPL 149, ICPL 90048 among testers were the good general combiners for yield and most of the yield contributing characters. Hence these good general combiners of males and females may be extensively used in future for pigeonpea breeding programmes. The negative GCA effect was desirable in days to 50 % flowering, days to maturity, which was observed in ICPA 2089, ICPA 2156 among lines and among testers it was observed in ICPL 88039. Among these parents, ICPL 161 and ICPL 149 had desirable GCA effect for grain yield per plant, plant height, number of secondary branches per plant, number of pods per plant, number of seeds per pod and harvest index. In general, good general combiners for grain yield also had good or average combining ability for one or more yield components. In most of the parents high GCA effects were associated with high *per se* mean for yield and yield components. It is important to mention here that the parents which showed good GCA effects for grain yield per plant also indicated significantly positive GCA effects for number of pods per plant. The results are in corroborance with the findings of Singh and Srivastava (2001), Banu *et al.* (2006), Baskaran and Muthiah (2007), Phad *et al.* (2007), Acharya *et al.* (2009), Singh *et al.* (2009), Shoba *et al.* (2010), Gupta *et al.* (2011), Thiruvengadam *et al.* (2012), Mesharam *et al.* (2013), Pandey *et al.* (2015) and Mhasal *et al.*(2015).

5.5.2 Specific Combining Ability (SCA) effect of crosses:

In crop improvement programme specific combining ability is important to pinpoint specific cross combination for commercial exploitation or varietal development. Specific combining ability effect is the index to determine usefulness of a particular combination in the exploitation of heterosis. The specific combining effects of the present investigation (table 5.3) are discussed below:

For the trait plant height, the cross ICPA 2089 x ICPL 149 and ICPA 2039 x ICPL 149 exhibited significant negative SCA effects. Similar results were earlier reported by Singh and Srivastava (2001), Banu *et al.* (2006).

For days to 50% flowering and days to maturity negative SCA effects are desirable. Only one cross ICPA 2039 x ICPL 88039 recorded significant negative SCA effect over both the traits. These results are in agreement with the earlier results reported by Singh and Srivastava (2001), Banu *et al.* (2006), Shoba *et al.* (2010), Meshram *et al.* (2013) and Yamamura *et al.* (2014).

Eight crosses exhibited significant positive SCA effect for pollen fertility. Maximum significant positive SCA effect was shown by ICPA 2156 x ICPL 88039 followed by ICPA 2156 x ICPL 161.

None of the crosses recorded significant positive SCA effect for number of primary branches per plant. For the trait number of secondary branches per plant, only one cross showed significant positive SCA effect *viz.,*ICPA 2156 x ICPL 88039. These findings were in perfect agreement with Phad *et al.* (2007), Thiruvengadam *et al.* (2012) and Pandey *et al.* (2015)

For the trait number of pods per plant ten crosses exhibited significant positive SCA effects. Maximum significant positive SCA effect was registered by ICPA 2039 x ICPL 161 followed by ICPA 2156 x ICPL 86022. Present observations are in close agreement with the earlier reports of Pandey *et al.* (2015) and Yamamura *et al.* (2014).

Only one cross recorded significant positive SCA effect *viz.,*ICPA 2156 x ICPL 90048. For the trait 100 seed weight, three crosses exhibited significant positive SCA effects. Maximum significant positive SCA effect was registered by the cross ICPA 2089 x ICPL 92047 These results are in agreement with the earlier results reported by Shoba *et al.* (2010), Meshram *et al.* (2013) and Yamamura *et al.* (2014).

Ten crosses exhibited significant positive SCA effect for grain yield among which ICPA 2039 x ICPL 161 manifested maximum positive SCA effect followed by ICPA 2156 x ICPL 86022. These results are in agreement with the findings of Sarode *et al.* (2009), Gupta *et al.* (2011), Arbad *et al.* (2013) and Yamamura *et al.*(2014) for grain yield per plant.

Table 5.3 Crosses showing desirable SCA effects

Sr. No.	Character	Crosses
1.	**Plant height (cm)**	ICPA 2089 x ICPL 149, ICPA 2039 x ICPL 149
2.	**Days to 50% flowering**	ICPA 2039 x ICPL 88039
3.	**Pollen fertility (%)**	ICPA 2156 x ICPL 89, ICPA 2156 x ICPL 161
4.	**Days to maturity**	ICPA 2039 x ICPL 88039
5.	**Number of primary branches per plant**	---
6.	**Number of secondary branches per plant**	ICPA 2156 x ICPL 88034
7.	**Number of pods per plant**	ICPA 2039 x ICPL 161, ICPA 2156 x ICPL 86022
8.	**Number of seeds per pod**	ICPA 2156 x ICPL 90048
9.	**100 seed weight (g)**	ICPA 2089 x ICPL 92047, ICPA 2039 x ICPL 161
10.	**Grain yield per plant (g)**	ICPA 2039 x ICPL 161, ICPA 2156 x ICPL 86022
11.	**Harvest Index (%)**	ICPA 2089 x ICPL 89, ICPA 2156 x ICPL 90048

For the trait harvest index four crosses recorded significant positive SCA effects. Maximum significant positive SCA effect was exhibited by ICPA 2089 x ICPL 89 followed by ICPA 2156 x ICPL 90048. This results are in agreement with Gupta *et al.* (2011)

On the basis of *per* se performance, combining ability and heterosis, the parents ICPA 2039, ICPL 88039, ICPL 161 and ICPL 149 can be used for future hybridization programmes and the crosses ICPA 2039 x ICPL 161 and ICPA 2039 x ICPL 90048 were the best specific combiner for yield and yield contributing characters. Besides this, these crosses had exhibited highest significant positive heterobeltiosis and standard heterosis over the checks VL Arhar1, ICPL 161 and ICPH 2433. Hence, these crosses can be further handled in future breeding programme for the improvement of pigeonpea.

CHAPTER- VI

SUMMARY AND CONCLUSION

The present investigation was undertaken with the objectives to study the heterosis and combining ability for yield and yield contributing characters in short duration hybrids of pigeonpea (*Cajanus cajan* (L.) Millsp.) It was sought through a line x tester mating design involving 3 lines (from ICRISAT, Patancheru) and 9 testers. A total number of 42 genotypes (3 lines, 9 testers, 27 hybrids, 3 standard checks) were sown in a randomized block design with three replications during *Kharif* 2016 at ICRISAT, Patancheru, Hyderabad. Mean data of genotypes (excluding standard checks) was analyzed as per line x tester mating design while mean data of 42 genotypes (including standard checks) was used for the estimation of heterosis.

The estimation of heterosis was done as per Fonesca and Patterson's (1968) and the analysis of combining ability as measure of gene action was carried out for line x tester mating design as per method by Kempthorne (1957). The results obtained are summarized as follows:

The parents ICPL 161, ICPL 149 ICPL 90048 had higher grain yield as well as better values for most of the yield contributing characters. The crosses made on male-sterile line ICPA 2089 were earlier to flower and mature. Out of twenty seven crosses, the crosses ICPA 2039 x ICPL161, ICPA 2039 x ICPL 90048, ICPA 2039 x ICPL 149, ICPA 2039 x ICPL 88034 and ICPA 2156 x ICPL 86022 showed better mean yield performance.

The heterosis breeding has been used extensively in improving yield potential through development of hybrid cultivars in most of the crops including pigeonpea. The exploitation of heterosis for developing high yielding commercial hybrids in pigeonpea has been found highly fruitful inspite of its often- cross pollinated nature because significant heterosis is encountered F_1 hybrids for successful and economical technology for commercial hybrid seed production is available. The crosses ICPA 2039 x ICPL 90048, ICPA 2156 x ICPL86022, ICPA 2039 x ICPL88034, ICPA 2089 x ICPL 89, ICPA 2039 x ICPL 161, ICPA 2156 x ICPL 89, ICPA 2039 x ICPL 92047, ICPA 2039 x ICPL 149 and ICPA 2089 x ICPL 88034 had significant positive heterobeltiosis for the grain yield and its components. The estimates of heterosis showed that the crosses ICPA 2039 x ICPL161 and ICPA 2039 x ICPL 90048 had significant standard heterosis for grain yield per plant and some of its components.

The analysis of variance indicated that the differences due to crosses were significant for all of the characters except number of primary branches per plant and number of seeds per pod. The analysis of variance due to lines were significant for all the characters except pollen fertility, number of primary branches per plant , number of seeds per pod , 100 seed weight and harvest index. The analysis of variance due to testers were significant for the characters plant height and 100 seed weight. The analysis of variance due to line x tester were significant for all the characters except number of primary branches per plant, number of secondary branches per plant and number of seeds per pod.

High magnitude of variances due to lines and testers against line x tester interaction for the characters indicated the presence of variability.

The mean squares of GCA effects were significant for all the eleven yield and yield contributing characters. The mean squares of SCA effects were significant for characters plant height, pollen fertility, number of secondary branches per plant, number of pods per plant, 100 seed weight, grain yield per plant and harvest index. This indicated the presence of significant differences between males and females for these traits. The estimates of GCA effects revealed that ICPA 2039, ICPL 161, ICPL 149 and ICPL 90048 were the good general combiners for grain yield per plant and most of the yield contributing characters. The lines ICPA 2089 and ICPA 2156 and the tester ICPL 86022 have registered significant negative GCA effects for days to 50% flowering and days to maturity.

In general, good general combiners for grain yield also had good or average combining ability for one or more yield components. In most of the parents high GCA effects were associated with high *per se* mean for yield and yield components. High GCA due to additive gene effects of parents helps for further selection of parents.

The relative ranking of hybrids on the basis of *per se* performance and SCA effects were different for some crosses. However, the crosses ICPA 2039 x ICPL 161 and ICPA 2156 x ICPL 90048 had high *per se* performance and desirable significant SCA effects for grain yield and other components.

Ultimate aim of breeding is to gain the heterotics yield associated with the other heterotic characters. On the basis of *per se* performance and general combining ability parents ICPA 2039, ICPA 2089, ICPL 149, ICPL 161 and ICPL 88039 were identified for their use in potential breeding programmes. The crosses ICPA 2039 X ICPL 161 and ICPA 2039 X ICPL 90048 may be exploited in near future after studying its stability across the environments.

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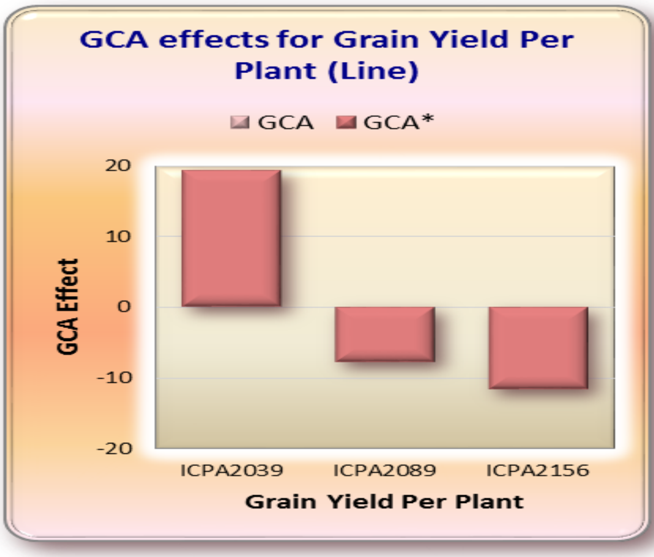
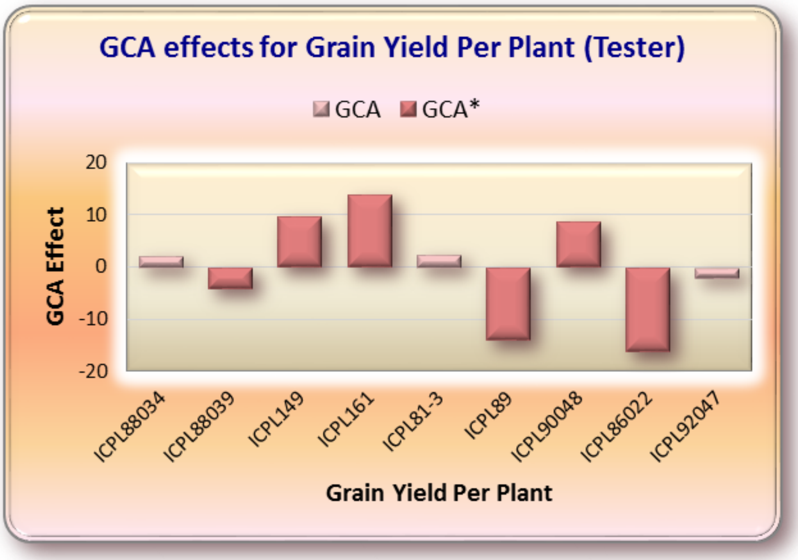
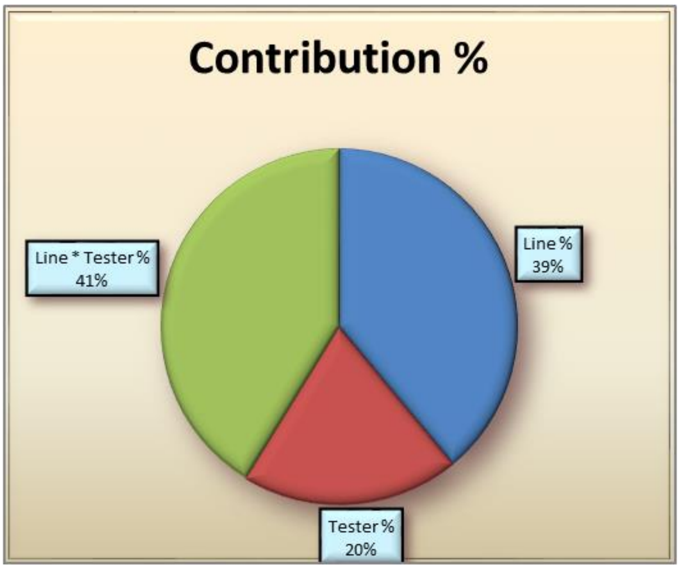


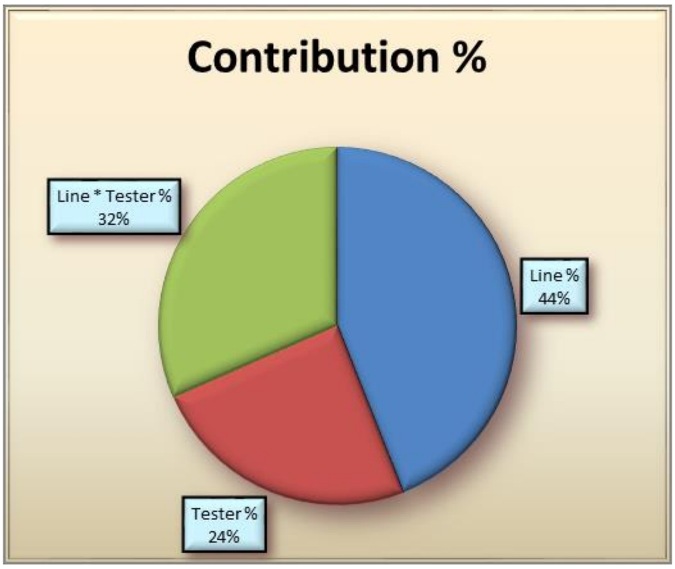
Graph1 : Graph showing the GCA effects of lines for Grain Yield per plant(g)



Graph2 : Graph showing the GCA effects of testers for Grain Yield per plant (g)



Pie diagram 1: Pie diagram showing the proportional contribution of lines, testers and line x tester interaction for the trait grain yield per plant



Pie diagram 2: Pie diagram showing the proportional contribution of lines, testers and line x tester interaction for the trait number of pods per plant

Plate 1: Pigeonpea Crossing in the Crossing Block during 2015

Plate 2: General view of the experimental field during Kharif 2016

Plate 3: Promising F_1 cross for yield (ICPA 2039 x ICPL161)

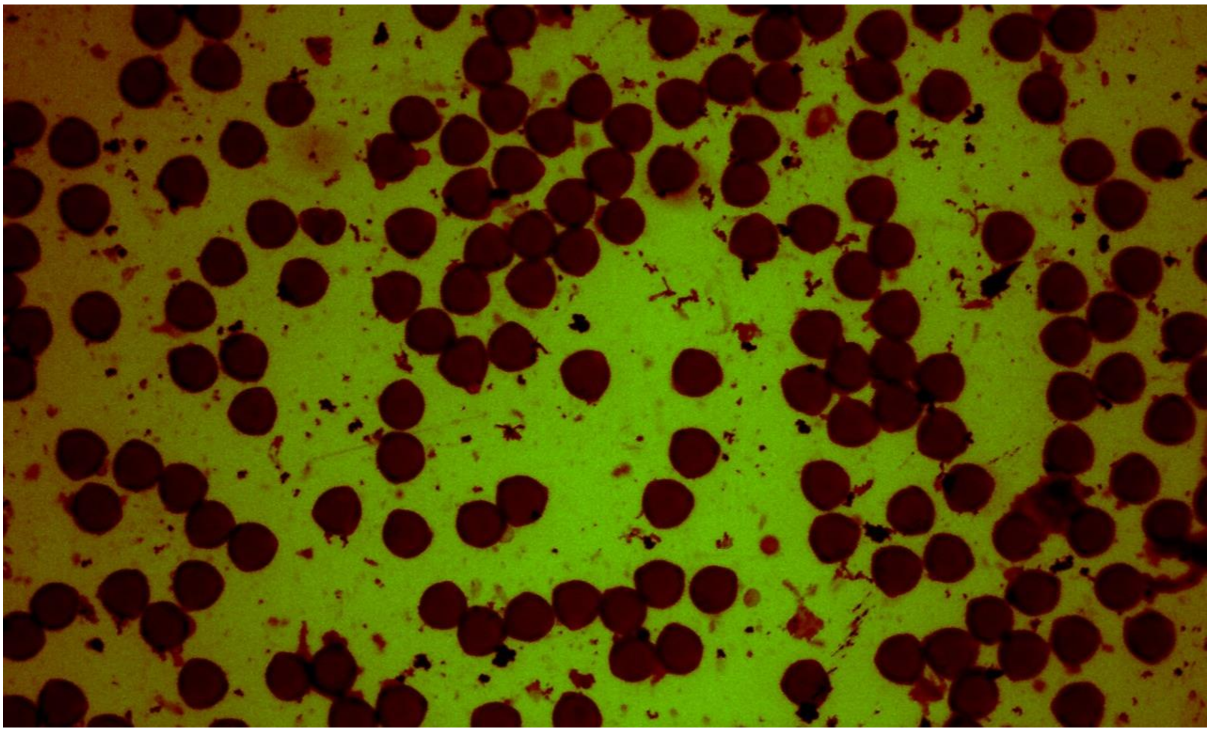


Plate 4: Microscopic view of fertile pollen of the promising F_1 cross for yield (ICPA 2039 x ICPL161)