HETEROSIS AND COMBINING ABILITY STUDIES IN MEDIUM DURATION PIGEONPEA EXPERIMENTAL HYBRIDS

THESIS

Submitted to
Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola
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IN
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DECLARATION OF STUDENT

I hereby declare that the experimental work and its interpretation of the Thesis entitled **"HETEROSIS AND COMBINING ABILITY STUDIES IN MEDIUM DURATION PIGEONPEA EXPERIMENTAL HYBRIDS"** or part of thereof has neither been submitted for any other degree or diploma of university, nor the data have been derived from any thesis / publication of any university or scientific organization. The source of materials used and all assistance received during the course of investigation has been duly acknowledged.

Place- Akola

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CERTIFICATE

This is to certify that thesis entitled **"HETEROSIS AND COMBINING ABILITY STUDIES IN MEDIUM DURATION PIGEONPEA EXPERIMENTAL HYBRIDS"** submitted in partial fulfillment of the requirements for the degree of "**Master of science in Agriculture (Agricultural Botany)"** of Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola is record of bonafide research work carried out by **Mhasal Gajanan Shrikrishna** under my guidance and supervision.

The subject of the thesis has been approved by the Student's Advisory Committee.

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(Mhasal Gajanan Shrikrishna)
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(A) List of Tables

(D) Abbreviations

%	-	Per cent
AICRP	-	All India Coordinated Research Project
Cm	-	Centimetres
CMS lines	-	Cytoplasmic male sterile lines
Dr. PDKV	-	Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola
G	-	Gram
GAU	-	Gujarat Agriculture University
gca / GCA	-	General Combining Ability
GMS	-	Genetic Male Sterility
Ha	-	Hectare
ICAR	-	Indian Council of Agriculture Research
ICRISAT	-	International Crop Research Institute for Semi-Arid Tropics
J.	-	Journal
Kg	-	Kilogram
M	-	Million
M / ha	-	Million per hectare
m^2	-	Square meter
MS	-	Mean square
MT	-	Metric Tonnes
q/ha	-	Quintals per hectare
Sci.	-	Science
SE(d)	-	Standard error of difference
SE(m)	-	Standard error of mean
Sr. No.	-	Serial number
Unpub.	-	Unpublished
Viz.,	-	Videlicet (namely)
Vs	-	Versus

(F) THESIS ABSTRACT

a) **Title of the thesis**	:	**"HETEROSIS AND COMBINING ABILITY STUDIES IN MEDIUM DURATION PIGEONPEA EXPERIMENTAL HYBRIDS"**
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ABSTRACT

The present investigation entitled "Heterosis and combinig ability studies in mediun duration pigeonpea experimental hybrids" was undertaken to estimate the extent of heterosis, combining ability effects and thereby to find out promising cross combinations using Line x Tester mating design (Kempthorne, 1957).

The set of 11 parents, six females (cms lines) *viz.,* AKCMS-81A, AKCMS-82-2A, AKCMS-83A, AKCMS-12A, AKCMS-93A and ICPA-2047A five males (testers) *viz.,* AKPR-303, AKPR-324, AKPR-364, AKPR-372 and AKPR-057 their 30 crosses along with two checks PKV-TARA and ASHA were evaluated in randomized block design with three replications at the field of Pulses Research Unit, Dr. PDKV, Akola during *Kharif* 2012-2013.

The data were recorded on the characters *viz.,* days to 50 per cent flowering, days to maturity, plant height (cm), number of branches, number of clusters, number of pods, number of seeds per pod, 100 seed weight (g), grain yield per plant (g) and plant fertility (%).

The mean squares due to genotypes were highly significant among the genotypes for all the traits under study indicating the presence of substaintial genetic variability.

The highest significant useful heterosis for grain yield per plant was recorded in ICPA-2047A X AKPR-324 (17.72% over check PKV-TARA and 23.17% over check ASHA). The same cross recorded the highest significant average heterosis (112.41%). In case of heterobeltiosis, the cross AKCMS-82-2A X AKPR-364 recorded the highest significant heterobeltiosis (94.09%) for grain yield per plant.

Among female parents, ICPA-2047A recorded significant gca effect for maximum six characters such as grain yield per plant, plant height, number of clusters, number of seed per pod, 100 seed weight and days to 50% flowering. The male parent AKPR-324 was found to posses highest gca effect for plant height, number of clusters, 100 seed weight and grain yield per plant. The male parent AKPR-372 recorded highest gca effect for number of branches, number of pods, number of seed per pod, and days to 50% flowering.

The cross ICPA-2047A X AKPR-372 (4.10) recorded the highest significant positive sca effect for grain yield per plant followed by ICPA-2047A X AKPR-324 (3.58).

The cross ICPA-2047A X AKPR-324 depicted high mean performance (33.67) high magnitude of useful heterosis (17.72% over check PKV-TARA and 23.17% over check ASHA), positive sca effect and both the parents involved revealed high gca effects. This cross could be successfully utilized to obtain the superior segregants in further segregating generations. Another cross ICPA-2047A X AKPR-372 revealed high mean performance (33.00g), high magnitude of useful heterosis (15.38 % over check PKV-TARA and 20.73% over check ASHA) and high sca effect. One of the parents (AKPR-372) though low combiner for grain yield but is was good combiner for number of branches, number of pods, number of seed per pod and days to 50% flowering. This cross may be employed to exploit non-additive component along with high heterotic response. However, the performances of this cross have to be evaluated in large scale trials.

CHAPTER I

INTRODUCTION

1.1 Background information

Pulses constitute an important ingredient in predominantly vegetarian diet and are important as source of protein that nutritionally balances the proteins from cereal grains. They supply minerals and vitamins and provide an abundance of food energy. Pulses provide a cheaper source of protein as they generally contain nearly twice as much protein as that of cereals and hence correctly called poor man's meat. Pulses are also important for sustainable agriculture, enriching the soil through biological nitrogen fixation. They enrich the soil with nitrogen up to 20-40 kg N/ha and organic matter through leaf fall and profuse underground root growth (Hariprasanna and Bhatt, 2002).

Pigeonpea [*Cajanus cajan* (L.) Millspaugh] is a short-lived perennial shrub that is traditionally cultivated as an annual crop in developing countries. It is an important pulse crop mostly produced in Asia, Africa, Latin America and the Caribbean region. It is a hardy, widely adapted and drought tolerant crop with a large temporal variation (90–300 days) for maturity. These traits allow its cultivation in a range of environments and cropping systems. It is the most versatile food legume with diversified uses as food, feed, fodder and fuel. It is one of the important pulse crops of India and ranks second to chickpea in area and production. It is commonly known as tur, red gram or arhar. It belongs to family leguminosae, sub family papilionaceae having chromosome number $2n = 2x = 22$ (Dundas, 1990).

Based on the occurrence of wild forms in Africa, particularly in the regions of the upper Nile and coastal districts of Angola, Krauss (1932) suggested Africa as the possible center of origin for pigeonpea. Keeping in view the wide range of diversity in India, pigeonpea was considered to be of the Indian origin (Vavilov, 1951). Based on the vast natural genetic variability in local germplasm and the presence of numerous wild relatives, Van der Maesen (1990) concluded that India is probably its primary center of origin. Abundance of *Cajanus cajan* and its wild relatives in the ever green forest area of western Ghats and Malabar coast of India confirmed that pigeonpea is originated in India (De, 1974). Presence of wild relatives, large diversity of gene pool, ample linguistic evidences, a few archaeological remains and wide home consumption usage shows that pigeonpea is originated in India. It is supposed to be evolved from tall bushy plants like *Cajanus cajanifolius* (Van der Maesen, 1990).

India being the largest producer of pigeon pea in the world, contributes to around 85% of the world total production (FAO Stat, 2010). In the year 2010-11, pigeonpea was cultivated in India on area of 4.09 million ha with production of 3.27 million tonnes and the productivity was 799 kg/ha (Anonymous 2010-11). In India, the important pigeonpea growing states are Uttar Pradesh, Maharashtra, Madhya Pradesh, Karnataka, Andhra Pradesh and Gujarat. In Maharashtra, the area under this crop was 1.20 million ha with production of 0.81 million tones and the productivity was 677 kg/ha during 2011-2012. In Vidarbha, it accounted 0.60 million ha area with production of 0.36 million tonnes and productivitywas 699 kg/ ha in year 2011-12 (Anonymous 2011-12).

The traditional pigeonpea cultivars and landraces are long duration types grown as an intercrop with other more early maturing cereals and legumes. In addition to its main use as de-hulled split dhals, its immature green seeds and pods are also consumed fresh as a green vegetable. The crushed dry seeds are fed to animals while the green leaves form a quality fodder. In rural areas, dry stems of pigeon pea are used for fuel. In a cropping season, pigeon pea plants fix 40 kg/ha atmospheric nitrogen and add valuable organic matter to the soil through fallen leaves. Its roots help in releasing soil-bound phosphorus to make it available for plant growth (Ae *et al.* 1990). With so many benefits at low cost, pigeon pea has become an ideal crop for sustainable agriculture systems in rain-dependent areas.

Pigeonpea is a rich source of proteins, carbohydrates and certain minerals. Protein content of commonly grown pigeonpea cultivars ranges between 17.9 and 24.3 g per 100 g for whole grain samples and split grains Pigeonpea seeds also contain about 57.3 to 58.7 per cent carbohydrate, 1.2 to 8.1 per cent crude fibre and 0.6 to 3.8 per cent lipids. Seed of pigeonpea is a good source of iron and iodine and rich in essential amino acids like lysine,tyrosine, cystein and arginine. It is sturdy crop and can be grown on wide range of soil and under diverse agroecological environments. Being legume, it has symbiotic association with *rhizobium* which play an important role in fixing atmospheric nitrogen for which pigeonpea is inevitable part of various cropping system. The outer covering of its seed together with part of kernels provides a valuable feed for milch cattle (Singh, 2003).

1.2 Importance and need of study

Green revolution made our nation self sufficient in case of cereals but we are still deficient in pulse production. India still imports red gram from countries like Myanmar, Australia and Africa to satisfy the pulse requirement. This impose great burden on our economy. To get rid of this bulky expenditure, we have to think about pigeonpea improvement, as a remedial measure (Singhal, 2003).

ICRISAT scientists developed a hybrid breeding system using partial natural out crossing of the crop coupled with genetic male-sterility (Reddy *et al.* 1978). Combining these two components, ICRISAT developed the world's first pigeon pea hybrid ICPH-8 which was released for cultivation in 1991. Performance of ICPH-8 in 100 multilocation trials under diverse agro-ecological conditions conducted over a period of 6 years recorded an average30.5 percent yield gain over the best available pure line variety UPAS 120. Such yield gains of the hybrid were confirmed in a series of on farm trials. These results revealed substantial levels of hybrid vigour that could be exploited commercially. This hybrid, in spite of high yields, failed to be adopted due to the high cost of seed production and this necessitated breeding for a more efficient cytoplasmic nuclear male-sterility (CMS) system.

In order to initiate hybrid production programme on commercial scale, there are some basic requirement that has to be fulfilled by the crop *viz.,* abundant natural out pollination, efficient system of emasculation, restoration system etc. to get good hybrid seed yieldefficient pollen transfer system and sufficient amount of natural out pollination is much essential for hybrid seed production. In pigeonpea pollination is mediated by honey bee (Bhatia *et al.,* 1981). Howard *et al.* (1919) observed the natural cross pollination upto 14 per cent. Whereas Saxena *et al.* (1990) recorded the ample amount of natural out pollination upto 70 per cent, which is favorable factor in production of hybrid seed.

For commercial hybrid seed production, there is need for ease in hybridization. Traditionally, it is achieved by hand emasculation followed by pollination. But in crops like pigeonpea which is cleistogamous in nature, hand emasculation and hand pollination are not feasible for hybrid seed production because these are tedious and costly operations. This difficulty can be overcome by genetical method of emasculation i.e. through male sterility system (Chaudhary, 1986).

First report of male sterility in pigeonpea was published by Deshmukh (1959). However, it was associated with female sterility, so it was of little use. In 1978, Reddy *et al.* has given first stable genetic male sterility system in pigeonpea. After these, Wanjari *et al.* (1995) discovered another male sterility source derived from cross *Cajanus volubilis* x *Cajanus cajan*. On the basis of GMS system reported by Reddy *et al.* (1978), there are six GMS based hybrids *viz.,* ICPH-8 (ICRISAT, Hyderabad), PPH-4 (PAU, Ludhiana), COH-1 and COH-2 (TNAU, Coimbatore), AKPH-4101and AKPH-2022 (Dr. PDKV, Akola) were released for commercial cultivation.

Genetic male sterility has its own limitations i.e In case of hybrid seed production, 50 percent fertile plants from female row have to be rougued out. This acount to near about 50 per cent loss of plant population from female plots at flowering stage. Male fertile plants, which need to be rogued out, if they are not identified properly at flowering, can lead to contamination and it interferes with the purity of hybrid seed. To avoid such problems, efforts are necessary to identify seedling markers associated with male sterility (Patil *et al.,* 1998).

The other alternative is to go for cytoplasmic genetic male sterility. Reddy and Faris (1981) reported the possibility of maternal inheritance of male sterility in progenies derived from "*Cajanus scarabaeoides* x *Cajanus cajan*". Zaveri (1992) reported the progenies from a cross "*Cajanus sericeus* x *Cajanus cajan*" showing cytoplasmic male sterility. Tikka *et al.* (1997) reported first stable cytoplasmic male sterility in derivatives of inter specific cross involving the cytoplasm of *Cajanus scarabaeoides*. Wanjari *et al.* (1999) identified new source from *Cajanus volubilis* cytoplasm. So far, five primary CMS sources derived from various inter specific crosses have been reported in pigeonpea. These are designated as i) A_1 cytoplasm, derived from *Cajanus sericeus* ii) A_2 cytoplsm, derived from *Cajanus scarabaeoides* iii) A_3 cytoplasm, derived from *Cajanus volubilis* iv) A_4 cytoplasm, derived from *Cajanus cajanifolius* v) A_5 cytoplsm, derived from cultivated pigeonpea. From these CMS sources, A_2 and A_4 cytoplasm have been found to be stable and are being used in the hybrid breeding programmes in India.

In order to make use of this cytoplasmic male sterility in commercial hybrid seed production, availability of good fertility in F_1 hybrids is essential.

1.3 Objectives of the study

Keeping in view the above facts, the present study is therefore undertaken with the following objectives.

1) To assess the *per se* performance of male sterile lines, restorer lines and their hybrids.
2) To study the extent of heterosis, heterobeltiosis and useful heterosis for grain yield and its components.
3) To estimate combining ability of the parents and their hybrids.

1.4 Hypothesis

Heterosis results in increase in size, yield, general vegetative growth, etc. in F_1 hybrids compared to parents.

Combining ability analysis provides the information for selection for the desirable parents and cross combinations for exploitation.

1.5 Scope and limitations of the study

The present study on "Heterosis and combining ability studies in pigeonpea hybrids" will be carried out using Line × Tester mating design. Application of biometrical techniques like line×tester analysis has beenappeared to be the most useful tool for screening lines with rapidity and reasonable degree of confidence. This approach has practical utility in breeding programme aimed at genetic improvement for yield.

In case of line×tester design each parent does not have opportunity to mate recombine with every parent.

CHAPTER II

REVIEW OF LITERATURE

Hybrid pigeonpea breeding has a very short history starting from the discovery of genetic male sterility in 1978. Further, emphasis has been shifted to cytoplasmic genetic male sterility. A brief review of related literature has been illustrated in this chapter, underthe following headings.

2.1 Pollination in Pigeonpea

2.2 Pod and seed setting on pigeonpea male sterile lines

2.3 Male sterility in pigeonpea

2.4 Heterosis

2.5 Combining ability

2.1 Pollination in pigeonpea

Pollination behaviour of crop plants plays an important role in deciding the breeding strategies for their improvement. In pigeonpea, early part of flower bud's life cycle is cleistogamous. This condition is known as pre-anthesis cleistogamy. This leads to maximum self pollination. However, certain reports showed considerably high level of cross pollination in pigeonpea.

Datta and Deb (1970) observed that out crossing in pigeonpea was due to slow growth of pollen tube.

Prasad *et al.* (1972) observed natural out crossing in pigeonpea to the extent of 3.79 per cent to 26.66 per cent. He also observed that different varieties differ in the extent of natural out crossing.

Faegri and Vander Pijl (1979) used special terminology i.e. Melittophily for out crossing by honey bees in pigeonpea.

Bhatia *et al.* (1981) reported that out crossing in pigeonpea is mediated by honeybees especially megachile and *Apis* species.

Onim (1981) observed a reason for out crossing in pigeonpea i.e. due to delay in pollen germination after anther dehiscence.

Saxena *et al.* (1990) observed ample amount of out pollination up to 70 per cent and stated that this is sufficient level of out crossing for hybrid seed production on commercial scale.

Wanjari *et al.* (1993) reported that establishment of honey bee colonies in pigeonpea plants promote hybrid seed setting and stated that sufficient amount of natural out pollination is very much essential for production of hybrid seed.

Kumar and Saxena (2001) reported wind pollination in GMS and CMS lines of pigeonpea.

Shiying *et al.* (2002) observed the natural out pollination in the range of 15 to 30 per cent and also found that in some progenies it was extended up to 60 per cent.

Sindhu *et al.* (2003) reported cross pollination in GMS line i.e. female of pigeonpea hybrid PPH-4 in the range of 73.2 to 81.8 per cent.

2.2. Pod and seed setting on pigeonpea male sterile lines

Pigeonpea generally flowers profusely but most of the flowers are shed without setting pods. Pod set is reduced by more pod shedding and about 10-20 per cent flowers set pods (Saxena, 1990). Pod setting also depend on the presence of already developing pod bearing on the plant. The balance of source-sink, probably depends on availability of assimilates and other nutrients (Sheldrake and Narayanan, 1979). The number of flowers produced by a plant is probably too high to be supported physiologically by the plants. Pandey and Singh (1981) reported flower abortion as high as 86 per cent.

In breeding programme concern lies with desired setting of pod / seed, selfed or crossed as per the objective of the programme. Successful hybridization depends upon time of emasculation and pollination (Veerswamy, 1973), size of bud, environmental conditions besides the technical skill and competence of the workers. Pod set in pigeonpea under natural (Hammerton., 1975; Pandey and Singh., 1981) as well as artificial hybridization (Singh *et al.*, 1980) is usually very low due to abundant flower drop. However, wide range of success in hybrid seed set has been reported in the literature. For the experimental testing to identify heterotic crosses; the hybrid seeds are produced by hand pollinating female (male sterile) flowers. One trained person can pollinate about 400 flowers in a day and around 20-40 per cent pod set is achieved (Saxena *etal.*, 1986). Despite proper conditions and careful handling of buds, the pod setting in mechanical hybridization of pigeonpea as a whole is rather poor.

Rangaswamy *et al.* (1975) studied flowering and pod setting pattern in red gram and reported that at Coimbatore, flower production and pod set were maximum during 1st three weeks of flowering in summer, seed set and pod seed ratio were highest for pod formed in the 1st week of flowering.

Pandey and Singh (1981) observed 86 per cent flower abortion in pigeonpea. The varieties of late maturity had generally less proportional pod setwhereas; it was comparatively high with the early maturing varieties. It may be affected adversely due to moisture stress at flowering of late types. Pod set percentage varied from 16 to 38 per cent.

Wanjari *et al.* (1993) and Patel (2000) reported that pod setting on male sterile plants depends upon extend of out-crossing, pollen source, insect pollination, agronomical practices etc. Varied degree of pod setting in pigeonpea is reported by many research workers. An average pod setting of 38 per cent with range of 2 to 10 per cent in a set of 28 crosses involving eight parents was recorded by Singh *et al.* (1980).

Chavan (2001) observed pod setting at weekly intervals from 14^{th} November, 2000 to 14^{th} December, 2000. Mean pod setting percentage on the male sterile plants in each week from 14^{th} November to 14^{th} December, 2000 showed significant differences for the pod setting behavior. Earlier period i.e. 1^{st} week (14-21 Nov., 2000) and 2^{nd} week (22-29 Nov., 2000) had better pod set (28.62 to 29.50%) than latter period i.e. 3^{rd} week (30^{th} Nov.- 6^{th}Dec. 2000) and 4^{th} week (7-14^{th} Dec. 2000) where pod set was 25.00 to 25.25 per cent.

Saxena *et al.* (2006) reported that insect-aided natural out-crossing in pigeonpea [*Cajanus cajan* (L.) Millsp.] is a common event. It is considered to be a prime constraint in maintaining genetic purity of cultivars and genetic stocks. On the contrary, the out-crossing has also been exploited to select high-yielding varieties from landraces. For the first time, they reported natural out-crossing in four wild relatives of pigeonpea. Highest natural out-crossing (17.1%) was recorded in *C. lineatus* and it was comparable to the control cultivar Asha (22.2%). *C. albicans* and *C. scarabaeoides* exhibited 10.0 and 8.3% outcrossing respectively. *C. sericeus*was found to have lowest natural out-crossing (2.3%).

2.3 Male sterility in pigeonpea

In hybridization programme of any field crop, emasculation is primary and essential operation. Emasculation involves removal of male organ from bisexual flower before dehiscence of anther. Emasculation carried out manually, physically, chemically or genetically. Generally, hand emasculation is hard and tough job, when flower are small and cleistogamous in nature as that of pigeonpea. Very small number of seeds is obtainedwith hand emasculation followed by hand pollination

Physical and chemical means of inducing male sterility are not much impressive due to indeterminate flowering habit of pigeonpea, which continues up to time of harvest. All these things created the need to search genetic mechanism of emasculation i.e. male sterility system, which can be effectively used in hybridization programme.

2.3.1 Male sterility

Male sterility refers to a condition in which pollen are either absent or if present, they are non-functional. Koelreuter in 1763 first reported male sterility in flowering plants. Later on numerous cases of male sterility in angiosperm were reported. Allard (1960) and Duvick (1965) presented good amount of male sterility in flowering plants. More recently, work on male sterility has been reviewed by Frankel (1977) and Kaul (1988). Evidence for genetic control of male sterility comes from the work of Bateson *et al.* (1908) on sweet peas. A recessive gene governing sterility was found in several plant species. However, Soloman (1910) demonstrated that dominant genes determine male sterility in potato. Correns (1908) reported for first time that cytoplasmic factor could influence the occurrence of male sterility in which the trait would be inherited maternally. Following these initial findings, spontaneously occurring as well as induced male sterility variants have been identified in large number of plant genera, species and crosses within and between them (Kaul, 1988). The male sterility may be heritable or non-heritable and may be produced by chemicals, ionizing radiations, environmental manipulations, genetic engineering etc., Kaul (1998) gave the general pattern of classification of male sterility.

Male sterility type

Genetic (Spontaneous or induced)		Non-genetic (Induced)	
1. Phenotypic	i) Sporogenous	1. Chemicals	Male gametocides and other chemicals
	ii) Structural		
	iii) Functional	2. Physiological	- Influenced by temperature
			- Photoperiod
			- Enzyme balance
			- Other biochemicals

Some male sterile plants exhibit more than one phenotypic manifestation. Therefore, classification of male sterility on genotypic basis is vital. Accordingly, depending upon nuclear and cytoplasmic genome constitution as evidenced by the inheritance pattern, male sterility has been primarily classified into genetic, cytoplasmic and genetic cytoplasmic type.

2.3.1.1 Genetic male sterility (GMS)

Genetic male sterility is controlled by nuclear genes whose action is not influenced by cytoplasm. So, inheritance pattern and expression of sterility is entirely Mendelian.It exhibits minimum reciprocal difference and it is controlled by recessive nuclear genes in majority of cases.

Deshmukh (1959) has given first report of male sterility in pigeonpea but it was associated with the female fertility, so it was of little use.

Reddy *et al.* (1977) made deliberate search for male sterility in more than 7000 germaplasm collections and derivatives of *Cajanus cajan* x *Atylosia* species at ICRISAT. This resulted into identification of 72 sterile plants which were classified into five aberrant floral types among this, only one type having translucent white anther was found stable and useful.

Reddy *et al.* (1978) reported that the sterility was found to be caused by non-separation of tetrads during microsporangenesis and thus, they disintegrated completely and it is found to be controlled by a single recessive gene MS_1.

Wallis *et al.* (1981) reported another source of GMS in pigeonpea. It is characterized by shrivelled arrow head shaped non dehiscent brown colored anthers.

Dundas *et al.* (1981) found that the abnormality in anther development was due to degeneration of the pollen mother cells at the young tetrad stages which is a cause of this male sterility.

Dundas *et al.* (1982) found a male sterile source from an elite photoperiod insensitive breeding line Q PL-2.

Saxena *et al.* (1983) studied the allelic relationship between the translucent anther and arrow head brown coloured male sterile characters and reported that these are governed by different independent genes MS_1 and MS_2, respectively in recessive form.

Charry and Bhalla (1988) found male sterile mutant with shrunken pollen grains which was isolated from line ICP 7295 in M_2 generation after treatment with 0.2 per cent ethyl methane sulphonate (EMS) which was governed by a single recessive gene.

Mehetre *et al.* (1992) reported a male sterile mutant from gamma irradiated pigeonpea variety C-11. However this was associated with chimeral tissues. The sterility was found to be controlled by two duplicate recessive genes designated as $Stfl_1$ and $Stfl_2$. It could not be maintained for further use.

Wanjari *et al.* (1995) found another male sterility source, derived from cross *Cajanus volubilis* x *Cajanus cajan*. From these two male sterile lines, AKMS-Vol-3 and AKMS-Vol-4 were isolated. These lines are characterized by reduced anther sterility and dirty anther sterility respectively.

Rajni Raina (1996) derived new male sterile pigeonpea line *viz.*, MSHUA-7 from high yielding, long duration variety MA-97 crossed with MS-ICP-3783, the donor of male sterility gene MS_1.

Pandey and Singh (1998) screened 550 genotypes and natural population of six cultivars. Out of these, three male sterile plants were identified, one from Bahar (DAMS-1) and second from BMT-46 (DAMS-2 andDAMS-3). Segregation analysis indicated that a single recessive gene governs male sterility in DAMS-1.

Saxena and Kumar (2001) reported that male sterility characterized by light yellow reduced anthers which is similar to AKMS vol. 3 in the population of a short duration pigeonpea (*Cajanus cajan*) cv. ICPL 95010. The test cross studies showed that male sterility is genetically governed by single recessive gene. Segregation in three way cross revealed that the male sterile gene was non-allelic to MS_1 and MS_2 loci and it is designated as MS_3.

Siddanagouda (2004) found that crosses of AKMS Sr_1 with AKMS vol-3, AKMS vol-4 and AKMS vol-1 segregated in F_1 for sterility (i.e. 1F:1S csr_1)) indicating single dominant gene governs the sterility of AKMS Sr1 which was earlier proved by Wanjari *et al.* (2000) and confirmed that AKMS Sr1 male sterility is governed by different systems of male sterility gene i.e. single dominant MS gene.

2.3.1.2 Cytoplasmic male sterility (CMS)

Another form of male sterility which is not under the influence of nuclear gene but under control of cytoplasmic heredity factors (organelle genes), is termed as cytoplasmic male sterility. This type of sterility is maternally inherited and generally leads to complete sterility under normal environmental conditions. It adversely affects the development of one or more types of cells in the anther during some stages of microsporogenesis (Duvick, 1965). Sterile cytoplasm is indicated as (S) in contrast to (F) or (N) notations for the normal fertile cytoplasm. Crossing between CMS plants and male fertile plant result in a complete male sterile progeny since theplasmagenes responsible for sterility are transferred from the mother to offspring through the egg cells.

In crops that are grown for their vegetative parts e.g. onions, beets, grasses etc. this type of male sterility is advantageous. In ornamental species, the offspring of all male sterile plants are also male sterile and will tend to bloom longer than their seeded counterparts (Allard, 1960).

2.3.1.3 Cytoplasmic genetic male sterility (CGMS)

Some plants have CMS system that contains nuclear restorer genes that override the CMS conditions (Kaul, 1988). These systems are designated as having cytoplasmic genetic male sterility. Wild germplasm can be a source of sterile cytoplasm. Mutagenesis has also been used to develop CGMS in pigeonpea.

This type of male sterility was first discovered by Jones and Davis in (1944) in onion. CGMS is highly stable and it is not affected by environmental factors. In search of sterile cytoplasm, tremendous efforts were made by various workers in many crop plants and vegetables. As a result of which number of cytoplasmic sterility sources were reported and few of them found to be efficient and stable in pigeonpea crops.

Reddy and Faris (1981) reported the possibility of maternal inheritance of male sterility in the progenies derived from "*Cajanus scrabaeiodes* x *Cajanus cajan*". But the material was associated with female sterility and other defects.

Ariyanayagam *et al.* (1993) used several accessions of four wild *Cajanus* species *viz.,C. scarabaeoides, C. sericeus, C. acutifolius* and *C. albicans* as female and *C. cajan* as male. Occurrences of sterile progenies were more in cross involving *C. scarabaeioides, C. sericeus* and *C. acutifolius* crosses. He also found that these responded well in triple as well as back cross yielding 21.4 to 100 per cent sterile progenies.

Rajani Raina *et al.* (1993) searched for cytoplasmic male sterile lines using five species of Atylosia, two of Rhynocosia and two of Flrmingia and crossed with nine varieties of *Cajanus cajan*. Out of seven crosses obtained, only one plant from a cross *C. canjan* cv. T-21 x A. *mollis* was male sterile. Failure in separation of tetrad was reason for sterility.

Ariyanagam *et al.* (1995) suggested a system "multiple cross genome transfer" to establish cytoplasmic male sterility in inter specific derivatives. They reported the reversion of male sterility to fertility and the morphological deformities noticed in conventional *C. sericeus* x *C. cajan* back crossing could be minimized if more than one genome are contributed to the expected interaction with the *C. sericeus* cytoplasm. The ongoing stages were named as "Genome Transfer Stage" (GTS). The F_1 arising from GTS_1 mating was used as the cytoplasm donor in mating with ICPL-87, ICP-9880 and ICPL 90035 (GTS_2). In the successive back crosses they obtained increase in sterility at successive GT stages. A success to get male sterility upto 97-100 per cent was observed upto GTS_4.

Tikka *et al.* (1997) reported stable cytoplasmic male sterility in pigeonpea utilizing *Cajanus scarabaeiodes* as female parent. The sterility was characterized by white translucent anthers.

Rathnaswamy *et al.* (1999) used two wild species *C. cajanifolia* and *C. acutifolius* to develop cytoplsmic male sterile line using MS-CO-5 (*C. cajan*) as a male pollinator. High degree of pollen sterility ranging from 42.2 to 85.7 per cent was observed in the cross

Wanjari *et al.* (1999) identified new cytoplasmic male sterility sources from *Cajanus volubilis*, wild genotypes in derivatives of cross *Cajanus volubilis* x *C. cajan* var. ICPL-83024. The CMS was characterized by yellow non-dehiscent or poorly dehiscent anthers bearing completely sterile pollen grains. The cytoplasmic nature of male sterility was observed in the back cross generations where ICPL-85030, AKMS-21 and AKT-8811 were used as recurrent parents. However, few crosses of AKT-8811 and AKMS-21 were partially fertile and suspected to carry restorer genes.

Wanjari and Patel (2003) reported the new source of cytoplasmic male sterility derived from *C. lanceolatus.* In the inter specific crosses of *C. lanceolatus* as female and cultivated *C. cajan* variety ICP-87119 and ICPL-8863 as males, F_1 hybrid showed partial pollen fertility. However, in F_2, a few plants with complete pollen sterility were identified. These sterile plants were crossed with 28 varieties of cultivated species. The evaluation of MS x variety hybrids indicated that BSMR-840, AKT-9827, ICP-10741, ICP-10875 and MDRL-11 varieties acted as sterility maintainer as their F_1

hybrids were complete sterile. On the other hand, a cross of MS x AL-313 was found to be complete fertile indicating restoration ability.

Saxena *et al.* (2003) reviewed the work on diversification of established cytoplasmic genetic male sterility in pigeonpea under national hybrid pigeonpea programme and selected twelve agronomically superior and good combiner lines *viz.*, Pusa 33, ICPL-87, GT-100, SKNP-289, BDN-2, SKNP-88-3, SKNP-9523, T-15-15, T-21, UPAS-120 and ICPL-34023 have been converted into CMS lines through simple backcross breeding method.

Nalini and Kalpana (2004) obtained cytoplasmic nuclear male sterile plants by crossing *C. acutifolius* as female with *C. cajan* as male. Two types of CMS plants distinguished by anther morphology were identified. Both types of CMS plants showed complete anther sterility. Type-I CMS had partially or totally brown and shrivelled anther and the process of microsporogenesis was inhibited at the pre-meotic stage. Type-II CMS plants had pale and shrivelled anthers and the breakdown of microsporogenesis observed at post meiotic stage after the formation of tetrad caused sterility in plants.

2.4 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 viogur 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.

Dobzhaunsky (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.

Although the basic meaning of heterosis was clear, yet there was disagreement regarding the situation to which the term should be applied. Shull (1948) strictly reserved heterosis to describe an increase in a characteristic arising from hybridity. On the other hand, Mackey (1976) considered heterosis as a 'two-way phenomenon. Similarly, Mayo (1987) considered 'negative heterosis' in addition to positive heterosis in the sense that it may be of value for certain characteristics such as maturity period.

2.4.1 Heterosis in pigeonpea

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.

Veeraswamy *et al.* (1973) recorded that the intervarietal hybrids in red gram between C0-1(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.

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.

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.* (1979) observed high heterotic effects in crosses involving diverse parents of different maturity groups. Specifically, midlate 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 midlate 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 hundred pod weight and 100 seed weight.

Singh *et al.* (1983) observed the maximum heterotic response upto 221 per cent for grain yield in line x tester studies of pigeonpea. The best heterotic cross, Mukta x Upas-120 was identified as potential cross for early maturing hybrid.

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.

Omanga (1985) studied heterosis in seven fertile lines crossed in line x tester design and reported high heterosis percentage over mid parent for yield and other three related characters. High magnitude of heterosis was seen with MS-Prabhat than with MS3A.

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 crossA_2 x EE 76 for yield,number of clusters and pods among thirty hybrids.

Patel *et al.* (1991) using line x tester design including three 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 MS3A x DL78-1 (80%) and MS-Prabhat x TCPL-684 (78%).

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

Paul *et al.* (1996) studied heterosis for yield and yield components in hybrid pigeonpea in twenty eight 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.

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, ICPL087 and BDN-7 gave marked heterosis for yield and its components.

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 oserved within range of 21.2 to 28.9 per cent.

Manivel *et al.* (1999) suggested the use of MS 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 twenty two 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 market heterosis for seed yield and most of component characters. The cross ICP MS-3783 x LRG-30 was best hybrid combination.

Chandirakala *et al.* (2002) studied 30 pigeonpea hybrids derived from three GMS line i.e. MS Prabhat DT, MS Prabhat NDT, MS-O-50 and ten tester lines (ICPL-87104, ICPL-85010, ICPL-88009, ICPL-89008, ICPL-889020, 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 three genetic male sterile lines with twenty one testers in L×T fashion. ICPH 8 was used at 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 Mirmal-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 per cent 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.

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.

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 (CO5) was observed.

2.5 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 a 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. The following methods are generally used to estimate the combining ability.

1. Top cross method (Davis, 1927)
2. Poly cross technique (Tysdal *et al.,* 1942)
3. Diallel analysis (Griffing, 1956)
4. Line x tester analysis (Kempthorne, 1957)

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' sires were taken and all of them were mated to each of'd' dams. They also precisely expressed the variance due to general combining ability (s^2gca) and variance due to specific combining ability (s^2sca) in terms of the covariance of half-sibs (Cov (HS) and covariance of full-sibs (Cov (FS) respectively.

s^2 gca = Cov (HS)
s^2 sca = 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.

Sharma, *et al.* (1973) studied a diallel cross analysis. They found that gca variances were higher than sca variances for the characters *viz.*, plant height, days to flowering and maturity, 100 seed weight and yield per plant. They also reported that estimates of gca effects of the individual parental lines indicated a good agreement between ranking of lines for such effects and the ranking based on parental performance.

Dahiya and Barar (1977) reported low gca for flowering time and high gca for pod number, hundred seed wt. 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.* (1979) 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 midlate x late and early x late combinations are likely to give recombinations of economic worth.

Reddy *et al.* (1980) evaluated sca and gca variances from a 10 x 10 group diallel, a 28 x 28 variety diallel and a 7 x 7 variety diallel. All the diallels had indicated predominance of additive gene action for most of the charactersstudied. However, highly significant sca variances were observed for yield in all the diallels. In 10 x 10 group diallel parent G-9 had highest highly significant gca effect for yield per plot. In 7 x 7 variety diallel parent 1900-11 had highest highly significant gca effect for yield per plant.

Saxena *et al.* (1980) in a diallel cross consisted of seven early maturing lines, F_1 and F_2 generation observed that there was a preponderance of additive gene action. The parent GPL-4 was good combiner for days to flower, plant height and yield per plant whereas 3 D-8103 was good combiner for number of pods per plant and yield per plant.

Chaudhari *et al.* (1980) reported the predominance of both additive and non-additive gene action. Gca effect was significant for days to 50 per cent flowering in No-148.In the cross No-148 x Hyderabad, they found negative signiticant sca effiect for days to 50 per cent flowering. The cross C-11 x No-148 was best cross in terms of yield.

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, for 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 hybridssince 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.

Mehetre *et al.* (1988) in their studies on diallel crosses reported No. 134, 28-17-1-9 and 4834-3 as best combiners for grain yield per plant. Most of the crosses exhibiting high sca effects involved one of the parents from good combiners.

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.

Satpute *et al.* (1992) from 6x 6 diallel crosses reported that No. 148 and T-21 were good combiners for seed yield, number of pods and number of seeds per pod. The two crosses *viz.,* ICPL-86007 x No. 148 and ICPL-86012 x NO.148 had positive and significant sca effects for seed yield, number of pods and seeds per pod.

Sindhu *et al.* (1992) evaluated 8 x 8 diallel crosses for days to 50 per cent flowering, days to maturity, plant height, number of pods per plant, 100 seed wt. and seed yield plant. Significant sca, gca and reciprocal differences were observed for all the characters except seed weight. In case of seed weight, only sca effects were significant. Equal magnitude of sca and reciprocal estimates pointed to considerable change in the performance of the cross depending upon order of the female/male parent in the same cross. This is important since only one way hybridization is feasible when sterile lines are used in production of hybrids.

Khapre *et al.* (1993) studied combining ability for grain yield and it's components in diallel crosses involving seven divers pigeonpea cultivars over three cropping systems viz. sole crop, intercrop with sorghum and intercrop with pearl millet. This study revealed the predominance of additive gene effects for the yield and yield contributing characters. Parents BDN 2, ICP 6997, PBNA 54 and Daintha 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.

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.* (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, Igithana 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 K PMS 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. He 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. He 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* (la.Bahar) 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, 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-1 and per cent pod setting.

Jahagirdar (2002) carried out combining ability analysis of 24 F1's of pigeonpea obtained from crosses between 3 lines and 8 testers along with their parents.This study revealed significant non-additive gene action for almost all morpho-physiological traits as variances due to sca were higher than gca variances. The parents BDN 2, ICPL 87, BSMR 736 and ICPL 87119 were the best general combiners for grain yield/plant, number of pods/plant, total biomass/plant and grain productivity/day. Ten, out of 24 F1's showed significant positive sca effects and high *per se* performance for grain yields.

Pawar and Tikka (2003) studied 64 hybrids and revealed higher magnitude of sca variances over gca variances for all the traits which indicated pre ponderance 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 pigeon pea 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.

Phad *et al.* (2007) evaluated five lines (females) and twelve testers and sixty crosses. The parents ICPL-87119, BDN-20M, ART-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 ART8811 were the best specific cross combinations for grain yield/plant, plant spread, number of primary branches/plant, number of secondary branches/plant and number of pods/plant.

Kumar *et al.* (2009) estimated the variances due to gca and sca 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.

Beekham and Umaharan (2010) studied the mode of inheritance of a number of quality traits known to affect consumer acceptance of pigeon peas. The results showed that pod length, pod width, seeds per pod, shelling percentage and phenolic content were under the control of additive genetic effects with the non-additive effects generally being either not significant or much smaller compared to the additive genetic effects. Hundred seed weight was controlled by both additive and non-additive effects while pod biochemical characteristics viz. sugar content, starch content and protein content were governed by preponderance of non-additive genetic effects.

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 scaeffects for seed yield per plant, number of pods per plant, 100 seed weight, water absorption, leaf area index at 100 DAS and rate of photo synthesis at 80 DAS.

CHAPTER III

MATERIAL AND METHODS

The present investigation was carried out during*kharif* 2012-13 at Pulses Research Unit, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola. Geographically Akola is situated at 23°43' N latitude and 77°64' E longitude with an altitude of 281m above mean sea level. It has typical semi arid climate.

The methodology and materials used for present investigation are presented below.

3.1 Experimental material

3.1.1 Parental material

The parental material for the present study comprised of following six CMS (cytoplasmic male sterile) lines (female parents) and five pollinators/testers (male parents).

Table 3.1 List of female parents and male parents

Sr. No	Female parents (male sterile lines)	Sr. No	Male parents (testers)	Checks
1.	AKCMS-81	1.	AKPR-303	PKV-TARA
2.	AKCMS-82-2	2.	AKPR-324	ICPL-87119 (ASHA)
3.	AKCMS-83	3.	AKPR-364	
4.	AKCMS-12	4.	AKPR-372	
5.	AKCMS-93	5.	AKPR-057	
6.	ICPA-2047			

3.1.2 Crossing programme

The Line x Tester programme was undertaken at the research field of Pulses Research Unit, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola during *kharif* 2011-12 to obtain 30 F_1's.

These F_1's along with their parents and two checks were evaluated at the research field of Pulses Research Unit, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola during *kharif* 2012-13.

3.2 Methods

3.2.1 Experimental details

The details of the experiment are as under.

1.	Experimental design	: Randomized Block Design (RBD)
2.	Replications	: Three
3.	Genotypes	: 43 (30 Hybrids + 11 parents + 2 check)
4.	Number of row per plot	: One
5.	Number of plants per row	: Twenty
6.	Spacing	:
	i) Row to row	: 60 cm
	ii) Plant to plant	: 20 cm
7.	Date of sowing	: 10thJuly 2012
8.	Method of sowing	: Hand dibbling
9.	Cultural practices	: All the cultural practices as per the recommendations for pigeonpea cultivation were followed.

3.2.2 Observations recorded on plot basis

1. Days to 50 per cent flowering

The number of days required from sowing to flowering of 50 per cent plants in each genotypes and replication were recorded as days to 50 per cent flowering.

2.Days to maturity

The number of days required from sowing to the full maturity in each genotype and replication days were recorded as days to maturity.

3.2.3 Observations recorded on plant basis

1. Plant height (cm)

The plant height was recorded in centimeters from the ground levels to the tip of the main branch at the time of harvest of five randomly selected competitive plants and the average plant height was worked out.

2. Number of branches

The number of branches of five randomly selected plants was recorded at the time of harvest and the average was worked out.

3. Number of clusters

The number of clusters of five plants was recorded before harvesting by counting total number of clusters on each observational plants and the average worked out.

4. Number of pods

The number of pods of five plants was recorded before harvesting by counting total number of pods on each of five observational plants and the average was worked out.

5. Number of seeds per pod

Five fully matured pods were randomly selected from each of five observational plants and the total numbers of seeds were counted. The average number of seeds per pod was recorded.

6. 100 seed weight (g)

The weight of 100 seeds from the observational plants was measured in grams and the average was calculated.

7. Grain yield per plant (g)

The total seed obtained from the each of five observational plants were weighed and averaged.

8. Plant fertility (%)

The pollens inside the anther were observed visually and on the basis of colour pattern of pollen powder, the fertility of plant is recognized.

3.2.3 Statistical analysis

The data was subjected to following statistical analysis.

1. Analysis of variance

The analysis of variance was performed to test the significance of differences among genotypes/crosses for all the characters. Analysis of variance was carried out as per standard method (Panse and Sukhatme, 1967) for all the characters under study. The statistical model for ANOVA is as under.

$$Y_{ijk} = \mu + g_{ij} + b_k + e_{ijk}$$

Where,

Y_{ijk} = Phenotypic performance of ij^{th} genotype in k^{th} block

μ = General mean

g_{ij} = The effect of ij^{th} genotype

b_k = The effect of k^{th} block

e_{ijk} = The environmental effect

Analysis of variance

Sources of variation	Degrees of freedom	Sum of squares	Mean sum of squares(observed)	Mean squares(expected)
Replication	r-1	SSr	MSr	$\sigma^2e + g\sigma^2r$
Genotype	g-1	SSg	MSg	$\sigma^2e + r\sigma^2_g$
Parents	p-1	SSp	MSp	$\sigma^2e + rc\sigma^2p$
Crosses	c-1	SSc	MSc	$\sigma^2e + rp\sigma^2c$
Parents Vs crosses	1	SSp/c	MSp/c	$\sigma^2e + rp\sigma^2$ pc
error	(r-1)(g-1)	SSe	Mse	σ^2e

Where, r = number of replication

g = number of genotypes

p = number of parents

c = number of crosses

df - degrees of freedom

2. Estimation of average heterosis, heterobeltiosis and standard heterosis

1. Average heterosis

$$\text{Average heterosis (H1) (\%)} = \frac{\overline{F1} - \overline{MP}}{\overline{MP}} \times 100$$

Where,

$\overline{F1}$ - Mean performance of F_1

$\overline{MP}$ – Mid parental value

$$\overline{MP} = \frac{\overline{P1} + \overline{P2}}{2}$$

P1 and P2 – Mean performance of parent 1 and 2,respectively.

2. Heterobeltiosis

$$\text{Heterobeltiosis (H2) (\%)} = \frac{\overline{F1} - \overline{BP}}{\overline{BP}} \times 100$$

Where,

$\overline{F1}$ - Mean performance of F_1

$\overline{BP}$ – Mean of better parent of a cross

3. Standard heterosis

$$\text{Standard heterosis (H3) (\%)} = \frac{\overline{F1} - \overline{CHECK}}{\overline{CHECK}} \times 100$$

Where,

$\overline{CHECK}$ – Mean performance of check

The standard error of differences and critical differences were computed as under.

SE (d) for H1 = $\sqrt{(3MSe / 2r)}$

CD for H1 = SE (d) H1 x t

SE (d) for H2 = $\sqrt{(2MSe / r)}$

CD for H2 = SE (d) H2 x t

SE (d) for H3 = $\sqrt{(2MSe / r)}$

CD for H3 = SE (d) H3 x t

Where,

t = table value at 5% and 1% level for error degrees of freedom.

The `t' test was used to determine whether the F_1 mean values differed significantly from mean values of mid parent, better parent or check.

3. Analysis of variance for combining ability (Line x Tester analysis)

ANOVA for combining ability was based on the methodology given by Kempthorne (1957).

Analysis of variance for combining ability

Sr. No.	Sources of variation	Degree of freedom	Sum of squares	Mean sum of squares	
				Observed	Expected
1	Replications	r-1	SSr		
2	Females (lines)	f-1	SSf	MSf	$\sigma^2 e + r\sigma^2 fm + rm\sigma^2 f$
3	Males (tester)	m-1	SSm	MSm	$\sigma^2 e + r\sigma^2 fm + rf\sigma^2 m$
4	Females x Males	(f-1) (m-1)	SSfm	MSfm	$\sigma^2 e + r\sigma^2 fm$
5	Error	(r-1) (fm-1)	SSe	MSe	σ^2 e

Where, f - Number of females (Lines)

m - Number of males (Tester)

r - Number of replications

4. Estimates of general and specific combining ability effects

i. Population mean $\mu = \frac{X_{...}}{rmf}$ ...... where, $X_{...} = \underset{i=1}{\overset{f}{?}} \; \underset{j=1}{\overset{m}{?}} \; \underset{k=1}{\overset{r}{?}} X_{ijk}$

ii. General combining ability effects of female parents

$$g_i = \frac{X_{i.}}{rm} - \frac{X_{...}}{rmf} \text{ ...... where, } Xi.. = \underset{j=1}{\overset{m}{?}} \; \underset{k=1}{\overset{r}{?}} X_{ijk}$$

iii. General combining ability effects of male parents

$$g_i = \frac{X_{.j}}{rf} - \frac{X_{...}}{rmf} \text{ ...... where, } X_{.j} = \underset{i=1}{\overset{f}{?}} \; \underset{k=1}{\overset{r}{?}} X_{ijk}$$

iv. Specific combining ability effect of crosses

$$S_{ij} = \frac{X_{ij.}}{r} - \frac{X_{i..}}{rm} - \frac{X_{.j.}}{rf} + \frac{X_{...}}{rmf}$$

Where,

$$Xij_{.} = \underset{k=1}{\overset{r}{?}} X_{ijk}$$

$X_{...}$ - Total of all hybrids

$X_{i..}$ - Total of i^{th} female parent over all males

$X_{.j.}$ - Total of j^{th} male parent over all females

$X_{i.j.}$ - Total of ij^{th} combinations over replications.

Standard error of effect will be calculated as square root of the variance of effects.

The variance of various effects will be calculated as:

1. gca effects for lines

$$\text{Var. } g_i = \frac{(f-1)\ \sigma^2 e}{rmf} = \frac{(f-1)\ Me}{rmf}$$

$$\text{SE of } g_i = \sqrt{\text{var. (gi)}}$$

2. gca effects for testers

$$\text{Var. } g_j = \frac{(m-1)\ \sigma^2 e}{rmf} = \frac{(m-1)\ Me}{rmf}$$

$$\text{SE of } g_j = \sqrt{\text{var. (gj)}}$$

3. sca effects for hybrids

$$\text{Var. } S_{ij} = \frac{(F-1)\ (m-1)\ \sigma^2 e}{rmf} = \frac{(f-1)\ (m-1)\ Me}{rmf}$$

$$\text{SE of } (s_{ij}) = \sqrt{\text{var. (gij)}}$$

Where,

f = Number of female parents

m = Number of male parents

r = Number of replications

Me = Error mean sum of square

The critical differences were calculated by multiplying the standard error of difference with respective `t' table value at 5% and 1% level at error degrees of freedom.

CHAPTER IV

RESULTS AND DISCUSSION

The experimental results of the present investigation "Heterosis and combining ability studies in medium duration pigeonpea experimental hybrids" for various characters obtained from the statistical analysis are presented under following subheads

4.1 Results

4.1.1 Analysis of variance

4.1.2 *Per se* performance of crosses, their parents and checks

4.1.3 Useful heterosis estimated over checks PKV-TARA and ASHA

4.1.4 Average heterosis estimated over mean value of parents

4.1.5 Heterobeltiosis estimated over better parents

4.1.6 Analysis of variance for combining ability

4.1.7 General combining ability effects of parents

4.1.8 Specific combining ability effects of crosses

4.1.1 Analysis of variance

The analysis of variance for various characters has been presented in Table 4.1.

It is revealed from Table 4.1 that mean squares due to genotypes were highly significant for all the traits studied. This indicated the presence of substantial genetic variability among genotypes all the traits studied.

Further partitioning of genotypic variance into components *viz.*, parents, crosses and parents vs. crosses revealed that the parents differed significantly among themselves for all the characters under study. The mean square due to crosses also showed highly significant differences for all the traits. The mean squares due to parents vs. crosses were also showed significant for all the characters indicating the significant differences between parents and crosses.

Table 4.1 Analysis of variance for various characters

Sources of variation	d.f.	Mean sum of squares								
		Days to 50 % flowering	Days to maturity	Plant height (cm)	Number of branches	Number of clusters	Number of pods	Number of seeds per pod	100 seed weight (g)	Grain Yield per plant (g)
		1	2	3	4	5	6	7	8	9
Replications	2	0.89	4.15	140.43	0.36	0.27	26.15	0.06	2.27	26.37
Genotypes	40	182.42**	82.82**	378.11**	6.00**	59.51**	761.13**	0.48**	13.72**	73.71**
Parents	10	497.82**	147.50**	268.84**	6.18**	93.06**	444.95**	0.54**	5.06**	67.18**
Crosses	29	70.29**	60.57**	368.24**	5.96**	47.91**	824.78**	0.39**	6.89**	25.92**
Parents Vs Crosses	1	280.29**	81.43**	1757.16**	5.43*	60.28*	2076.86**	2.75**	298.57**	1524.91**
Error	80	8.80	5.27	80.92	1.04	10.84	62.00	0.15	0.41	10.08

* - Significant at 5 % level of significance

** - Significant at 1 % level of significance

4.2 *Per se* performance of crosses, their parents and checks

Per se performance of crosses their parents and checks *viz*., PKV-TARA and ICPL-87119 (ASHA) for various characters are presented in Table 4.2.

1) Days to 50% flowering

The average number of days to 50 per cent flowering ranged from 116.67 days to 134.67 days and 103.67 days to 138.33 days among the crosses and parents respectively with general mean of 125.01 days.

Among the crosses, thirteen crosses was found to be significantly superior over both the checks PKV-TARA (129.00 days) and ASHA (132.67 days) The cross AKCMS-12A X AKPR-364 (116.67 days) followed by AKCMS-93 X AKPR-364 (117.33days), AKCMS-93 X AKPR-303 (118.33 days) and AKCMS-93 X AKPR-372 (118.33 days) whereas the cross AKCMS-93A X AKPR-324 (127.67 days) and AKCMS-82-2A X AKPR-364 (125.00 days) showed significant superiority over check ASHA (132.67 days) only.

Among the parents, four female exhibited significant superiority over both the checks PKV-TARA (129.00 days) and ASHA (132.67 days) The female parents AKCMS-82-2A (103.67 days) followed by AKCMS-83A (106.00 days) AKCMS-81A (116.67 days) and AKCMS-12A (119.67 days) male parent AKPR-372 (105.67 days) was found to be early as compared to the both checks.

2) Days to maturity

The average number of days to maturity ranged from 163.67 days to 179.67 days and 155.00 days to 180.00 days among the crosses and parents respectively with general mean of 171.67 days.

Among the crosses, three crosses showed significant superiority over both the checks PKV-TARA (170.00 days) and ASHA (179.00 days). The crosses ICPA-2047A X AKPR-303 (163.67days), AKCMS-93A X AKPR-303 (164.67 days) and AKCMS-81A X AKPR-303 (166.00 days) showed earliness over both the checks PKV-TARA (170.00

days) and ASHA (179.00 days) whereas the twenty crosses showed earliness over the check ASHA (179.00 days) only. The crosses AKCMS-81A X AKPR-324 (174.67 days) followed by AKCMS-12A X AKPR-372 (174.33 days) and ICPA-2047A X AKPR-324 (173.33 days) showed earliness over the check ASHA (179.00 days).

Among the female parents, two female parents i.e. AKCMS-82-2A (155.00 days) and AKCMS-83A (165.33 days) exhibited significant superiority over the checks PKV-TARA (170.00 days) and ASHA (179.00 days).

Among male parents, AKPR-172 (166.33 days), AKPR-303 (171.00 days) and AKPR-364 (175.33 days) were significantly earlier than the check ASHA (179.00 days).

3) Plant height (cm)

The average plant height ranged from 121.90 cm to 166.00 cm and 116.33 cm to 151.67 cm among the crosses and the parents respectively with general mean of 137.18 cm.

Out of 30 crosses, not a single cross showed significantly higher plant height over both the checks PKV-TARA (151.93 cm) and ASHA (165.80 cm). The cross AKCMS-93A X AKPR-324 (166.00 cm) showed highest plant height among all the crosses followed by AKCMS-93A X AKPR-057 (160.93 cm).

None of the parents showed significant superiority over both the checks PKV-TARA (151.93 cm) and ASHA (165.80 cm) for this character.

4) Number of branches

Number of branches per plant ranged from 6.40 to 12.67 and 6.50 to 11.53 among the crosses and the parents respectively with general mean of 10.26.

Table 4.2 *Per se* performance of crosses, their parents and checks PKV (TARA) and ICPL-87119 (ASHA)

Sr. No	Crosses	Days to 50% flowering	Days to maturity	Plant height (cm)	Number of branches	Number of clusters	Number of pods	Number of seeds per pod	100 seed weight (g)	Grain Yield per plant (g)	Plant fertility (%)
		1	2	3	4	5	6	7	8	9	10
	Crosses										
1	AKCMS -81A X AKPR-303	122.67**	166.00**	133.33	9.87	23.87	71.80	4.07	11.34	24.47	90.00 (71.95)
2	AKCMS -81A X AKPR -324	129.33	174.67**	137.93	9.00	23.40	68.13	3.87	11.04	23.27	78 .33 (62.29)
3	AKCMS -81A X AKPR -364	123.00**	168.00**	129.33	9.27	17.80	107.60	3.87	10.92	27.07	100.00 (90.00)
4	AKCMS -81A X AKPR -372	123.67**	170.67**	131.27	9.93	17.53	85.80	4.07	10.85	23.27	95.77 (80.33)
5	AKCMS -81A X AKPR -057	128.00	170.67**	138.47	10.93	16.27	67.13	4.00	10.56	26.00	96.58 (81.27)
6	AKCMS -82-2A X AKPR-303	123.33**	170.33**	136.13	11.33	16.07	88.87	4.33	12.27	20.67	91.30 (73.06)
7	AKCMS -82-2A X AKPR -324	131.33	177.67	141.47	10.77	17.70	105.80	4.00	11.55	29.00	100.0 (90.00)
8	AKCMS -82-2A X AKPR -364	125.00**	169.33**	128.27	11.00	21.80	86.67	4.47	12.03	26.27	94.17 (78.79)
9	AKCMS -82-2A X AKPR -372	128.33	177.33	138.53	11.47	21.07	114.33	4.20	11.43	26.47	100.00 (90.00)
10	AKCMS -82-2A X AKPR -057	129.33	179.00	141.67	10.80	21.83	98.87	4.13	10.31	26.07	87.22 (69.70)
11	AKCMS -83A X AKPR-303	129.00	177.00	124.13	10.80	22.00	87.60	4.20	9.95	23.93	100.00 (90.00)
12	AKCMS -83A X AKPR -324	134.67	179.67	126.60	11.33	22.87	85.33	4.13	10.29	25.40	95.56 (80.10)
13	AKCMS -83A X AKPR -364	131.33	177.00	121.90	6.40	25.00	65.67	3.87	9.60	23.67	92.78 (74.41)
14	AKCMS -83A X AKPR -372	132.67	178.67	127.27	10.07	12.60	79.00	4.13	9.66	23.07	96.37 (81.01)
15	AKCMS -83A X AKPR -057	130.67	176.33	125.00	11.67	16.00	69.33	4.07	9.79	26.80	96.67 (81.39)
16	AKCMS -12A X AKPR-303	122.00**	168.33**	135.07	10.53	16.87	87.33	4.40	11.05	23.93	100.00 (90.00)
17	AKCMS -12A X AKPR -324	123.67**	168.33**	144.13	10.53	20.60	79.13	4.40	12.32	31.00	95.30 (79.84)
18	AKCMS -12A X AKPR -364	116.67**	173.00**	135.60	7.43	22.33	77.47	4.93*	12.11	24.43	91.67 (73.41)
19	AKCMS -12A X AKPR -372	123.33**	168.33**	138.67	11.20	20.27	121.00	3.93	11.34	30.00	100.00 (90.00)
20	AKCMS -12A X AKPR -057	120.00**	167.67***	140.87	9.73	13.40	77.67	4.13	12.68*	23.87	95.00 (79.55)
21	AKCMS -93A X AKPR -303	118.33**	164.67**	150.20	11.53	15.53	88.87	3.87	10.63	26.40	95.30 (79.84)

Contd...

Sr.No	Crosses	Days to 50% flowering	Days to maturity	Plant height (cm)	Number of branches	Number of clusters	Number of pods	Number of seeds per pod	100 seed weight (g)	Grain Yield per plant (g)	Plant fertility (%)
		1	2	3	4	5	6	7	8	9	10
22	AKCMS -93A X AKPR -324	127.67*	171.00**	166.00	11.27	23.60	83.67	3.87	11.50	26.43	91.79 (73.53)
23	AKCMS -93A X AKPR -364	117.33**	166.33**	151.27	12.67*	21.80	73.33	4.77*	10.63	25.67	94.17 (78.79)
24	AKCMS -93A X AKPR -372	118.33**	174.33**	156.87	11.40	19.20	61.40	4.33	11.51	25.87	85.61 (68.42)
25	AKCMS -93A X AKPR -057	128.00	170.00**	160.93	11.33	24.93	68.93	3.73	12.43	24.00	100.00 (90.00)
26	ICPA -2047A X AKPR-303	123.00**	163.67**	144.47	10.33	17.07	62.93	3.73	12.48	23.67	91.19 (73.12)
27	ICPA -2047A X AKPR -324	130.33	173.33**	152.53	10.00	27.73	75.40	5.00*	12.85**	33.67**	100.00 (90.00)
28	ICPA -2047A X AKPR -364	130.33	171.33**	135.93	7.00	22.33	65.07	4.57	12.49	24.87	91.67 (76.84)
29	ICPA -2047A X AKPR -372	128.00	173.00**	151.53	11.60	27.93	119.33	4.90*	12.72*	33.00*	100.00 (90.00)
30	ICPA -2047A X AKPR -057	128.33	170.33**	138.73	10.30	25.00	80.63	3.73	11.31	23.93	98.33 (85.69)
	Females										
1	AKCMS -81A	116.67**	169.33	131.00	10.13	24.80*	82.43	4.18	9.17	20.20	100.00 (90.00)
2	AKCMS -82-2A	103.67**	155.00	128.00	11.00	15.40	86.27	3.33	9.47	12.40	100.00 (90.00)
3	AKCMS -83A	106.00**	165.33	116.33	11.53	11.97	49.23	3.67	6.77	16.07	100.00 (90.00)
4	AKCMS -12A	119.67**	169.33	127.40	10.53	27.63**	66.63	3.87	8.83	14.13	100.00 (90.00)
5	AKCMS -93A	127.67	173.00	151.67**	11.07	24.53*	77.20	3.73	9.00	25.27**	100.00 (90.00)
6	ICPA -2047	133.33	166.67	139.80	10.50	13.43	80.40	3.87	9.61	11.43	100.00 (90.00)
	Males										
1	AKPR -303	128.00	171.00	128.07	10.07	13.80	73.47	4.80**	9.87	19.20	100.00 (90.00)
2	AKPR -324	138.33	180.00	128.67	8.20	20.53	94.63	4.00	9.39	20.27	100.00 (90.00)
3	AKPR -364	133.33	175.33	120.33	6.50	14.40	68.53	3.60	9.64	13.53	100.00 (90.00)

Contd...

Sr.No.	Genotypes	Days to 50% flowering	Days to maturity	Plant height (cm)	Number of branches	Number of clusters	Number of pods	Number of seeds per pod	100 seed weight (g)	Grain Yield per plant (g)	Plant fertility (%)
		1	2	3	4	5	6	7	8	9	10
4	AKPR-372	105.67**	166.33**	133.60	9.73	24.00	64.77	4.07	8.83	24.47*	100.00 (90.00)
5	AKPR-057	135.33	179.00	135.47	9.73	17.40	72.59	3.27	9.17	20.20	100.00 (90.00)
	Checks										
1	PKV -TARA	129.00	170.00	151.93	10.73	26.00	110.67	4.43	11.90	28.60	100.00 (90.00)
2	ICPL -87119 (ASHA)	132.67	179.00	165.80	11.17	24.33	106.33	4.13	11.47	27.33	100.00 (90.00)
	General Mean	125.01	171.37	137.18	10.26	20.06	80.98	4.10	10.72	23.74	(83.01)
	SE (m) ±	1.70	1.32	5.1	0.59	1.87	7.33	0.22	0.36	1.80	(2.01)
	CD at 5%	4.79	3.72	14.4	1.65	5.25	20.63	0.61	1.03	5.06	(5.65)
	CD at 1%	6.36	4.93	19.07	1.65	6.96	27.36	0.80	1.36	6.71	(7.49)

(Figures shown in parentheses are arc sign transformed value)

Observation taken from the counter part of B line (Maintainer / Female line)

Out of 30 crosses, one cross recorded significant superiority over the check PKV-TARA (10.73). Not a single cross showed significant superiority over the check ASHA (11.17). Among the crosses, the cross AKCMS-93A X AKPR-364 (12.67) revealed significant superiority over the check ASHA (11.17).

The female parent AKCMS-83A (11.53) and male parent AKPR-303 (10.07) recorded the maximum number of branches per plant.

5) Number of clusters

Table 4.2 revealed that the average number of clusters per plant ranged from 12.60 to 27.93 and 11.97 to 27.63 among the crosses and the parents respectively with the general mean of 20.06.

Among the crosses, not a single cross was found to significantly superior over both the checks PKV-TARA (26.00) and ASHA (24.33). The cross ICPA-2047A X AKPR-372 (27.93) recorded maximum number of clusters among all crosses followed by ICPA-2047A X AKPR-324 (27.73) and AKCMS-83A X AKPR-364 (25.00).

Among the parents, none of the male parents was found to significantly superior over both the checks PKV-TARA (26.00) and ASHA (24.33). The female parents AKCMS-12A (27.63) showed maximum number of clusters.

6) Number of pods

The average number of pods per plant ranged from 61.40 to 121.00 and 49.23 to 94.63 among the crosses and the parents respectively with general mean of 80.98 (Table 4.2)

Among the crosses, not a single cross was found to be significantly superior over the both checks PKV-TARA (110.67) and ASHA (106.33). The cross AKCMS-12A X AKPR-372 (121.00) showed maximum number of pods among all crosses followed by ICPA-2047A X AKPR-372 (119.33) and AKCMS-82-2A X AKPR-372 (114.33).

Among the parents, the male parent AKPR-324 (94.63) recorded the highest number of pods followed by AKCMS-82-2A (86.27) and AKCMS-81A (82.43), while minimum numbers of pods were recorded by the parent AKCMS-83A (49.23). None of the parents showed significant superiority for number of pods over both the checks PKV-TARA (110.67) and ASHA (106.33).

7) Number of seeds per pod

Number of seeds per pod ranged between 3.73 to 5.00 for crosses and 3.27 to 4.80 for parents with the general mean of 4.10.

Out of 30 crosses, none of the cross exhibited significant superiority over both checks PKV-TARA (4.43) and ASHA (4.13) and four crosses i.e. ICPA-2047A X AKPR-324 (5.00), AKCMS-12A X AKPR-364 (4.93), ICPA-2047A X AKPR-372 (4.90) and AKCMS-93A X AKPR-364 (4.77) exhibited significant superiority over the check ASHA (4.13) only.

Among the male parents, maximum number of seeds per pod was observed in AKPR-303 (4.80). It also showed significant superiority over the check ASHA (4.13). Among female parents, none of the parents showed significant superiority over both checks PKV-TARA (4.43) and ASHA (4.13).

8) 100 seed weight (g)

Table 4.2 revealed that average 100 seed weight ranged between 9.60 g to 12.85 g and 6.77 g to 9.87 g among the crosses and the parents respectively with the general mean of 10.72 g.

Out of 30 crosses, none of the crosses exhibited significantly higher 100 seed weight over checks PKV-TARA (11.90 g) and ASHA (11.47 g). Maximum 100 seed weight was observed in the cross ICPA-2047A X AKPR-324 (12.85 g) followed by ICPA-2047A X AKPR-372 (12.72 g) and AKCMS-12A X AKPR-324 (12.68 g) where as the cross AKCMS-83A X AKPR-364 (9.60 g) showed least 100 seed weight.

Among the parents, the male parent AKPR-303 (9.87g) recorded the highest 100 seed weight followed by AKPR-364 (9.64 g).

9) Grain yield per plant (g)

Average grain yield per plant ranged from 20.67 g to 33.67 g and 11.43 g to 25.27 g among the crosses and the parents respectively with the general mean of 23.74 g.

Out of 30 crosses, only one cross was found significantly superior over both the checks. The cross, ICPA-2047A X AKPR-344 (33.37 g) exhibited the highest grain yield per plant. This cross also showed significant superiority over both the checks PKV-TARA (28.60 g) and ASHA (27.33 g).

None of the parents showed significant superiority over both the check PKV-TARA (28.60 g) and ASHA (27.33 g). The female parent AKCMS-93A (25.27 g) recorded the highest grain yield per plant among the parents.

10) Plant fertility (%)

Average plant fertility ranged from 62.29% to 90% among the crosses and the parents showed 100% plant fertility.

Out of 30 crosses, nine crosses recorded 100% plant fertility such as AKCMS-81A X AKPR-364 (100%), AKCMS-82-2A X AKPR-324 (100%), AKCMS-82-2A X AKPR-372 (100%), AKCMS-83A X AKPR-303 (100%), AKCMS-12A X (100%), AKPR-303 (100%), AKCMS-12A X AKPR-372 (100%), AKCMS-93A X AKPR-057 (100%), ICPA-2047A X AKPR-324 (100%) and ICPA-2047A X AKPR-372 (100%). All the parents showed 100% Plant fertility.

4.1.3 Useful heterosis estimated over the checks PKV-TARA and ASHA

The percentage of useful heterosis over the checks PKV-TARA and ASHA for the characters studied is given in Table 4.3. The character wise results of useful heterosis observed in 30 crosses are presented as under.

1) Days to 50% flowering

For this character, standard heterosis ranged from -9.56 per cent to 4.39 per cent over the check PKV-TARA. Out of 30 crosses, twelve crosses showed significant negative heterosis. Highest significant negative useful heterosis was observed in the cross AKCMS-12A X AKPR-364 (-9.56%) followed by AKCMS-93A X AKPR-364 (-9.04%) and AKCMS-93A X AKPR-372 (-8.27%).

Useful heterosis ranged from -12.06 to 1.51 per cent over the check ASHA. Out of 30 crosses, fourteen cross exhibited significant negative heterosis. The highest negative significant useful heterosis was observed in the cross AKCMS-12A X AKPR-364 (-12.06%) over the check ASHA.

2) Days to maturity

Useful heterosis ranged from -3.73 per cent to 5.69 per cent over the check PKV-TARA. Out of 30 crosses, two crosses exhibited significant negative heterosis. Maximum negative heterosis was observed in the crosses ICPA-2047A X AKPR-303 (-3.73%), and AKCMS-93A X AKPR-303 (-3.14%).

The range for useful heterosis was from -8.57 per cent to 0.37 per cent over the check ASHA. Twenty two crosses exhibited significant negative useful heterosis. Highest significant negative useful heterosis was recorded by the cross ICPA-2047A X AKPR-303 (-8.57%) followed by AKCMS-93A X AKPR-303 (-8.01%) and AKCMS-81A X AKPR-303 (-7.26%) over the check ASHA.

Table 4.3 Estimates of useful heterosis over checks PKV-TARA and ICPL-87119 (ASHA) (A = check PKV-TARA and B = check ICPL-87119 (ASHA))

Crosses		Days to 50% flowering	Days to maturity	Plant height (cm)	Number of branches	Number of clusters	Number of pods	Number of seeds per pod	100 seed weight (g)	Grain yield per plant (g)
		1	2	3	4	5	6	7	8	9
AKCMS- 81A X AKPR- 303	A	-4.91 *	-2.35	-12.24 *	-8.07	-8.21	-35.12 **	-8.27	-4.71	-14.45
	B	-7.54 **	-7.26 **	-19.58 **	-11.64	-1.92	-32.48 **	-1.61	-1.11	-10.49
AKCMS- 81A X AKPR- 324	A	0.26	2.75 *	-9.21	-16.15 *	-10.00	-38.43 **	-12.78	-7.23	-18.65 *
	B	-2.51	-2.42 *	-16.81 **	-19.40 **	-3.84	-35.92 **	-6.45	-3.72	-14.88
AKCMS- 81A X AKPR- 364	A	-4.65 *	-1.18	-14.87 **	-13.66	-31.54 **	-2.77	-12.78	-8.22	-5.36
	B	-7.29 **	-6.15 **	-21.99 **	-17.01 *	-26.85 *	1.19	-6.45	-4.76	-0.98
AKCMS- 81A X AKPR- 372	A	-4.13	0.39	-13.60 **	-7.45	-32.56 **	-22.47 **	-8.27	-8.84 *	-18.65 *
	B	-6.78 **	-4.66 **	-20.83 **	-11.04	-27.95 *	-19.31 **	-1.61	-5.40	-14.88
AKCMS- 81A X AKPR- 057	A	-0.78	0.39	-8.86	1.86	-37.44 **	-39.34 **	-9.77	-11.27 *	-9.09
	B	-3.52	-4.66 **	-16.49 **	-2.09	-33.15 **	-36.87 **	-3.23	-7.92	-4.88
AKCMS- 82-2A X AKPR- 303	A	-4.39 *	0.20	-10.40 *	5.59	-38.21 **	-19.70 **	-2.26	3.07	-27.74 **
	B	-7.04 **	-4.84 **	-17.89 **	1.49	-33.97 **	-16.43 **	4.84	6.97	-24.39 *
AKCMS- 82-2A X AKPR- 324	A	1.81	4.51 **	-6.89	0.31	-31.92 **	-4.40	-9.77	-2.92	1.4
	B	-1.01	-0.74	-14.68 **	-3.58	-27.26 *	-0.50	-3.23	0.74	6.1
AKCMS- 82-2A X AKPR- 364	A	-3.10	-0.39	-15.58 **	2.48	-16.15	-21.69 **	0.75	1.07	-8.16
	B	-5.78 **	-5.40 **	-22.64 **	-1.49	-10.41	-18.50 **	8.06	4.89	-3.9
AKCMS- 82-2A X AKPR- 372	A	-0.52	4.31 **	-8.82	6.83	-18.97	3.31	-5.26	-3.92	-7.46
	B	-3.27	-0.93	-16.45 **	2.69	-13.42	7.52	1.61	-0.29	-3.17
AKCMS- 82-2A X AKPR- 057	A	0.26	5.29 **	-6.76	0.62	-16.03	-10.66	-6.77	-13.33 **	-8.86
	B	-2.51	0.00	-14.56 **	-3.28	-10.27	-7.02	0.00	-10.05 *	-4.63
AKCMS- 83A X AKPR- 303	A	0.00	4.12 **	-18.30 **	0.62	-15.38	-20.84 **	-5.26	-16.37 **	-16.32
	B	-2.76	-1.12	-25.13 **	-3.28	-9.59	-17.62 **	1.61	-13.21 **	-12.44
AKCMS- 83A X AKPR- 324	A	4.39 *	5.69 **	-16.67 **	5.59	-12.05	-22.89 **	-6.77	-13.50 **	-11.19
	B	1.51	0.37	-23.64 **	1.49	-6.03	-19.75 **	0.00	-10.23 *	-7.07

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Crosses		Days to 50% flowering	Days to maturity	Plant height (cm)	Number of branches	Number of clusters	Number of pods	Number of seeds per pod	100 seed weight (g)	Grain yield per plant (g)
		1	2	3	4	5	6	7	8	9
AKCMS- 83A X AKPR- 364	A	1.81	4.12 **	-19.77 **	-40.37 **	-3.85	-40.66 **	-12.78	-19.34 **	-17.25
	B	-1.01	-1.12	-26.48 **	-42.69 **	2.74	-38.24 **	-6.45	-16.29 **	-13.41
AKCMS- 83A X AKPR- 372	A	2.84	5.10 **	-16.24 **	-6.21	-51.54 **	-28.61 **	-6.77	-18.82 **	-19.35 *
	B	0.00	-0.19	-23.24 **	-9.85	-48.22 **	-25.71 **	0.00	-15.75 **	-15.61
AKCMS- 83A X AKPR- 057	A	1.29	3.73 **	-17.73 **	8.70	-38.46 **	-37.35 **	-8.27	-17.75 **	-6.29
	B	-1.51	-1.49	-24.61 **	4.48	-34.25 **	-34.80 **	-1.61	-14.64 **	-1.95
AKCMS- 12A X AKPR- 303	A	-5.43 *	-0.98	-11.10 *	-1.86	-35.13 **	-21.08 **	-0.75	-7.15	-16.32
	B	-8.04 **	-5.96 **	-18.54 **	-5.67	-30.68 *	-17.87 **	6.45	-3.65	-12.44
AKCMS- 12A X AKPR- 324	A	-4.13	-0.98	-5.13	-1.86	-20.77	-28.49 **	-0.75	3.55	8.39
	B	-6.78 **	-5.96 **	-13.07 **	-5.67	-15.34	-25.58 **	6.45	7.47	13.41
AKCMS- 12A X AKPR- 364	A	-9.56 **	1.76	-10.75 *	-30.75 **	-14.10	-30.00 **	11.28	1.78	-14.57
	B	-12.06 **	-3.35 **	-18.21 **	-33.43 **	-8.22	-27.15 **	19.35 *	5.62	-10.61
AKCMS- 12A X AKPR- 372	A	-4.39 *	-0.98	-8.73	4.35	-22.05	9.34	-11.28	-4.67	4.90
	B	-7.04 **	-5.96 **	-16.37 **	0.30	-16.71	13.79 *	-4.84	-1.06	9.76
AKCMS- 12A X AKPR- 057	A	-6.98 **	-1.37	-7.28	-9.32	-48.46 **	-29.82 **	-6.77	6.55	-16.55
	B	-9.55 **	-6.33 **	-15.04 **	-12.84	-44.93 **	-26.96 **	0.00	10.58 *	-12.68
AKCMS- 93A X AKPR- 303	A	-8.27 **	-3.14 *	-1.14	7.45	-40.26 **	-19.70 **	-12.78	-10.67 *	-7.69
	B	-10.80 **	-8.01 **	-9.41 *	3.28	-36.16 **	-16.43 **	-6.45	-7.30	-3.41
AKCMS- 93A X AKPR- 324	A	-1.03	0.59	9.26	4.97	-9.23	-24.40 **	-12.78	-3.36	-7.58
	B	-3.77	-4.47 **	0.12	0.90	-36.16 **	-21.32 **	-6.45	0.29	-3.29
AKCMS- 93A X AKPR- 364	A	-9.04 **	-2.16	-0.44	18.01 *	-16.15	-33.73 **	7.52	-10.67 *	-10.26
	B	-11.56 **	-7.08 **	-5.39	13.43	-10.41	-31.03 **	15.32	-7.30	-6.10
AKCMS- 93A X AKPR- 372	A	-8.27 **	2.55 *	3.25	6.21	-26.15 *	-44.52 **	-2.26	-3.27	-9.56
	B	-10.80 **	-2.61 *	-2.94	2.09	-21.10	-42.26 **	4.84	0.39	-5.37

Contd...

Crosses		Days to 50% flowering	Days to maturity	Plant height (cm)	Number of branches	Number of clusters	Number of pods	Number of seeds per pod	100 seed weight (g)	Grain yield per plant (g)
		1	2	3	4	5	6	7	8	9
AKCMS- 93A X AKPR-057	A	-0.78	0.00	5.92	5.59	-4.10	-37.71 **	-15.79 *	4.45	-16.08
	B	-3.52	-5.03 **	-2.94	1.49	2.47	-35.17 **	-9.68	8.40	-12.20
ICPA- 2047A x AKPR-303	A	-4.65 *	-3.73 **	-4.91	-3.73	-34.36 **	-43.13 **	-15.79 *	4.89	-17.25
	B	-7.29 **	-8.57 **	-12.87 **	-7.46	-29.86 *	-40.82 **	-9.68	8.85	-13.41
ICPA- 2047A x AKPR-324	A	1.03	1.96	0.39	-6.83	6.67	-31.87 **	12.78	7.99	17.72
	B	-1.76	-3.17 **	-8.00	-10.45	13.97	-29.09 **	20.97 *	12.08 *	23.17 *
ICPA- 2047A x AKPR-364	A	1.03	0.78	-10.53 *	-34.78 **	-14.10	-41.20 **	3.01	5.00	-13.05
	B	-1.76	-4.28 **	-18.01 **	-37.31 **	-8.22	-38.81 **	10.48	8.97	-9.02
ICPA- 2047A x AKPR-372	A	-0.78	1.76	-0.26	8.07	7.44	7.83	10.53	6.92	15.38
	B	-3.52	-3.35 **	-8.60	3.88	14.79	12.23	18.55 *	10.96 *	20.73 *
ICPA- 2047A x AKPR-057	A	-0.52	1.76	-8.69	-4.04	-3.85	-27.14 **	-15.79 *	-4.99	-16.32
	B	-3.27	-4.84 **	-16.32 **	-7.76	2.74	-24.17 **	-9.68	-1.40	-12.44
SE (d) ±		2.75	2.08	7.23	0.77	2.92	6.52	0.34	0.52	2.55
CD at 5 %		5.51	4.17	14.46	1.55	5.84	13.06	0.68	1.04	5.10
CD at 1 %		7.33	5.55	19.24	2.06	7.77	17.37	0.91	1.39	6.79

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

3) Plant height

Useful heterosis over the check PKV-TARA ranged from -19.77 per cent to 9.26 per cent. Out of 30 crosses, none of the crosses revealed significant positive useful heterosis over the check PKV-TARA. Maximum heterosis was depicted by the crosses AKCMS-93A X AKPR-324 (9.26%) followed by AKCMS-93A X AKPR-057 (5.92%) and AKCMS-93A X AKPR-372 (3.25%).

Over the check ASHA, useful heterosis ranged from -26.48 per cent to -0.12 per cent. Out of 30 crosses, twenty three crosses showed significant negative useful heterosis over the check ASHA. However, none of the cross showed significant positive useful heterosis over the check ASHA for this character.

4) Number of branches

Standard heterosis for this character ranged from -40.37 per cent to 18.01 per cent over the check PKV-TARA. Only one cross exhibited significant and positive standard heterosis for this trait over the check PKV-TARA. The cross AKCMS-93A X AKPR-364 (18.01 %) showed highest standard heterosis over the check PKV-TARA.

Over the check ASHA, standard heterosis for number of branches per plant ranged from -42.69 per cent to 13.43 per cent. Out of 30 crosses, none of the crosses showed significant and positive standard heterosis for this trait. The maximum useful heterosis over check ASHA was exhibited by the cross AKCMS-93A X AKPR-364 (13.43%) followed by AKCMS-83A X AKPR-057 (4.48%), and ICPA-2047A X AKPR-372 (3.88%).

5) Number of clusters

Useful heterosis ranged from -51.54 per cent to 7.44 per cent over the check PKV-TARA for this trait. Out of 30 crosses, none of the cross showed significant and positive standard heterosis for this trait. The maximum useful heterosis over the check PKV-TARA was exhibited by the cross ICPA-2047A X AKPR-372 (7.44%).

The range of useful heterosis was from -48.22 per cent to 14.79 per cent over the check ASHA for this character. Out of 30 crosses, none of the cross showed significant positive useful heterosis for this trait. The maximum useful heterosis over the check ASHA was exhibited by the cross ICPA-2047A X AKPR-372 (14.79%).

6) Number of pods

The useful heterosis over the check PKV-TARA ranged from -44.52 per cent to 9.34 per cent for this character. Out of 30 crosses, none of the cross showed significant positive useful heterosis for this trait. The maximum useful heterosis over the check PKV-TARA was exhibited by the cross AKCMS-12A X AKPR-372 (9.34).

The range of useful heterosis was from -42.26 to 13.79 per cent over the check ASHA for this trait. Out of 30 crosses, only one cross exhibited significant positive useful heterosis over the check ASHA. The cross AKCMS-12A X AKPR-372 (13.79) showed significant positive useful heterosis over the check ASHA.

7) Number of seeds per pod

For this trait, the range of useful heterosis was observed from -15.79 per cent to 12.78 per cent was observed over the check PKV-TARA. None of the cross showed positive and significant useful heterosis over the check PKV-TARA. However, the cross ICPA-2047A X AKPR-324 (12.78) showed the maximum positive useful heterosis over the check PKV-TARA.

Useful heterosis ranged from -9.68 per cent to 20.97 per cent over the check ASHA. Only three crosses showed significant positive useful heterosis. Maximum significant positive useful heterosis was observed in the cross ICPA-2047A X AKPR-324 (20.97%) followed by

AKCMS-12A X AKPR-364 (19.35%) and ICPA-2047A X AKPR-372 (18.55%).

8) 100 seed weight

For this trait, useful heterosis ranged from -19.34 per cent to 7.99 per cent over the check PKV-TARA. None of the crosses showed positive significant useful heterosis over the check PKV-TARA. The cross ICPA-2047A X AKPR-324 (7.99%) exhibited maximum positive useful heterosis over the check PKV-TARA.

Useful heterosis ranged from -16.29 to 12.08 per cent over the check ASHA. Out of 30 crosses, only three crosses showed positive significant useful heterosis. Maximum useful heterosis was observed in the crosses ICPA-2047A X AKPR-324 (12.08%) followed by ICPA-2047A X AKPR-372 (10.96%) and AKCMS-12A X AKPR-057 (10.58%).

9) Grain Yield per plant (g)

Useful hetrosis for this character ranged from -27.74 per cent to 17.72 per cent over the check PKV-TARA. Out of 30 crosses, none of the crossshowed significant and positive useful heterosis. Maximum positive useful heterosis was observed in the cross ICPA-2047A X AKPR-324 (17.72%) followed by ICPA-2047A X AKPR-372 (15.38%) and AKCMS-12A X AKPR-372 (4.90%) over the check PKV-TARA.

The range of useful heterosis was observed from -24.39 per cent to 23.17 per cent over the check ASHA. Only two crosses exhibited significant and positive useful heterosis. Maximum positive and significant useful heterosis was observed in the crosses ICPA-2047A X AKPR-324 (23.17%)and ICPA-2047A X AKPR-372 (20.73%).

4.1.4 Average heterosis (%)

Average heterosis can be defined as the superiority or inferiority of the F_1 hybrid over mid parental value. The percentage of average heterosis over mid parent for the characters studied is given in Table 4.4. The character wise results of average heterosis observed in 30 crosses tested are presented as under.

1) Days to 50% flowering

For this character, negative heterosis is desirable. Average heterosis ranged from -10.09 per cent to 25.35 per cent. Out of 30 crosses, only ten crosses showed significant negative average heterosis. Highest significant negative heterosis was observed in the cross AKCMS-93A X AKPR-364 (-10.09%) followed by AKCMS-12A X AKPR-364 (-7.77%) and AKCMS-93A X AKPR -303 (-7.43%).

2) Days to maturity

The average heterosis ranged from -4.50 per cent to 10.37 per cent. Out of 30 crosses, nine crosses exhibited significant negative average heterosis. Maximum negative average heterosis was observed in the cross AKCMS-93A X AKPR-364 (-4.50%) followed by AKCMS-93A X AKPR-303 (-4.26 %) and AKCMS-12A X AKPR-057 (-3.73%).

3) Plant height (cm)

The average heterosis for plant height ranged from -0.71 per cent to 18.43 per cent. Out of 30 crosses, eight crosses revealed significant positive average heterosis. Maximum average heterosis was depicted by the cross AKCMS-12A X AKPR-364 (18.43%) followed by ICPA-2047A X AKPR-324 (13.63%) and AKCMS-12A X AKPR-324 (12.57%).

4) Number of branches

Average heterosis for this character ranged from -29.02 per cent to 44.21 per cent (Table 4.4). Out of 30 crosses, five crosses exhibited positive significant average heterosis for this trait. The cross AKCMS-93A X AKPR-364 (44.21%) showed highest average heterosis followed by the crosses AKCMS-82-2A X AKPR-364 (25.71%) and AKCMS-93A X AKPR-324 (16.96%).

5) Number of clusters

The range of average heterosis was from -40.49 per cent to 89.63 per cent (Table 4.4). Nine crosses recorded significant and positive average heterosis for this trait. The cross AKCMS-83A X AKPR-364 (89.63%) showed maximum positive average heterosis followed by ICPA-2047A X AKPR-324 (63.30%) and ICPA-2047A X AKPR-057 (62.16%).

6) Number of pods

For number of pods, average heterosis ranged from -23.04 per cent to 84.17 per cent (Table 4.4). Out of 30 crosses, twelve crosses showed significant and positive heterosis. The cross AKCMS-12A X AKPR-372 (84.17%) depicted the highest significant positive heterosis followed by ICPA-2047A X AKPR-372 (64.41%) and AKCMS-82-2A X AKPR-364 (51.40%).

7) Number of seeds per pod

For this trait, average heterosis was in the range of -13.85 per cent to 32.14 per cent. Out of 30 crosses, eight crosses showed significant positive average heterosis. Maximum positive significant average heterosis was observed in the crosses AKCMS-12A X AKPR-364 (32.14%) followed by AKCMS-93A X AKPR -364 (30.00%) and AKCMS-82-2A X AKPR -364 (28.85%)

Table 4.4 Estimates of average heterosis (%)

Sr.No.	Crosses	Days to 50 % flowering	Days to maturity	Plant Height (cm)	Number of branches	Number of clusters	Number of pods	Number of seeds per pod	100seed weight (g)	Grain Yield per plant (g)
		1	2	3	4	5	6	7	8	9
1	AKCMS -81A X AKPR-303	0.27	-2.45 *	2.93	-2.31	23.66	-7.89	-9.43	19.12 **	24.20 *
2	AKCMS -81A X AKPR -324	1.44	0.00	6.24	-1.82	3.24	-23.04 **	-5.46	18.97 **	14.99
3	AKCMS -81A X AKPR -364	-1.60	-2.51 *	2.92	11.42	-9.18	42.55 **	-0.60	16.13 **	60.47 **
4	AKCMS -81A X AKPR -372	11.24 **	1.69	-0.78	0.00	-28.14 **	16.58 *	-1.37	20.50 **	4.18
5	AKCMS -81A X AKPR -057	1.59	-2.01	3.93	10.07	-22.91	-13.39	7.43	15.16 **	28.71 *
6	AKCMS -82-2A X AKPR-303	6.47 **	4.50 **	6.33	7.59	10.05	11.27	6.56	26.87 **	30.80 *
7	AKCMS -82-2A X AKPR -324	8.54 **	6.07 **	10.23 *	12.15	-1.48	16.97 **	9.09	22.52 **	77.55 **
8	AKCMS -82-2A X AKPR -364	5.49 **	2.52 *	3.30	25.71 **	46.31 **	11.97	28.85 **	25.90 **	102.57 **
9	AKCMS -82-2A X AKPR -372	22.61 **	10.37 **	5.91	10.61	6.94	51.40 **	13.51	24.94 **	43.58 **
10	AKCMS -82-2A X AKPR -057	8.23 **	7.19 **	7.54	4.18	33.13 *	24.48 **	25.25 **	10.69 *	59.92 **
11	AKCMS -83A X AKPR-303	10.26 **	5.25 **	1.58	0.00	70.76 **	42.79 **	-0.79	19.63 **	35.73 **
12	AKCMS -83A X AKPR -324	10.23 **	4.05 **	3.35	14.86 *	40.72 *	18.63 *	7.83	27.40 **	39.82 **
13	AKCMS -83A X AKPR -364	9.75 **	3.91 **	3.01	-29.02 **	89.63 **	11.52	6.42	17.00 **	59.91 **
14	AKCMS -83A X AKPR -372	25.35 **	7.74 **	1.84	-5.33	-29.94 *	38.60 **	6.90	23.82 **	13.82
15	AKCMS -83A X AKPR -057	8.29 **	2.42 *	-0.71	9.72	8.97	13.83	17.31 *	22.83 **	47.79 **
16	AKCMS -12A X AKPR-303	-1.48	-1.08	5.74	2.27	-18.58	24.67 **	1.54	18.17 **	43.60 **
17	AKCMS -12A X AKPR -324	-4.13 *	-3.63 **	12.57 *	12.46	-14.46	-1.86	11.86	35.26 **	80.23 **
18	AKCMS -12A X AKPR -364	-7.77 **	0.39	9.47	-12.72	6.26	14.62	32.14 **	31.15 **	76.63 **
19	AKCMS -12A X AKPR -372	9.47 **	0.30	6.26	10.53	-21.50 *	84.17 **	-0.84	28.43 **	55.44 **
20	AKCMS -12A X AKPR -057	-5.88 **	-3.73 **	7.18	-3.95	-40.49 **	11.57	15.89	40.89 **	39.03 **

Contd...

Sr.No.	Crosses	Days to 50 percent flowering	Days to maturity	Plant height (cm)	Number of branches	Number of clusters	Number of pods	Number of seeds per pod	100 seed weight (g)	Grain Yield per plant (g)
		1	2	3	4	5	6	7	8	9
21	AKCMS -93A X AKPR -303	-7.43 **	-4.26 **	7.39	9.15	-18.96	17.96 *	-9.37	12.69 *	18.74
22	AKCMS -93A X AKPR -324	-4.01 *	-3.12 **	18.43 **	16.96 *	4.73	-2.62	0.00	25.08 **	16.11
23	AKCMS -93A X AKPR -364	-10.09 **	-4.50 **	11.23 *	44.21 **	11.99	0.64	30.00 **	14.08 **	32.30 **
24	AKCMS -93A X AKPR -372	1.43	2.75 *	9.98 *	9.62	-20.88 *	-13.50	11.11	29.10 **	4.02
25	AKCMS -93A X AKPR -057	-2.66	-3.41 **	12.10 **	8.97	18.92	-7.96	6.67	36.84 **	5.57
26	ICPA -2047A X AKPR -303	-5.87 **	-3.06 **	7.86	0.49	25.34	-18.20 *	-13.85 *	28.18 **	54.52 **
27	ICPA -2047A X AKPR -324	-4.05 *	0.00	13.63 **	6.95	63.30 **	-13.84 *	27.12 **	35.30 **	112.41 **
28	ICPA -2047A X AKPR -364	-2.25	0.19	4.51	-17.65 *	60.48 **	-12.62	22.32 **	29.84 **	99.20 **
29	ICPA -2047A X AKPR -372	7.11 **	3.90 **	10.85 *	14.66 *	49.24 **	64.41 **	23.53 **	37.98 **	83.84 **
30	ICPA -2047A X AKPR -057	-4.47 *	-1.45	0.80	1.81	62.16 **	5.41	4.67	20.44 **	51.32 **
	SE (d) ±	2.38	1.81	6.26	0.67	2.53	5.65	0.30	0.45	2.21
	CD at 5 %	4.77	3.61	12.53	1.34	5.06	11.31	0.59	0.90	4.42
	CD at 1 %	6.35	4.81	16.67	1.78	6.73	15.05	0.79	1.20	5.88

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

8) 100 seed weight (g)

Average heterosis ranged from 10.69 per cent to 40.89 per cent. Out of 30 crosses, thirty crosses exhibited significant and positive heterosis for this character. Maximum positive significant average heterosis was depicted by the crosses AKCMS-12A X AKPR-057 (40.89%) and ICPA-2047A X AKPR-324 (37.98%).

9) Grain Yield per plant (g)

The range of average heterosis of 4.02 per cent to 112.41 per cent was observed for grain yield per plant. Out of 30 crosses, twenty three crosses showed positive significant average heterosis. Maximum average heterosis was recorded in the cross ICPA-2047A X AKPR-324 (112.41%) followed by AKCMS-82-2A X AKPR-364 (102.57%) and ICPA-2047A X AKPR-364 (99.20%).

4.1.5 Heterobeltiosis (%)

Heterobeltiosis can be defined as the superiority of the hybrid over the better parent. The percentage of heterobeltiosis estimated for the characters studied is given in Table 4.5. Positive heterobeltiosis is desirable for all the characters except days to 50 per cent flowering and days to maturity for which negative heterobeltiosis are desirable. Character wise results of heterobeltiosis observed in the 30 crosses evaluated are presented as under.

1) Days to 50% flowering

For this character negative heterobeltiosis is desirable. The heterobeltiosis ranged from -8.09 per cent to 26.69 per cent (Table 4.5). Out of 30 crosses, two cross showed significant negative heterobeltiosis i.e. AKCMS-93A X AKPR -364 (-8.09%) and AKCMS-93A X AKPR-303 (-7.31%).

2) Days to maturity

Heterosis over better parent ranged from -3.85 per cent to 15.48 per cent (Table 4.5). For this trait, out of 30 crosses, two crosses showed significant negative heterobeltiosis i.e. AKCMS-93A X AKPR-364 (-3.85%) and AKCMS-93A X AKPR-303 (-3.70%).

3) Plant height

For this trait heterobeltosis ranged from -7.73 per cent to 12.02 per cent. One out of the 30 crosses revealed significant positive heterobeltiosis. Maximum positive significant heterobeltiosis was depicted by the cross AKCMS-12A X AKPR-324 (12.02%) while minimum heterobeltiosis was displayed by the cross AKCMS-83A X AKPR-057 (-7.73%) which is not desirable for this character.

4) Number of branches

Heterobeltiosis for number of branches ranged from -44.51 per cent to 14.46 per cent. One cross depicted significant and positive heterobeltiosis for this trait. The cross AKCMS-93A X AKPR-364 (14.46%) expressed highest positive significant heterobeltiosis.

5) Number of clusters

The range for this trait was observed from -51.51 per cent to 73.61 per cent. Out of 30 crosses, six crosses exhibited positive significant heterobeltiosis for this trait. The cross AKCMS-83A X AKPR-364 (73.61%) showed maximum positive significant heterobeltiosis followed by AKCMS-83A X AKPR-303 (59.42%) and ICPA-2047A X AKPR-364 (55.09%).

6) Number of pods

The heterobeltiosis range of -28.00 per cent to 81.59 per cent was observed for this character. Out of 30 crosses seven crosses showed significant and positive heterobeltiosis. The cross AKCMS-93A X AKPR-372 (81.59%) followed by ICPA-2047A X AKPR-372 (48.42%) and AKCMS-82-2A X AKPR-372 (32.53%) recorded maximum positive heterobeltiosis.

Table 4.5 Estimates of heterobeltiosis (%)

Sr.No.	Crosses	Days To 50 % flowering	Days to maturity	Plant Height (cm)	Number of branches	Number of clusters	Number of pods	Number of seeds per pod	100seed weight (g)	Grain Yield per plant (g)
		1	2	3	4	5	6	7	8	9
1	AKCMS -81A X AKPR-303	5.14 *	-1.97	1.78	-2.63	-3.76	-12.90	-15.28 *	14.93 **	21.12
2	AKCMS -81A X AKPR -324	10.86 **	3.15 *	5.29	-11.18	-5.65	-28.00 **	-7.50	17.60 **	14.80
3	AKCMS -81A X AKPR -364	5.43 *	-0.79	-1.27	-8.55	-28.23 *	30.53 **	-7.50	13.33 *	33.99 **
4	AKCMS -81A X AKPR -372	17.03 **	2.61 *	-1.75	-1.97	-29.30 *	4.08	-2.71	18.28 **	-4.90
5	AKCMS -81A X AKPR -057	9.71 **	0.79	2.21	7.89	-34.41 **	-18.56 *	-4.31	15.13 **	28.71 *
6	AKCMS -82-2A X AKPR-303	18.97 **	9.89 **	6.30	3.03	4.33	3.01	-9.72	24.31 **	7.64
7	AKCMS -82-2A X AKPR -324	26.69 **	14.62 **	9.95	-2.12	-13.80	11.80	0.00	21.99 **	43.09 **
8	AKCMS -82-2A X AKPR -364	20.58 **	9.25 **	0.21	0.00	41.56 *	0.46	24.07 *	24.81 **	94.09 **
9	AKCMS -82-2A X AKPR -372	23.79 **	14.41 **	3.69	4.24	-12.22	32.53 **	3.28	20.74 **	8.17
10	AKCMS -82-2A X AKPR -057	24.76 **	15.48 **	4.58	-1.82	25.48	14.61	24.00 *	8.92	29.04 *
11	AKCMS -83A X AKPR-303	21.70 **	7.06 **	-3.07	-6.36	59.42 **	19.24 *	-12.50	0.86	24.65
12	AKCMS -83A X AKPR -324	27.04 **	8.67 **	-1.61	-1.73	11.36	-9.83	3.33	9.64	25.33 *
13	AKCMS -83A X AKPR -364	23.90 **	7.06 **	1.30	-44.51 **	73.61 **	-4.18	5.45	-0.39	47.30 **
14	AKCMS -83A X AKPR -372	25.55 **	8.06 **	-4.74	-12.72	-47.50 **	21.98 *	1.64	9.37	-5.72
15	AKCMS -83A X AKPR -057	23.27 **	6.65 **	-7.73	1.16	-8.05	-4.48	10.91	6.78	32.67 *
16	AKCMS -12A X AKPR-303	1.95	-0.59	5.47	0.00	-38.96 **	18.87 *	-8.33	11.98 *	24.65
17	AKCMS -12A X AKPR -324	3.34	-0.59	12.02 *	0.00	-25.45 *	-16.38 *	10.00	31.26 **	52.96 **
18	AKCMS -12A X AKPR -364	-2.51	2.17	6.44	-29.43 **	-19.18	13.04	27.59 **	25.68 **	72.88 **
19	AKCMS -12A X AKPR -372	16.72 **	1.20	3.79	6.33	-26.66 *	81.59 **	-3.28	28.43 **	22.62 *
20	AKCMS -12A X AKPR -057	0.28	-0.98	3.99	-7.59	-51.51 **	7.00	6.90	38.33 **	18.15

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Sr.No.	Crosses	Days to 50 percent flowering	Days to maturity	Plant height (cm)	Number of branches	Number of clusters	Number of pods	Number of seeds per pod	100 seed weight (g)	Grain Yield per plant (g)
		1	2	3	4	5	6	7	8	9
21	AKCMS -93A X AKPR -303	-7.31 **	-3.70 **	-0.97	4.22	-36.68 **	15.11	-19.44 **	7.74	4.49
22	AKCMS -93A X AKPR -324	0.00	-1.16	9.45	1.81	-3.80	-11.59	-3.33	22.50 **	4.62
23	AKCMS -93A X AKPR -364	-8.09 **	-3.85 **	-0.26	14.46 *	-11.14	-5.01	27.68 **	10.31	1.58
24	AKCMS -93A X AKPR -372	11.99 **	4.81 **	3.43	3.01	-21.74	-20.47 *	6.56	27.90 **	2.37
25	AKCMS -93A X AKPR -057	0.26	-1.73	6.11	2.41	1.63	-10.71	0.00	35.60 **	-5.01
26	ICPA -2047A X AKPR -303	-3.91	-1.80	3.34	-1.59	23.67	-21.72 **	-22.22 **	26.51 **	23.26
27	ICPA -2047A X AKPR -324	-2.25	4.00 **	9.11	-4.76	35.06 *	-20.32 **	25.00 **	33.74 **	66.12 **
28	ICPA -2047A X AKPR -364	-2.25	2.80 *	-2.77	-33.33 **	55.09 **	-19.07 *	18.10 *	29.66 **	83.74 **
29	ICPA -2047A X AKPR -372	21.14 **	4.01 **	8.39	10.48	16.39	48.42 **	20.49 *	32.41 **	34.88 **
30	ICPA -2047A X AKPR -057	-3.75	2.20	-0.76	-1.90	43.68 *	0.29	-3.45	17.66 **	18.48
	SE (d) ±	2.75	2.08	7.23	0.77	2.92	6.52	0.34	0.52	2.55
	CD AT 5 %	5.51	4.17	14.46	1.55	5.84	13.06	0.68	1.04	5.10
	CD AT 1 %	7.33	5.55	19.24	2.06	7.77	17.37	0.91	1.39	6.79

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

7) Number of seeds per pod

For this trait, heterobeltiosis ranged from -22.22 per cent to 27.68 per cent. Out of 30 crosses, seven crosses showed significant positive heterobeltiosis. The cross AKCMS-93A X AKPR-364 (27.68%) showed maximum positive significant heterobeltiosis followed by AKCMS-12A X AKPR-364 (27.59%) and ICPA-2047A X AKPR-324 (25.00%).

8) 100 seed weight

For this trait, heterobeltiosis ranged from -0.39 per cent to 38.33 per cent. Twenty two crosses exhibited positive significant heterosis over better parent for this character. Maximum positive significant heterobeltiosis was displayed by the cross AKCMS-12A X AKPR-057 (38.33%) followed by the crosses AKCMS-93A X AKPR-057 (35.60%) and ICPA-2047A X AKPR-324 (33.74%).

9) Grain yield per plant

Heterobeltiosis for grain yield per plantranged from -5.01 per cent to 94.09 per cent. Out of 30 crosses, fourteen crosses expressed significantly positive heterobeltiosis. Maximum heterosis over better parent was observed in cross AKCMS-82-2A X AKPR-364 (94.09%) followed by ICPA-2047A X AKPR-364 (83.74%) and AKCMS-12A X AKPR-364 (72.88%).

4.1.6 Analysis of variance for combining ability

Line x tester analysis of 30 crosses obtained by crossing 6 CMS lines with 5 testers was carried out and the total variance due to crosses was partitioned into portions attributable to females (lines), males (testers), interaction females vs. males (lines vs. testers) and error sources. Analysis of variance for combining ability is presented in Table 4.6.

The mean squares due to females were significant for days to 50% flowering, days to maturity, plant height and 100 seed weight. While the mean squares due to males were significant for days to 50% flowering, days to maturity, plant height and number of branches. The mean squares due to females vs. males were highly significant for days to maturity, number of branches, number of clusters, number of pods, number of seeds per pod, 100 seed weight and grain yield per plant. This indicated the presence of significant differences between males and females for these traits.

Table 4.6 Analysis of variance for combining ability

Sources of variation	d.f.	Mean sum of squares								
		Days to 50 % flowering	Days to maturity	Plant height (cm)	Number of branches	Number of clusters	Number of pods	Number of seeds per pod	100 seed weight (g)	Grain Yield per plant (g)
		1	2	3	4	5	6	7	8	9
Replications	2	0.31	7.03	402.241	1.33	4.01	154.47	0.03	0.69	18.25
Crosses	29	70.292 **	60.566 **	368.237 **	5.956 **	47.908 **	824.784 **	0.387 **	2.830 **	25.916 **
Females (Lines)	5	236.678 **	188.107 **	1741.546 **	9.12	53.09	1163.27	0.40	11.289 **	21.90
Males (Testers)	4	122.044 **	100.128 **	314.935 **	11.876 *	52.04	1086.02	0.51	0.45	50.51
Females Vs Males (Lines Vs Testers)	20	18.34	20.768 **	35.57	3.981 **	45.785 **	687.917 **	0.359 *	1.191 **	22.001 **
Error	58	11.37	6.52	78.31	0.89	12.76	63.83	0.18	0.41	9.75

* - Significant at 5 % level of significance

** - Significant at 1 % level of significance

4.1.7 General combining ability effects of parents

The estimates of general combining ability effect of the female and male parents are presented in Table 4.7. Character wise gca effects of female and male parents are presented as under.

1) Days to 50% flowering

The female parent, AKCMS-12A (-4.79), AKCMS-93A (-3.99) and AKCMS-81A (-0.59) showed negative significant gca effect and was the best general combiner among all the females.

The male parent, AKPR-303 (-2.87), AKPR-364 (-1.98) and AKPR-372 (-0.20) showed significant negative gca effect and was the best general combiner among all the males.

2) Days to maturity

Among the females, AKCMS-12A (-2.73), AKCMS-93A (-2.60) AKCMS-81A (-1.87) and ICPA-2047A (-1.53) showed highest negative significant gca effect.

Among the male parents, AKPR-303 (-3.53) and AKPR-364 (-1.03) revealed the highest negative significant gca effects.

3) Plant height (cm)

The study revealed that among females, AKCMS-93A (17.58) and ICPA-2047A (5.17) expressed positive significant gca effectsfor this trait. The best general combiner among all the females.

The four female parent showed significant negative gca effects were exhibited by AKCMS-83A (-14.49) and AKCMS-81A (-5.40).

The male parent AKPR-372 (5.31) expressed positive significant gca effect for this trait and was the best general combiner among all the males.

Table 4.7 Estimates of general combining ability effects of parents

Parents	Days to 50 % flowering	Days to maturity	Plant height (cm)	Number of branches	Number of clusters	Number of pods	Number of seeds per pod	100 seed weight (g)	Grain yield per plant (g)
	1	2	3	4	5	6	7	8	9
Females (Lines)									
AKCMS- 81A	-0.59 **	-1.87 **	-5.40 **	-0.58**	-0.71 **	-3.38 **	-0.21 **	-0.38 **	-1.06 **
AKCMS-82-2A	1.54	2.87 **	-2.26 **	0.69 **	-0.79 **	15.44**	0.04	0.20 **	-0.18 **
AKCMS- 83A	5.74 **	5.87 **	-14.49 **	-0.33 **	-0.79**	-6.08 **	-0.11 **	-1.46 **	-1.30 **
AKCMS- 12A	-4.79 **	-2.73 **	-0.60 **	-0.50 **	-1.79 **	5.05**	0.17 **	0.58 **	0.78
AKCMS- 93A	-3.99 **	-2.60 **	17.58**	1.26 **	0.53	-8.23 **	-0.077 **	0.02	-0.20**
ICPA- 2047A	2.08**	-1.53 **	5.17**	-0.54 **	3.53 **	-2.80 **	0.20 **	1.05 **	1.96**
SE (gi) ±	0.87	0.66	2.28	0.24	0.92	2.06	0.11	0.16	0.81
SE(gi-gj) ±	1.23	0.93	3.23	0.35	1.30	2.92	0.15	0.23	1.14
CD at 5 %	1.74	1.32	4.57	0.49	1.85	4.13	0.22	0.33	1.61
CD at 1 %	2.32	1.76	6.09	0.65	2.46	5.49	0.29	0.44	2.15
Males (Testers)									
AKPR-303	-2.87 **	-3.53 **	-2.24 **	0.35*	-1.91 **	-2.23 **	-0.09 **	-0.03 **	-2.03 **
AKPR-324	3.58 **	2.24 **	5.31**	0.10	2.17**	-0.56 **	0.02	0.27 **	2.26 **
AKPR-364	-1.98 **	-1.03 **	-5.75 **	-1.42 **	1.36	-4.17 *	0.22 **	-0.02 **	-0.54 **
AKPR-372	-0.20 **	1.86 **	1.22	0.56 **	-0.71 **	13.34**	0.07 **	-0.07**	1.07
AKPR-057	1.47	0.47	1.47	0.41 **	-0.90 **	-6.38 **	-0.22 **	-0.14 **	-0.76 **
SE (gj) ±	0.79	0.60	2.09	0.22	0.84	1.88	0.10	0.15	0.74
SE (gi-gj) ±	1.12	0.85	2.95	0.32	1.19	2.66	0.14	0.21	1.04
CD at 5 %	1.59	1.20	4.18	0.45	1.69	3.77	0.20	0.30	1.47
CD at 1 %	2.12	1.60	5.56	0.59	2.24	5.02	0.26	0.40	1.96

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

4) Number of branches

Among the female parents, AKCMS-93A (1.26) was found to be the best general combiner for this trait followed by AKCMS-82-2A (0.69). These female showed significant positive gca effects.

Among male parents, AKPR-372 (0.56) displayed the positive significant gca effect followed by AKPR-057 (0.41) and AKPR-303 (0.35) and hence was the best general combiner among the males for number of branches per plant.

5) Number of clusters

Among the female parents, only ICPA-2047A (3.53) was the best general combiner for this trait, which showed significant positive gca effect.

Among the male parents AKPR-324 (2.17) and AKPR-364 (1.36) expressed positive significant gca effects for this trait.

6) Number of pods

The study revealed that among female parents, AKCMS-82-2A (15.44) and AKCMS-12A (5.05) female parents expressed positive significant gca effects for this trait. Significant negative gca effects were exhibited by AKCMS-93A (-8.23) followed by AKCMS-83A (-6.08) and AKCMS-81A (-3.37).

Among the male parents, AKPR-372 (13.34) male parent showed highest positive gca effect.

7) Number of seeds per pod

Among the female parents, AKCMS-93A (0.20) and AKCMS-12A (0.17) showed positive significant gca effect.

Among males, AKPR-364 (0.22) and AKPR-372 (0.07) exhibited highest significant positive gca effect.

8) 100 Seed weight (g)

Among the female parents, ICPA-2047A (1.05) was found to be the best general combiner for grain yield which exhibited highest significant positive gca effect followed by AKCMS-12A (0.58) and AKCMS-82-2A (0.20). The AKCMS-83A (-1.46) and AKCMS-81A (-0.38) exhibited significant but negative gca effects.

Among male parents, AKPR-324 (0.27) displayed the highest significant positive gca effects and hence was the best general combiner among the males for 100 seed weight. All males showed significant negative gca effects.

9) Grain yield per plant (g)

Among the female parent, ICPA-2047A (1.96) exhibited significant positive gca effect and was the best general combiner among the female parents.

AKPR-324 (2.26) exhibited the highest significant positive gca effect and was the best general combiner among the male parents.

4.1.8 Specific combining ability effect of crosses

The estimates of specific combining ability effects of 30 crosses are presented in Table 4.8. The character wise sca effects of the 30 crosses are presented as under.

1) Days to 50% flowering

Out of the 30 crosses, not a single cross revealed significant negative sca effect, which is desirable for days to 50% flowering.

The maximum negative sca effect for this trait observed in the cross AKCMS-93A X AKPR-364 (-2.62) followed by AKCMS-12A X AKPR-057 (-2.60) and AKCMS-12A X AKPR-364 (-2.49).

2) Days to maturity

Out of the 30 crosses, three crosses exhibited significant negative sca effect, which is desirable for days to maturity. The cross combination AKCMS-82-2A X AKPR-364 (-4.37) followed by ICPA-2047A X AKPR-303 (-3.13) and AKCMS-12A X AKPR-324 (-3.04) showed significant negative sca effect and was the best specific cross combination for this trait.

3) Plant height (cm)

Out of the 30 crosses, not a single cross revealed significant positive sca effect and not a single cross revealed significant negative sca effect. The maximum positive sca effect for this trait observed in the cross ICPA-2047A X AKPR-372 (5.67) followed by AKCMS-93A X AKPR-324 (3.64).

4) Number of branches

Five crosses reflected significant positive sca effects for number of branches. The cross AKCMS-93A X AKPR-364 (2.45) was the best specific cross combination. It exhibited the highest significant positive sca effect followed by AKCMS-82-2A X AKPR-364 (1.35) and AKCMS-83A X AKPR-057 (1.20). Two crosses showed significant but negative sca effects.

5) Number of clusters

Out of 30 crosses, only four crosses revealed highly significant positive sca effects. The cross combination AKCMS-81A X AKPR-303 (6.00) recorded the highest significant positive sca effect and hence was the best specific cross combination followed by AKCMS-93A X AKPR-057 (4.83), ICPA-2047A X AKPR-372 (4.63) and AKCMS-83A X AKPR-303 (4.22). Four crosses showed significant negative sca effects for number of clusters per plant.

Table 4.8 Estimates of specific combining ability effects for crosses

Sr.No.	Crosses	Days to 50% flowering	Days to maturity	Plant height (cm)	Number of branches	Number of clusters	Number of pods	Number of seeds per pod	100 seed weight (g)	Grain yield per plant (g)
		1	2	3	4	5	6	7	8	9
1	AKCMS -81A X AKPR-303	0.20	-0.47	1.51	-0.28	6.00 **	-6.06	0.18	0.43	1.68
2	AKCMS -81A X AKPR -324	0.42	2.42	-1.44	-0.90	1.46	-11.40 *	-0.13	-0.17	-3.80 *
3	AKCMS -81A X AKPR -364	-0.36	-0.97	1.02	0.89	-3.34	31.68 **	-0.33	0.01	2.80
4	AKCMS -81A X AKPR -372	-1.47	-1.19	-4.02	-0.43	-1.53	-7.63	0.02	-0.03	-2.62
5	AKCMS -81A X AKPR -057	1.20	0.20	2.93	0.72	-2.60	-6.58	0.25	-0.24	1.95
6	AKCMS -82-2A X AKPR-303	-1.27	-0.87	1.17	-0.09	-1.71	-7.80	0.20	0.78*	-3.00
7	AKCMS -82-2A X AKPR -324	0.29	0.69	-1.05	-0.41	-4.16 *	7.45	-0.25	-0.24	1.05
8	AKCMS -82-2A X AKPR -364	-0.49	-4.37 **	-3.19	1.35 *	0.74	-8.07	0.02	0.53	1.12
9	AKCMS -82-2A X AKPR -372	1.07	0.74	0.10	-0.17	2.09	2.09	-0.10	-0.02	-0.30
10	AKCMS -82-2A X AKPR -057	0.40	3.80 *	2.98	-0.68	3.05	6.34	0.13	-1.06 **	1.13
11	AKCMS -83A X AKPR-303	0.20	2.80	1.40	0.40	4.22 *	12.45 **	0.21	0.13	1.39
12	AKCMS -83A X AKPR -324	-0.58	-0.31	-3.69	1.18 *	1.00	8.51	0.03	0.16	-1.43
13	AKCMS -83A X AKPR -364	1.64	0.30	2.67	-2.23 **	3.94	-7.55	-0.43	-0.24	-0.36
14	AKCMS -83A X AKPR -372	1.20	-0.92	1.07	-0.55	-6.38 **	-11.72 *	-0.02	-0.13	-2.58
15	AKCMS -83A X AKPR -057	-2.47	-1.87	-1.45	1.20 *	-2.79	-1.68	0.21	0.07	2.99
16	AKCMS -12A X AKPR-303	3.73	2.73	-1.55	0.30	0.09	1.05	0.13	-0.82 *	-0.69
17	AKCMS -12A X AKPR -324	-1.04	-3.04 *	-0.04	0.55	-0.26	-8.83	0.02	0.15	2.10
18	AKCMS -12A X AKPR -364	-2.49	4.90 **	2.49	-1.03	2.28	-6.88	0.35	0.24	-1.67
19	AKCMS -12A X AKPR -372	2.40	-2.66	-1.42	0.75	2.29	19.14 **	-0.50 *	-0.49	2.28
20	AKCMS -12A X AKPR -057	-2.60	-1.93	0.53	-0.56	-4.39 *	-4.48	0.00	0.92 *	-2.02

contd....

Sr. No.	Crosses	Days to 50 % flowering	Days to maturity	Plant height (cm)	Number of branches	Number of clusters	Number of pods	Number of seeds per pod	100 seed weight (g)	Grain yield Per plant (g)
		1	2	3	4	5	6	7	8	9
21	AKCMS -93A X AKPR -303	-0.73	-1.07	-4.61	-0.46	-3.57	15.87 **	-0.16	-0.68	2.75
22	AKCMS -93A X AKPR -324	2.16	-0.51	3.64	-0.47	0.42	8.99	-0.27	-0.11	-1.50
23	AKCMS -93A X AKPR -364	-2.62	-1.90	-0.03	2.45 **	-0.58	2.26	0.43	-0.69	0.54
24	AKCMS -93A X AKPR -372	-3.40	3.21 *	-1.41	-0.80	-1.10	-27.18 **	0.15	0.24	-0.88
25	AKCMS -93A X AKPR -057	4.60 *	0.27	2.41	-0.72	4.83 *	0.07	-0.16	1.23**	-0.91
26	ICPA -2047A X AKPR -303	-2.13	-3.13 *	2.07	0.14	-5.03 *	-15.50 **	-0.57 *	0.15	-2.13
27	ICPA -2047A X AKPR -324	-1.24	0.76	2.59	0.05	1.55	-4.71	0.60 *	0.21	3.58
28	ICPA -2047A X AKPR -364	4.31 *	2.03	-2.95	-1.42 *	-3.04	-11.44 *	-0.04	0.15	-2.42
29	ICPA -2047A X AKPR -372	0.20	0.81	5.67	1.19 *	4.63 *	25.32 **	0.44	0.42	4.10 *
30	ICPA -2047A X AKPR -057	-1.13	-0.47	-7.38	0.04	1.89	6.34	-0.4[illegible]	-0.92 *	-3.13
	SE (Sij) ±	1.95	1.47	5.11	0.55	2.06	4.61	0.24	0.37	1.80
	SE (Sij-Skl) ±	3.90	2.08	7.23	0.77	2.92	6.52	0.34	0.52	2.55
	SE (Sij-Sik) ±	5.18	2.47	8.55	0.91	3.45	7.72	0.40	0.62	3.02
	CD at 5 %	2.75	2.95	10.23	1.09	4.13	9.23	0.48	0.74	3.61
	CD at 1 %	3.26	3.93	13.61	1.45	5.49	12.29	0.64	0.98	3.61

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

Observation taken from the counter part of B line (Maintainer / Female line)

6) Number of pods

Out of 30 crosses, only five crosses depicted highly significant positive sca effects. The cross combination AKCMS-81A X AKPR-364 (31.68) expressed the highest significant positive sca effect and hence was the best specific cross combination followed by ICPA-2047A X AKPR-372 (25.32) and AKCMS-12A X AKPR -372(19.14).

Five crosses showed significant negative sca effect for number of pods per plant. The remaining crosses show non-significant sca effects.

7) Number of seeds per pod

Out of 30 crosses, only one cross displayed significant positive sca effects. The cross ICPA-2047A X AKPR-324 (0.59) recorded the highest significant positive sca effect and hence was the best specific cross combination.

Two crosses showed significant negative sca effects for number of seeds per pod. The remaining crosses showed non-significant sca effects.

8) 100 Seed weight (g)

Out of the 30 crosses, three crosses revealed significant positive sca effect. The cross AKCMS-93A X AKPR-057 (1.23) followed by AKCMS-12A X AKPR-057 (0.92) and AKCMS-82-2A X AKPR-303 (0.78).

9) Grain yield per plant (g)

Out of 30 crosses, only one cross revealed highly significant positive sca effects and can be considered as best cross combinations for grain yield per plant. One cross exhibited significant negative sca effects which are not desirable. The remaining crosses revealed non-significant sca effects.

The cross ICPA-2047A X AKPR-372 (4.10) recorded the highest significant positive sca effect. The cross AKCMS-81A X AKPR-324 (-3.80) recorded the highest significant negative sca effect.

4.2 Discussion

Green revolution made our nation self sufficient in case of cereals but we are still deficient in pulse production. India still imports red gram from countries like Myanmar, Australia and Africa to satisfy the pulse requirement. This impose great burden on our economy. Therefore, emphasis is being given recently on the breeding hybrids in pigeonpea. Possibilities of hybrid pigeonpea seed production on commercial scale had been feasible with available genetic male sterility (Reddy et al., 1978) and considerably high amount of pod set can be obtained on male sterile with pollination. ICPH-8 is the first ever pigeonpea hybrid released for cultivation in India in 1989 (Asthana et al., 1991).

The seed production is bottleneck of GMS-based hybrids, which encouraged the breeder to breed a more efficient cytoplasmic-nuclear male sterility (CMS) system. So far five primary CMS systems derived from various inter specific crosses have been reported in pigeonpea. These are designed as. i) A1 cytoplasm, derived from *Cajanus sericeus* ii) A2 cytoplasm, derived from *Cajanus scarabaeiodes* iii) A3 cytoplasm, derived from *Cajanus volubilis*. iv) A4 cytoplasm, derived from *Cajanus cajanifolius* v) A5 cytoplasm, derived from cultivated pigeonpea (Saxena et al., 2006). In order to make use of these cytoplasmic male sterile lines in commercial hybrid seed production, fertility restoration programme is in progress at many research centres.

Besides male sterility system, the studies on heterosis and combining ability are important to develop superior hybrids and parents for their further exploitation

Keeping in view the above facts, the present study "Heterosis and combining ability studies in medium duration pigeonpea experimental hybrids" was therefore undertaken to estimate the gca and sca effects and the extent of heterosis to find out promising high yielding cross combinations.

The results obtained in the present investigation are discussed in the light of previous studies reported by various workers under following sub heads.

4.2.1 Analysis of variance

4.2.2 *Per se* performances

4.2.3 Heterosis

4.2.4 Combining ability analysis

4.2.5 GCA and SCA effects

4.2.1 Analysis of variance

The mean squares due to genotypes were highly significant for all the traits studied. This indicated the presence of substantial genetic variability among genotypes all the traits studied. Further partitioning of genotypic variance into components *viz.*, parents, crosses and parents vs. crosses revealed that the parents differed significantly among themselves for all the characters under study. The mean square due to crosses also showed highly significant differences for all the traits. The mean squares due to parents vs. crosses were also showed significant for all the characters indicating the significant differences between parents and crosses.

Similar results were reported by Verulkar and Singh (1997), Wankhade (1998), Wanjari *et al.* (1998), Singh and Srivastava (2001), Pawar and Tikka (2003), Sunilkumar *et al.* (2003) and Aher *et al.* (2006).

4.2.2 *Per se* performances

Among the crosses, the cross AKCMS-12A X AKPR-364, AKCMS-93A X AKPR-364, AKCMS-93A X AKPR-303 and AKCMS-93A X AKPR-372 was found to be earliest for days to 50% flowering over both the checks i.e. PKV-TARA and ASHA. The cross ICPA-2047A X AKPR-303 was found to be earliest for days to maturity. The cross AKCMS-93A X AKPR-324 recorded highest mean performance for plant height. The cross AKCMS-93A X AKPR-364 revealed highest mean performance for number of branches. The cross ICPA-2047A X AKPR-372 recorded highest mean performance for number of clusters. The cross AKCMS-12A X AKPR-372 recorded highest mean performance for number of pod. The cross ICPA-2047A X AKPR-324 revealed highest mean performance for number of seeds per pod, 100 seed weight and grain yield per plant. Thus, these cross combinations with high *per se* performance for one or more traits can be employed for improvement of these traits.

It has been reported by various workers that grain yield per plant in pigeonpea is mostly depends upon plant height, flowering duration, number of pods and seed size (Upadhaya, 1980), days to 50% flowering (Veeraswamy *et al.* 1973), number of pods (Munoz and Abbrams, 1971), number of seeds per pod, 100 seed weight and days to 50% flowering (Shoran, 1982).

4.2.3 Heterosis

The *per se* performance alone may not be useful to predict the best cross combination. The studies on extent of heterosis are useful to support the results on the basis of *per se* performance particularly undertaken in comparison with the checks for their practical utility at field level. The heterosis plays an important role for increasing the productivity of crop without much increase in the cost of production. Therefore, it is of great importance to plant breeders. The aim of the present study was to identify superior cross combinations, which will exhibit good amount of heterosis for grain yield per plant and its component traits.

Considerable amount of useful heterosis in desirable direction was observed for days to 50% flowering, days to maturity, plant height, number of branches, number of pods, number of clusters, number of seeds per pod, 100 seed weight and grain yield per plant.

The highest useful heterosis in desirable direction was recorded for days to 50% flowering in AKCMS-12A X AKPR-364 (-9.56% over check PKV-TARA and -12.06% over check ASHA), for days to maturity in ICPA-2047A X AKPR-303 (-3.73% over check PKV-TARA and -8.57% over check ASHA), for plant height in AKCMS-93A X AKPR-324 (9.26% over check PKV-TARA and -0.12% over check ASHA), for number of branches in AKCMS-93A X AKPR-364 (18.01% over check PKV-TARA and 13.43% over check ASHA), for number of clusters in ICPA-2047A X AKPR-372 (7.44% over check PKV-TARA and 14.49% over check ASHA). The cross AKCMS-12A X AKPR-372 showed highest positive significant useful heterosis for number of pods (9.34% over check PKV-TARA and 13.79% over check ASHA), for number of seeds per pods in the cross ICPA-2047A X AKPR-324 (12.78% over check PKV-TARA and 20.97% over check ASHA). The cross ICPA-2047A X AKPR-324 showed highest useful heterosis simultaneously for two characters *viz.,* number of seeds pods (12.78% over check and PKV-TARA and 7.99% over check ASHA) and grain yield per plant. (17.72% over check PKV-TARA and 23.11% over check ASHA).

These crosses showing significant superiority in respect of standard heterosis are most important and can be utilized for improvement of these characters as the comparison is being made with commercial cultivars.

Useful heterosis for these characters in pigeonpea was also reported earlier by several researchers *viz.,* Reddy *et al.* (1979), Venkateswarlu *et al.* (1981). Marekar *et al.* (1982), Jain and Saxena (1990), Tuteja *et al.* (1992), Malik *et al.* (1995), Khapre *et al.* (1996), Manivel *et al.* (1999), Singh *et al.* (1999), Pandey and Singh (2002), Aher *et al.* (2006), Wanjari *et al.* (2007) and Anatha and Muthian (2007).

The highest average heterosis in desirable direction was recorded for days to 50% flowering in AKCMS-93A X AKPR-364 (-10.09%), for days to maturity in AKCMS-12A X AKPR-364 (-4.50%), for plant height in AKCMS-12A X AKPR-324 (18.43%), for number of branches in AKCMS-93A X AKPR-364 (44.21), for number of clusters in AKCMS-83A X AKPR-364 (89.63%), for number pods in AKCMS-12A X AKPR-372 (84.17%), for number of seeds per pod in AKCMS-12A X AKPR-364 (32.14%), for 100 seed weight in AKCMS-12A X AKPR-057 (40.89%) and for grain yield per plant in ICPA-2047A X AKPR-372(112.41%). The cross AKCMS-93A X AKPR-364 recorded highest average heterosis for days to 50% flowering (-10.09%) and for number of branches (44.21%).

The highest heterobeltiosis in desirable direction was recorded for days to 50% flowering in AKCMS-93A X AKPR-364 (-8.09%), for days to maturity in AKCMS-93A X AKPR-364 (-3.85%). The highest heterobeltiosis in desirable direction was recorded for grain yield per plant in AKCMS-82-2A X AKPR-364 (94.09%). The cross AKCMS-12A X AKPR-324 (12.02%) recorded highest heterobeltiosis for plant height, for number of branches in AKCMS-93A X AKPR-364 (14.46%). for number of clusters AKCMS-12A X AKPR-372 (73.61%). for number pods in AKCMS-12A X AKPR-372 (81.59%), for number of seeds per pod in AKCMS-93A X AKPR-364 (27.68%), for 100 seed weight in AKCMS-12A X AKPR-057 (38.33%) indicating usefulness for improving these characters in comparision with the commercial cultivars.

Average heterosis and heterobeltiosis, for these characters in pigeonpea was also reported earlier by several researchers *viz.,* Sharma *et al.* (1973), Srivastava *et al.* (1975), Venkateswarlu *et al.* (1981), Marekar *et al.* (1982), Jadhav and Nerkar (1983), Omanga (1985), Saxena *et al.* (1986), Patel *et al.* (1991), Khapre *et al.* (1996), Manivel *et al.* (1999), Singh *et al.* (1999), Chandirkala *et al.* (2002), Kalaimangal and Ravikesavan (2003) Aher *et al.* (2006) and Wanjari *et al.* (2007).

4.2.4 Combining ability analysis

Line x tester analysis of 30 crosses obtained by crossing 6 CMS lines with 5 testers was carried out and the total variance due to crosses was partitioned into portions attributable to females (lines), males (testers), interaction females vs. males (lines vs. testers) and error sources. The variance due to females were significant for days to 50% flowering, days to maturity, plant height and 100 seed weight. While the variance due to males were significant for days to 50% flowering, days to maturity, plant height and number of branches. The variance due to females vs. males were highly significant for days to maturity, number of branches, number of clusters, number of pods, number of seeds per pod, 100 seed weight and grain yield per plant. This indicated the presence of significant differences between males and females.

Similar results were reported by Wanjari *et al.* (1998), Singh and Srivastava (2001), Pawar and Tikka (2003), Sunilkumar *et al.* (2003), Banu *et al.* (2006) and Beekham and Umaharan (2010).

4.2.5 GCA and SCA effects

Among female parents, ICPA-2047A recorded significant gca effect for maximum six characters such as grain yield per plant, plant height, number of clusters, number of seed per pod, 100 seed weight and days to 50% flowering. The female parent AKCMS-12A was found to posses highest gca effect for number of pods, number of seed per pod, 100 seed weight, days to 50% flowering and days to maturity.

The male parent AKPR-324 was found to posses highest gca effect for plant height, number of clusters, 100 seed weight and grain yield per plant. The male parent AKPR-372 recorded highest gca effect for number of branches, number of pods, number of seed per pod and days to 50% flowering. Hence, these genotypes were recognized as the best parental material among the available genotypes and can be used as parents in hybridization programmes.

Similar results were reported by Hazarizka (1988), Ghodke *et al.* (1993), Wanjari *et al.* (1998), Singh and Srivastava (2001), Pandey and Sing (2002), Jahagirdar (2002), Pawar and Tikka (2003), Sunilkumar *et al.* (2003), Banu *et al.* (2006) and Kumar *et al.* (2009).

The highest significant desirable sca effect was observed for days to maturity in AKCMS-82-2A X AKPR-364 (-4.37), for number of branches in AKCMS-93A X AKPR-364 (2.45), for number of clusters in AKCMS-81A X AKPR-303 (6.00), for number of pods in AKCMS-81A X AKPR-364 (31.68), for number of seed per pods in ICPA-2047A X AKPR-324 (0.59), for 100 seed weight AKCMS-93A X AKPR-057 (1.23) and for grain yield per plant in ICPA-2047A X AKPR-372 (4.10).

The crosses viz, ICPA-2047A X AKPR-372 (number of branches, number of clusters, number of pods, grain yield per plant) AKCMS-83A X AKPR-303 (number of branches, number of clusters) AKCMS-93A X AKPR-303 (days to 50% flowering, days to maturity, number of pods) and AKCMS-93A X AKPR-057 (number of clusters, 100 seed weight) revealed significant desirable sca effect simultaneously for more than one characters studied. Hence, these crosses were found to be promising to exploit non-additive component for particular character and can be utilized in breeding programme.

It was observed that the crosses with high and significant specific combining ability for grain yield per plant had also high specific combining ability for one or more other yield components suggesting that the improvement in grain yield per plant could be obtained by improving its component characters. Similar results were reported by Narladkar and Khapre (1997), Wanjari *et al.* (1998), Singh and Srivastava (2001), Pawar and Tikka (2003), and Sunilkumar *et al.* (2003), Banu *et al.* (2006), Kumar *et al.* (2009), Vaghela *et al.* (2009), Singh and Singh (2009) and Gupta *et al.* (2011).

Two promisings crosses were selected on the basis of *per se* performance, heterotic response, gca and sca effects. The crosses ICPA-2047A X AKPR-324 and ICPA-2047A X AKPR-372 were found to be the most promising crosses among all the 30 crosses studied.

The cross ICPA-2047A X AKPR-324 depicted high mean performance (33.67) high magnitude of useful heterosis (17.72% over check PKV-TARA and 23.17% over check ASHA), positive sca effect and both the parents involved revealed high gca effects. This cross could be successfully utilized to obtain the superior segregants in further segregating generations. Another cross ICPA-2047A X AKPR-372 revealed high mean performance (33.00g), high magnitude of useful heterosis (15.38 % over check PKV-TARA and 20.73% over check ASHA) and high sca effect. One of the parents (AKPR-372) though low combiner for grain yield but is was good combiner for number of branches, number of pods, number of seed per pod and days to 50% flowering.

This cross may be employed to exploit non-additive component along with high heterotic response. However, the performances of this cross have to be evaluated in large scale trials.

Table 4.9 Yield performance, useful heterosis, gca effects and sca effects in promising crosses

	Crosses	Grain yield per plant (g)	Useful heterosis (%)		sca effects	gca effects of parents	Significant gca effects for other characters in desirable direction	Significant sca effects for other characters in desirable direction	Plant fertility (%)
			PKV-TARA	ASHA					
1.	ICPA-2047A X AKPR-324	33.67**	17.72	23.17*	3.58	1.96** x 2.26** H H	P_1 :2,3,5,7,8,9 P_2 : 3,5,8,9	1,3,4,5,7,8,9	100%
2.	ICPA-2047A X AKPR-372	33.00*	15.38	20.73*	4.10 *	1.96**x 1.07 H H	P_1 : 2,3,5,7,8,9 P_2 : 1,4,6,7	3,4,5,6,7,8,9	100%

H : High gca
L : Low gca

P_1 & P_2 : Female parent and male parent of the concerned cross, respectively
* : Significant at 5 % level of significance
** : Significant at 1 % level of significance

1: Days to 50% flowering, 2 : Days to maturity, 3 : Plant height, 4 : Number of branches,
5: Number of clusters, 6: Number of pods, 7: Number of seeds per pods (g), 8 : 100 seed weight (g)
9: Grain yield (g) 10: Plant fertility (%)

CHAPTER V

SUMMARY AND CONCLUSIONS

The present investigation entitled "Heterosis and combining ability studies in medium duration pigeonpea experimental hybrids" was undertaken to estimate the *per se* performance, extent of useful heterosis, average heterosis, heterobeltiosis and combining ability effects to find out superior cross combinations for their further exploitation.

Line x Tester mating design was selected for the study. The experimental material comprised of 6 females (lines) viz., AKCMS-81A, AKCMS-82-2A, AKCMS-83A, AKCMS-12A, AKCMS-93A and ICPA-2047A and 5 males (Testers) viz., AKPR-303, AKPR-324, AKPR-364, AKPR-372 and ICPA-2047 along with their 30 crosses. This material was evaluated along with the standard checks PKV-TARA and ASHA.The parents and crosses were randomized separately and sown using randomly complete block designduring *kharif* 2012-2013 at the field of Pulses Research Unit Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola.

The mean squares due to genotypes were highly significant for all the traits studied. This indicated the presence of substantial genetic variability among genotypes all the traits studied. Further partitioning of genotypic variance into components *viz.*, parents, crosses and parents vs. crosses revealed that the parents differed significantly among themselves for all the characters under study. The mean square due to crosses also showed highly significant differences for all the traits. The mean squares due to parents vs. crosses were also showed significant for all the characters indicating the significant differences between parents and crosses.

The results showed that the cross AKCMS-12A X AKPR-364 (116.67 days), AKCMS-93A X AKPR-364 (117.33 days), AKCMS-93A X AKPR-303 (118.33 days) and AKCMS-93A X AKPR-372 (118.33 days) and the female parent AKCMS-82-2A (103.67 days) were earliest for days to 50% flowering. The cross ICPA-2047A X AKPR-303 (163.67 days) and the female parent AKCMS-82-2A (155.00 days) were the earliest for days to maturity. The cross AKCMS-93A X AKPR-324 (166.00 cm) and the female parent AKCMS-93A (151.67cm) were the tallest genotypes for plant height. The cross AKCMS-93A X AKPR-364 (12.67) and the female parent AKCMS-83A (11.53) revealed maximum number of branches. The cross ICPA-2047A X AKPR-372 (27.93) and the female parent AKCMS-12A (27.63) recorded highest number of clusters. The cross AKCMS-12A X AKPR-372 (121.00) and the male parent AKPR-324 (94.63) recorded highest number of pods. The cross ICPA-2047A X AKPR-324 (5.00) and the male parent AKPR-303 (4.80) revealed highest number of seeds per pod. The cross ICPA-2047A X AKPR-324 (12.85) and the male parent AKPR-303 (9.87) recorded highest 100 seed weight. The cross ICPA-2047A X AKPR-324 (33.67) and the female parent AKCMS-93A (25.27) recorded highest grain yield per plant. Nine crosses and all the parents showed 100% plant fertility.

The phenomenon of heterosis was of general occurrence for all the traits. However, considerable amount of heterosis in desirable direction was observed for most of the traits under study.

The highest useful heterosis in desirable direction was recorded for days to 50% flowering in AKCMS-12A X AKPR-364 (-9.56% over check PKV-TARA and -12.06% over check ASHA), for days to maturity in ICPA-2047A X AKPR-303 (-3.73% over check PKV-TARA and -8.57% over check ASHA), for plant height inAKCMS-93A X AKPR-324 (9.26% over check PKV-TARA and -0.12% over check ASHA), for number of branches in AKCMS-93A X AKPR-364 (18.01% over check PKV-TARA and 13.43% over check ASHA), for number of clusters in ICPA-2047A X AKPR-372 (7.44% over check PKV-TARA and 14.49% over check ASHA). The cross AKCMS-12A X AKPR-372 showed highest positive significant useful heterosis for number of pods (9.34% over check PKV-TARA and 13.79% over check ASHA), for number of seeds per pods in the cross

ICPA-2047A X AKPR-324 (12.78% over check PKV-TARA and 20.97% over check ASHA). The cross ICPA-2047A X AKPR-324 showed highest useful heterosis simultaneously for two characters *viz.*, number of seeds pods (12.78% over check and PKV-TARA and 7.99% over check ASHA) and grain yield per plant (17.72% over check PKV-TARA and 23.11% over check ASHA).

These crosses showing significant superiority in respect of standard heterosis are most important and can be utilized for improvement of these characters as the comparison is being made with commercial cultivars.

The highest average heterosis in desirable direction was recorded for days to 50% flowering in AKCMS-93A X AKPR-364 (-10.09%), for days to maturity in AKCMS-12A X AKPR-364 (-4.50%), for plant height in AKCMS-12A X AKPR-324 (18.43%), for number of branches in AKCMS-93A X AKPR-364 (44.21), for number of clusters in AKCMS-83A X AKPR-364 (89.63%), for number pods in AKCMS-12A X AKPR-372 (84.17%), for number of seeds per pod in AKCMS-12A X AKPR-364 (32.14%), for 100 seed weight in AKCMS-12A X AKPR-057 (40.89%) and for grain yield per plant in ICPA-2047A X AKPR-372 (112.41%). The cross AKCMS-93A X AKPR-364 recorded highest average heterosis for days to 50% flowering (-10.09%) and for number of branches (44.21%).

The highest heterobeltiosis in desirable direction was recorded for days to 50% flowering in AKCMS-93A X AKPR-364 (-8.09%), for days to maturity in AKCMS-93A X AKPR-364 (-3.85%). The highest heterobeltiosis in desirable direction was recorded for grain yield per plant in AKCMS-82-2A X AKPR-364 (94.09%). The cross AKCMS-12A X AKPR-324 (12.02%) recorded highest heterobeltiosis for plant height, for number of branches in AKCMS-93A X AKPR-364 (14.46%), for number of clusters in AKCMS-12A X AKPR-372 (73.61%), for number pods in AKCMS-12A X AKPR-372 (81.59%), for number of seeds per pod in AKCMS-93A X AKPR-364 (27.68%), for 100 seed weight in AKCMS-12A X AKPR-057

(38.33%) indicating usefulness for improving these characters in comparision with the commercial cultivars.

Line x tester analysis of 30 crosses obtained by crossing 6 CMS lines with 5 testers was carried out and the total variance due to crosses was partitioned into portions attributable to females (lines), males (testers), interaction females vs. males (lines vs. testers) and error sources. The variance due to females were significant for days to 50% flowering, days to maturity, plant height and 100 seed weight. While the variance due to males were significant for days to 50% flowering, days to maturity, plant height and number of branches. The variance due to females vs. males were highly significant for days to maturity, number of branches, number of clusters, number of pods, number of seeds per pod, 100 seed weight and grain yield per plant. This indicated the presence of significant differences between males and females.

The GCA effects revealed that among the female parents AKCMS-12A (-4.79), AKCMS-93A (-3.99) and AKCMS-81A (-0.59) and among the male parents AKPR-303 (-2.87), AKPR-364 (-1.98) and AKPR-372 (-0.20) were the best general combiners for days to 50% flowering. The female parents AKCMS-12A (-2.73), AKCMS-93A (-2.60), AKCMS-81A (-1.87), and ICPA-2047A (-1.53) and among the male parents AKPR-303 (-3.53) and AKPR-364 (-1.O3) were the best general combiners for days to maturity. The female parents AKCMS-93A (17.58) and ICPA-2047A (5.17) and among the male parents AKPR-324 (5.31) were the best general combiners for plant height. The female parents AKCMS-93A (1.26) and AKCMS-82-2A (0.69) and among the male parents AKPR-372 (0.56) AKPR-057 (0.41) and AKPR-303 (0.35) were the best general combiners for number of branches. The female parents ICPA-2047A (3.53) and among the male parents AKPR-324 (2.17) and AKPR-364 (1.36) were the best general combiners for number of clusters. The female parents AKCMS-82-2A (15.44) and AKCMS-12A (5.05) and among the male parents AKPR-372 (13.34) were the best general combiners for number of pods. The female parents ICPA-2047A (0.20) and among the male parents

AKPR-364 (0.22) and AKPR-372 (0.07) were the best general combiners for number of seed per pod. The female parents ICPA-2047A (1.05), AKCMS-12A (0.58) and AKCMS-82-2A (0.20) and among the male parents AKPR-324 (0.27) were the best general combiners for 100 seed weight. The female parents ICPA-2047A (1.96) and among the male parents AKPR-324 (2.26) were the best general combiners for gran yield per plant. Among female parents, ICPA-2047A recorded significant gca effect for maximum six characters such as grain yield per plant, plant height, number of clusters, number of seed per pod, 100 seed weight and days to 50% flowering andthe male parent AKPR-324 was found to posses highest gca effect for plant height, number of clusters, 100 seed weight and grain yield per plant. So these genotypes can be used as parent in hybridization programme for improvement of these traits.

The highest significant desirable sca effect was observed for days to maturity in AKCMS-82-2A X AKPR-364 (-4.37), for number of branches in AKCMS-93A X AKPR-364 (2.45), for number of clusters in AKCMS-81A X AKPR-303 (6.00), for number of pods in AKCMS-81A X AKPR-364 (31.68), for number of seed per pods in ICPA-2047A X AKPR-324 (0.59), for 100 seed weight AKCMS-93A X AKPR-057 (1.23) and for grain yield per plant in ICPA-2047A X AKPR-372 (4.10).

The crosses viz, ICPA-2047A X AKPR-372 (number of branches, number of clusters, number of pods, grain yield per plant) AKCMS-83A X AKPR-303 (number of branches, number of clusters) AKCMS-93A X AKPR-303 (days to 50% flowering, days to maturity, number of pods) and AKCMS-93A X AKPR-057 (number of clusters, 100 seed weight) revealed significant desirable sca effect simultaneously for more than one characters studied. Hence, these crosses were found to be promising to exploit non-additive component for particular character and can be utilized in breeding programme.

Two promisings crosses were selected on the basis of *per se* performance, heterotic response, gca and sca effects. The crosses ICPA-

2047A X AKPR-324 andICPA-2047A X AKPR-372 were found to be the most promising crosses among all the 30 crosses studied.

The cross ICPA-2047A X AKPR-324 depicted high mean performance (33.67) high magnitude of useful heterosis (17.72% over check PKV-TARA and 23.17% over check ASHA), positive sca effect and both the parents involved revealed high gca effects. This cross could be successfully utilized to obtain the superior segregants in further segregating generations. Another cross ICPA-2047A X AKPR-372 revealed high mean performance (33.00g), high magnitude of useful heterosis (15.38 % over check PKV-TARA and 20.73% over check ASHA) and high sca effect. One of the parents (AKPR-372) though low combiner for grain yield but is was good combiner for number of branches, number of pods, number of seed per pod and days to 50%flowering.

This cross may be employed to exploit non-additive component along with high heterotic response. However, the performances of this cross have to be evaluated in large scale trials.

CHAPTER VI

IMPLICATIONS

Among female parents, ICPA-2047A recorded significant gca effect for maximum six characters such as grain yield per plant, plant height, number of clusters, number of seed per pod, 100 seed weight and days to 50% flowering. Thus, these genotypes can be used as parent in hybridization programme for improvement of these characters. The female parent AKCMS-12A was found to posses highest gca effect for number of pods, number of seed per pod, 100 seed weight, days to 50% flowering and days to maturity. The male parent AKPR-324 was found to posses highest gca effect for plant height, number of clusters, 100 seed weight and grain yield per plant. The male parent AKPR-372 recorded highest gca effect for number of branches, number of pods, number of seed per pod and days to 50% flowering. Hence, these genotypes were recognized as the best parental material among the available genotypes and can be used as parents in hybridization programmes.

The cross viz, ICPA-2047A X AKPR-372 (number of branches, number of clusters, number of pods, grain yield per plant) revealed significant desirable sca effect simultaneously for grain yield and one of its component characters. Hence these cross were found to be promising for improvement of grain yield through exploitation of non-additive component in the breeding programme.

Two promisings crosses were selected on the basis of *per se* performance, heterotic response, gca and sca effects. The crosses ICPA-2047A X AKPR-324 and ICPA-2047A X AKPR-372 were found to be the most promising crosses among all the 30 crosses studied.

The cross ICPA-2047A X AKPR-324 depicted high mean performance (33.67) high magnitude of useful heterosis (17.72% over check PKV-TARA and 23.17% over check ASHA), positive sca effect and both the parents involved revealed high gca effects. This cross could be successfully utilized to obtain the superior segregants in further segregating generations. Another cross ICPA-2047A X AKPR-372 revealed high mean performance (33.00g), high magnitude of useful heterosis (15.38 % over check PKV-TARA and 20.73% over check ASHA) and high sca effect. One of the parents (AKPR-372) though low combiner for grain yield but it was good combiner for number of branches, number of pods, number of seed per pod and days to 50% flowering. This cross may be employed to exploit non-additive component along with high heterotic response. However, the performances of this cross have to be evaluated in large scale trials.

CHAPTER VII

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* Original not seen.

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APPENDIX I

Weekly weather Data for the Year 2012 recorded at Agromet. Observatory, Dr. PDKV, Akola

Weeks	Dates	T MAX (°C)		T MIN (°C)		BSH (hrs)		WS (km/hr)		RH I (%)		RH II (%)		Evap (mm)		RF (mm)		CRF (mm)	Rainy Days	
		N	A	N	A	N	A	N	A	N	A	N	A	N	A	N	A		N	A
26	25-1Jul	33.8	37.71	24.3	26.44	4.8	6.6	12.8	12.35	80	71.28	55	36.85	7.4	12.51	43.4	20.6	20.6	2.2	1.0
27	2-8	33.2	30.71	24.0	23.91	4.8	2.2	12.0	5.81	81	90	58	72.28	6.5	4.05	39.4	101	121.6	2.2	5.0
28	9-15	32.3	31.84	23.8	24.6	3.8	3.95	11.2	7.44	83	86.57	60	57	5.5	5.31	42.8	20.3	141.9	2.5	3.0
29	16-22	31.9	33.08	23.6	24.95	4.0	2.62	10.4	8.85	84	80.85	63	58.28	5.2	5.77	52.8	46.1	188	2.4	4.0
30	23-29	31.3	26.71	23.3	23.18	4.0	0.0	10.8	9.12	86	87	64	82.85	4.8	2.55	43.4	91.1	279.1	2.6	5.0
31	30-5 Aug	30.9	28.04	23.3	23.01	3.5	0.15	10.6	8.04	86	84.4	67	77	4.6	2.97	49.6	30.1	308.1	2.4	4.0
32	6-12	29.9	28.12	23.0	23.35	3.2	1.02	10.9	9.32	88	89.85	70	80	4.1	4.05	61.0	15.9	324	2.8	2.0
33	13-19	30.4	28.67	23.0	23	4.0	1.15	12.4	5.6	87	90.14	67	75.85	4.5	3.64	35.9	18.4	342.4	2.0	2.0
34	20-26	30.4	29.12	22.8	23.02	4.1	3.35	11.9	4.91	87	93.85	67	71.57	4.3	3.91	42.5	25.8	368.2	1.9	3.0
35	27-2 Sep	30.5	30.9	22.7	23.61	4.2	3.52	9.3	2.08	87	94.14	66	68.71	4.6	3.68	42.4	44.9	413	2.1	3.0
36	3-9	31.0	30.07	22.5	23.44	5.3	4.28	8.6	5.5	87	88.57	62	67.71	5.3	4.47	33.6	93.8	506.9	1.5	5.0
37	10-16	32.1	30.22	22.4	22.92	6.6	5.0	8.0	4.24	85	84.71	57	61	5.1	3.91	22.0	10.4	517.3	1.1	2.0
38	17-23	32.9	31.67	22.4	23.02	6.8	4.98	6.4	2.5	84	86.42	55	54.28	5.2	4.21	23.7	23.8	541.1	1.4	1.0
39	24-30	33.5	32.5	22.1	22.6	7.3	7.05	5.1	1.18	84	84.85	50	45.42	5.0	4.05	24.4	9.3	550.4	1.4	2.0
40	1-7 Oct	33.7	33.05	21.2	22.54	7.6	7.65	4.8	2.6	82	87.71	47	48.27	5.4	5.07	23.4	40.9	591.3	1.1	2.0
41	8-14	34.0	33.57	19.8	16.2	8.1	7.65	4.5	0.3	78	84.57	40	32.57	5.3	4.71	13.1	1.5	592.8	0.7	0.0
42	15-21	33.7	34.05	18.3	17.62	8.2	7.07	4.6	1.22	76	78.42	37	24.14	5.3	5.57	6.1	0.0	592.8	0.4	0.0
43	22-28	33.1	32.95	16.8	18.58	8.3	4.78	4.4	1.02	74	76.14	34	28.28	5.3	5.57	7.6	0.0	592.8	0.4	0.0
44	29-4 Nov	32.7	31.38	16.0	14.37	8.4	4.97	4.1	1.72	73	75.42	32	35.42	5.3	5.07	2.3	0.0	592.8	0.2	0.0
45	5-11	32.3	32.05	15.2	14.82	8.4	7.65	3.9	1.28	71	72.42	32	23.14	5.1	5.21	3.0	0.0	592.8	0.2	0.0
46	12-18	31.6	31.02	14.6	11.94	8.3	7.57	3.9	1.18	73	73	32	21.14	4.8	4.5	5.3	0.0	592.8	0.2	0.0
47	19-25	31.0	30.65	13.3	13.02	8.4	7.58	3.7	1.25	72	72.85	30	26.25	4.6	3.97	7.7	0.0	592.8	0.3	0.0
48	26-2 Dec	30.5	31.82	12.8	15.52	8.4	6.95	3.6	1.24	71	74	32	28	4.4	3.94	5.5	0.0	592.8	0.3	0.0
49	3-9	30.0	31.11	11.9	15.08	8.4	7.54	3.8	1.22	71	64.57	30	21.42	4.3	4.54	1.0	0.0	592.8	0.1	0.0
50	10-16	29.6	31.42	10.9	15.08	8.4	7.47	3.6	0.8	71	75.85	28	26	4.2	3.72	0.8	0.0	592.8	0.1	0.0
51	17-23	29.5	29.24	10.8	11.88	8.5	7.07	3.8	1.02	70	78.71	29	27.14	4.1	4.14	0.9	0.0	592.8	0.1	0.0
52	24-31	29.1	28.12	10.65	12.17	8.3	8.23	4.5	0.81	71	71.87	30	27.25	4.2	3.97	2.6	0.0	592.8	0.2	0.0
											Total RF June to Dec					636.2	592.8	592.8	34.2	44