"Study of heterosis, combining ability, stability and quality parameters in CGMS-based pigeonpea [*Cajanus cajan* (L.) Millsp.] hybrids"

By

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M.Sc. (Agri.)

DISSERTATION

Submitted To The

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DOCTOR OF PHILOSOPHY

IN

Genetics and Plant Breeding

DEPARTMENT OF AGRICULTURAL BOTANY
MARATHWADA AGRICULTURAL UNIVERSITY
PARBHANI - 431 402 [M.S.] INDIA

[2010]

Dedicated
to
my
beloved parents
and
grand father

CANDIDATE'S DECLARATION

I hereby declare that the dissertation or part thereof has not been previously submitted by me to any other University or Institution for a degree or diploma.

Place : Parbhani **(Sawargaonkar S.L.)**

Date : October 2010

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CERTIFICATE - I

This is to certify that the dissertation entitled "**Study of heterosis, combining ability, stability and quality parameters in CGMS-based pigeonpea [*Cajanus cajan* (L.) Millsp.] hybrids**" submitted to Marathwada Agricultural University, Parbhani in partial fulfillment of the requirement for the award of degree of **Doctor of Philosophy** in **Genetics and Plant Breeding** embodies the results of bonafide research carried out by **Shri. Sawargaonkar S.L.** under my guidance and supervision and that no part of this dissertation has been submitted for any degree or diploma.

The assistance and help received during the course of this investigation have been fully acknowledged.

Place : Parbhani **(I. A. Madrap)**

Date : October, 20,2010 **Research Guide**

CERTIFICATE - II

This is to certify that the dissertation entitled "**Study of heterosis, combining ability, stability and quality parameters in CGMS-based pigeonpea [*Cajanus cajan* (L.) Millsp.] hybrids**" submitted by **Shri. Sawargaonkar S.L.** to the Marathwada Agricultural University, Parbhani in partial fulfillment of the requirements for the degree of **DOCTOR OF PHILOSOPHY** in the subject of **Genetics and Plant Breeding** has been approved by the student's advisory committee after oral examination in collaboration with the external examiner.

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Place : Parbhani

Date : October 2010 **(Shrikant L. Sawargaonkar)**

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ABBREVIATIONS

%	:	Per cent
/	:	Per
>	:	More than
<	:	Less than
^{0}C	:	Degree celsius
Av.	:	Average
CD	:	Critical difference
cm	:	Centimeter
DAS	:	Days after sowing
et al.	:	Et alia (and others)
etc.	:	Etcetera
ed.	:	Edited by
Fig.	:	Figure
g	:	Gram
ha	:	Hectare
hrs.	:	Hours
i.e.	:	That is
Kg	:	Kilogram(s)
M	:	Metre(s)
No./no.	:	Number
N	:	North
Pp	:	Pages
Q	:	Quintal
S	:	South
SE	:	Standard error
Viz.,	:	Videlicet (namely)
χ^2	:	Chi-square

CHAPTER I

INTRODUCTION

Red gram or pigeonpea [*Cajanus cajan* (L.) Millspaugh] is an often cross pollinated crop (20 – 70%) with diploid (2n = 2x) chromosome number of 22 and genome size of 1C = 858 Mbp. It is a short-lived perennial shrub in which plants may grow for about five years and turn into small trees. Invariably, the traditional pigeonpea cultivars and landraces are of long duration and grown as intercrop with other earlier maturing cereals and legumes. It is an important pulse mostly grown in Asia, Africa, Latin America and the Caribbean islands. Considering the vast natural genetic variability in local germplasm and presence of various wild relatives, India is considered as the primary centre of origin of pigeonpea (Van der Maesen, 1980). It is the fourth most important legume crop in the world and second most important food legumes in India, contributing over 76.5 per cent of the world acreage and production (http://www.cgiar.org /impact/research /pigeonpea.html). It is cultivated worldwide on 4.92 million hectares (m ha) with an annual production of 3.65 million tones (m t) and mean productivity of 898 kg ha^{-1} (FAO, 2008). In India, pigeonpea is cultivated on 3.58 m ha with production of 2.74 m t and productivity of 687 kg ha^{-1}. In Maharashtra, pigeonpea is cultivated on 1.12 m ha with annual production of 0.92 m t and productivity of 833 kg ha^{-1} (http://nfsm.gov.in). In Asia besides India, Myanmar (0.54 m ha), China (0.15 m ha) and Nepal (0.72 m ha) are other major pigeonpea growing countries. In African continent Kenya (0.196 m ha), Malawi (0.168 m ha), Uganda (0.088 m ha), Mozambique (0.085 m ha) and Tanzania (0.068 m ha) produce considerable amounts of pigeonpea. It is widely known as a drought tolerant crop (Nene and Shaila, 1990) with a large temporal variation (90 – 300 days) for maturity. The plant is remarkably hardy to both low (as low as 5^0C - 10^0C) and high (up to 40^0C) temperatures and thus, ideal crop to fit into cropping systems in many parts of the World (Sinha, 1977).

Globally, pigeonpea is mainly traded for food use. It is a rich source of protein, carbohydrate, and certain minerals. The protein content of

commonly grown pigeonpea cultivars ranges between 17.9 - 24.3 $g100g^{-1}$ (Salunkhe *et al*., 1986) for whole grain samples, and between 21.1 - 28.1 $g100g^{-1}$ for split seed. Wild species of pigeonpea have been found to be promising source of high-protein and several high-protein genotypes have been developed with a protein content as high as 32.5% (Singh *et al*., 1990). Pigeonpea seeds contain about 57.3 to 58.7% carbohydrate, 1.2 to 8.1% crude fiber, and 0.6 to 3.8% lipids (Sinha 1977). Pigeonpea is most widely eaten in the form of split seeds. Green pods and green seeds are also consumed as a vegetable. The vegetable pigeonpea types are important in Central America as well as in Western and Eastern Africa, where green peas are consumed (Morton 1976). Vegetable types are generally large podded with large, sweet green seeds. Canned pigeonpeas are marketed in certain parts of the world (Morton, 1976). By-products of split and shriveled seed are used as livestock feed. It provides excellent forage for livestock and there is a great scope for selecting cultivars with not only higher grain yields but also higher forage yields and crude protein. The dry sticks, obtained after threshing, are used for various purposes such as fuel, thatching roof, fencing the sides of bullock carts and basket making. It is grown in a wide range of soils from sandy to heavy pH of 5.0 to 8.0. It produces more nitrogen from plant biomass per unit area of land than many other legumes although it usually produces fewer nodules than other legumes (Onim, 1987). The residual effect on a following cereal crop can be as much as 40 kg N ha^{-1} (Rao *et al*. 1983). With so many benefits at low cost, pigeonpea has become an ideal crop for sustainable agriculture systems in rain-dependent areas.

The discovery of genetic male sterility (GMS) coupled with the natural out crossing, has opened the possibility of commercial utilization of heterosis in pigeonpea (Reddy *et al*. 1978 and Saxena *et al*. 1983). The GMS based world's first pigeonpea hybrid ICPH 8 was released by ICRISAT for cultivation in 1991 (Saxena *et al*. 1992). Since in any pulse crop no commercial hybrids were available, the release of ICPH 8 is considered as a milestone in the history of breeding pulses. However, the hybrid seed production with a genetically determined male-sterile sibs, which account for 50% of the population grown. It is time and labour-intensive, involving 40-

50% of the seed production cost (Muthiah *et al*. 1998). Inefficiency in eliminating the fertile sibs reduces the quality of the hybrid seed. Further, the removal of 50% of the population (Fertile sibs) results in reduced yields. The first unsuccessful attempt to develop cytoplasmic-genetic male-sterile (CGMS) lines in pigeonpea by using the crossable wild relatives of pigeonpea was made by Reddy and Faris (1981). Ariyanayagam *et al*. (1995) and Saxena *et al*. (2004) reported *Cajanus sericeus* as the CGMS source. The first CGMS line of GT 288A was developed by using *C. scarabaeoides* at Gujarat Agricultural University, S.K. Nagar, India (Tikka *et al*. 1997 and Saxena and Kumar 2003). Consequently, several scientists have identified male-sterile from the interspecific crosses involving *C. volubilis* (Wanjari *et al*. 2001), *C. acutifolius* (Rathnaswamy *et al*. 1998a; Malikarjuna and Saxena 2002), and *C. cajanifolius* (Saxena *et al*. 2005b), while Mallikarjuna and Saxena (2005) reported a CMS source from a pigeonpea cultivar itself (*C. cajan*). The experience with GMS hybrid technology has conclusively demonstrated that in pigeonpea the exploitation of hybrid vigour is possible, if the seed production techniques are optimized (Saxena *et al*. 1998; Rathnaswamy *et al*. 1998b). Hence, it was felt that hybrid breeding could revolutionize if the CGMS system is exploited for hybrid breeding (Saxena *et al*. 1998). During the past 4-5 decades, pigeonpea productivity in India has remained almost stagnant around 700 kg ha^{-1}. There may be a number of climatic, edaphic, and crop management factors for low productivity but lack of high yielding cultivars appears to be a major factor underlying this bottleneck. In India, the annual pigeonpea grain production of 2.74 m t fall short of domestic demand, and about 0.5 to 0.6 million tones is imported mainly from Myanmar and southern and eastern Africa. Therefore in order to meet the ever-growing demand of this pulse its productivity has to be increased significantly.

Hybrid technology has successfully been used to increase the yields. A new hybrid pigeonpea breeding technology, developed jointly by the International Crops Research Institute for the Semi-arid Tropics (ICRISAT) and Indian Council of Agriculture Research (ICAR) is capable of substantially increasing the productivity of red gram, and thus offering hope of pulse revolution in the country (Saxena and Nadarajan, 2010). CGMS based hybrids

in extra short, short and medium maturity groups have recorded grain yield superiority of 61% over the best control cultivar in different locations across India (Saxena 2008). This technology is also being transferred to China and Myanmar. As these newly developed hybrids are inter-specific one, there is presence of the wild gene in the hybrid. Due to presence of the wild genes quality in most of the hybrids affected. Poor quality of pigeonpea lacked acceptability by consumers and millers. The increasing demand of quality pigeonpea in the local and international markets has paid attention on quality breeding. Improving pigeonpea quality has now become one of the objectives in most of pulse breeding programs. The quality characteristics of pigeonpea include physico-chemical as well as cooking quality. In pigeonpea, heterosis for grain yield and its component have not been reported for various quality parameters in pigeonpea hybrids by using CGMS lines and diverse restorers that will be expected to stable, good combiner across the environment. However, varieties good in *per se* performance may not necessarily produce desirable progenies when used in hybridization, proper understanding of underlying inheritance of quantitative traits and also in identifying the promising crosses for further use in breeding program. However, environmental effect greatly influence the combining ability estimates. In view of above consideration, the present study has been planned on heterosis, combining ability, stability, and quality parameters in CGMS-based pigeonpea hybrids with the following objectives.

1. Study of heterosis and combining ability of newly developed hybrids under different environments.
2. Study of stability of CGMS lines for sterility.
3. Study of stability of hybrids under different environments.
4. Study genetics of restoration.
5. Study of quality parameters in new hybrids.

CHAPTER II

REVIEW OF LITERATURE

The commercial exploitation of heterosis or hybrid vigour through the cultivation of hybrid cultivars is one of the landmark achievements of plant breeding. Ever since the two pioneering publications by George H. Shull about 100 years ago, in which he scientifically described heterosis and laid the foundation of modern hybrid breeding in maize. The exploitation of heterosis in various crop and tree species has greatly expanded and the area under hybrid cultivars has tremendously increased. Thus, hybrid breeding has made commendable contributions in meeting the food, feed, and fiber needs of the burgeoning global population, and benefited farmers and consumers. It also gave birth to a viable seed industry, which was a tremendous stimulus for the research in plant breeders. The pertinent review of literature in respect of heterosis, combining ability, genetics of fertility restoration, stability and some quality parameters in CGMS-based pigeonpea hybrids is described in the following pages.

2.1 Heterosis

The term 'hybrid vigour' or 'heterosis' means superiority of F_1 hybrid over its parents and it has been exploited commercially in a number of cereal and vegetable crops. But in case of legumes it was never thought to be due to their floral morphology. Although critical information on the occurrence and magnitude of non-additive variance (dominance and epistasis) that is responsible for the manifestation of heterosis, is lacking. In pigeonpea, a considerable amount of hybrid vigour with the mid-parent and better parent has been reported by several workers for grain yield and other economic characters. Solomon *et al*. (1957) were the first to report hybrid vigour in pigeonpea in 10 inter-varietal crosses. In some crosses they observed hybrid vigour over the better parent up to a maximum of 24.5% for grain yield together with plant height, and number of fruiting branches. The components analyses of hybrids have shown high yield in the heterotic crosses to be

closely associated with heterosis for pods per plant, number of primary branches, and plant height. All three traits contribute to the increased total biomass. Subsequently, a number of reports have been published on hybrid vigour for yield and yield components (Saxena and Sharma, 1990). Most of the reports on hybrid vigour are from experiments conducted in one environment, and such estimates, suffer from considerable bias due to genotype × environment interaction. This bias is considerably accentuated if a particular phenological group is better adapted to the test environment. The studies conducted at ICRISAT conclusively showed that a single location suffers from the bias caused by genotype × environment interaction, and may give an impression of "pseudo-heterosis" (Byth *et al*., 1980). To exploit this phenomenon commercially, it is necessary to know the extent of heterosis present in the CGMS based hybrids. Saxena (2007) reported that CMS based pigeonpea hybrids gave 50 – 100% yield advantage over the popular variety. The world's first cytoplasmic male sterility (CMS) based pigeonpea hybrid Pushkal (ICPH 2671) had broken the yield barrier that has plagued Indian agriculture for the past five decades (Saxena, 2009).

The hybrid pigeonpea breeding technology, developed jointly by the International Crops Research Institute for the Semi-arid Tropics (ICRISAT) and Indian Council of Agriculture Research (ICAR) is capable of substantially increasing the productivity of red gram, and thus offering hope of pulse revolution in the country. The hybrid technology, based on cytoplasmic nuclear male-sterility (CMS) system, has given an opportunity of achieving the long-cherished goal of breaking yield barrier in pigeonpea. In the past few years ICRISAT and ICAR have tested over 1000 experimental hybrids and among these GTH 1 and ICPH 2671 were found the most outstanding. GTH-1 yielded 32% more yield than best local variety GT 101 while ICPH 2671 was highly resistant to fusarium wilt and sterility mosaic diseases and produced 38% more yield over the popular variety Maruti in multi-location trials conducted for over four years. In the on-farm trials conducted in the states of Maharashtra, Karnataka, Andhra Pradesh, Madhya Pradesh, and Jharkhand during 2007, 2008 and 2009 hybrids have demonstrated 30% yield advantage over local varieties. So far the progress in the mission of enhancing the

productivity of pigeonpea has been encouraging and the reality of commercial hybrids is just around the corner. The new hybrid pigeonpea will serve as the platform for the tremendous growth of pulse production in India (Saxena and Nadarajan, 2010). Many workers have emphasized the usefulness of heterosis as an important criterion for evaluation of hybrids. Among the three types of heterosis, standard heterosis is mainly considered important from practical point of view by plant breeders. In the present study the extent of standard heterosis were taken into account for the evaluation of hybrids.

2.1.1 Grain yield plant^{-1} (g)

In pigeonpea the extent of heterosis for grain yield was reported up to 24.51% by Solomon *et al*. (1957), 34.80% by Singh (1971), 72.20%, by Sharma *et al*. (1973), and 67.44% by Srivastava *et al*. (1976). Reddy (1976) observed the range of heterosis from 0.01 to 43.79% over better parent. Saxena (1977) reported heterosis was from -74.65 to 232.75% over better parent. Chaudhari (1979) recorded heterosis over better parent from -52.09 to 62.05% at one location and -50.58 to 73.94% at another. Patel *et al*. (1991) reported highest heterosis of 71.9 % in hybrid MS 3A x DL 78-1 followed by 71.6 % in MS Prabhat x T 15-15. Tutesa *et al*. (1992) reported highest mid parent and better parent heterosis of 238.0% and 211.9% respectively, in a single cross hybrid. Similarly, in a three-way cross (H73-20 x EE76) x UPAS 120 they reported the highest heterosis of 136.9% over mid parent and 113.9% over better parent for seed yield plant^{-1}. Jain and Saxena (1990), Sinha *et al*. (1994), Murugarajendran *et al*. (1995), Narladkar and Khapre (1996), Paul *et al*. (1996), Verulkar and Singh (1997), Hooda *et al*. (1999) and Pandey (1999) reported positive heterosis for seed yield. Pandey and Singh (2002) reported standard heterosis from 8.75 to 144.32%. Kalaimagal and Ravikesavan (2003) reported heterosis value from 9.13 to 404.57%, 10.11 to 57.92% and 10.42 to 106.175% over mid parent, better parent and standard check, respectively. Sekhar *et al.* (2004) reported heterosis from 51.3 to 171.6% and 33.4 to 98.3% over the standard check and better parent, respectively for yield plant^{-1}. Wankhade *et al*. (2005) reported that the phenomenon of heterosis was of general occurrence for most of the traits, the best cross exhibited better parent

heterosis up to 63.19% and standard heterosis of 83.34% over BDN 2. Aher *et al*. (2006) reported better parent heterosis of 20.66 % and 23.79% respectively in crosses BSMR 736 x NIRMAL2 and BDN-2 x BDN 2010. Saxena *et al*. (2006) reported for seed yield the heterosis of 50 % in experimental hybrids of pigeonpea. Khandalkar (2007) found that CMS based hybrids recorded standard heterosis from -61.2 to 155.7% for grain yield and -38.8 to 91.2% for harvest index. Dheva *et al*. (2008 a) observed a range of heterosis from 2.53 to 415.09% over male parent, 3.57 to 263.15% over better parent, and 0.72 to 57.35% over the standard check for grain yield. Dheva *et al*. (2008 b) observed positive heterosis from 15.62 to 168% over male parent, 0.86 to 68.06% over better parent, and 5.12 to 28.20% over standard check, respectively. Kumar *et al*. (2009) observed heterosis of 54.14 %, 53.14 %, and 51.38% respectively over mid, better parent and standard check for seed yield plant^{-1}. Chandirakala *et al*. (2010) and Shoba and Balan (2010) reported the significant positive standard heterosis for yield plant^{-1} in the CMS-based hybrids of pigeonpea.

2.1.2 Days to 50 % flowering and maturity

Solomon *et al*. (1957) reported -7.69 to 12.17% heterosis over late parent. Veeraswamy *et al*. (1973) observed five crosses noteworthy for the maximum expression of heterosis for 50% flowering. Chaudhari (1979) observed a range of heterosis for days to flowering from -4.47 to 51.25 over standard check and from -7.31 to 75.31% over better parent; He also recorded -5.63 to 26.32% and -3.17 to 25.68% heterosis for days to maturity in two sets over better parent. The magnitude of positive heterosis for days to 50% flower and maturity was reported by Reddy *et al*. (1979), which ranged from 0.00 to 65.90% and 0.3 to 30.70%, respectively over better parent. Singh *et al*. (1989) reported positive heterosis for days to 50% flower and maturity. Patel *et al*. (1991), Tutesa *et al*. (1992), reported significant negative heterosis for days to flower and maturity. Pandey and Singh (2002) reported significant negative heterosis in three crosses evaluated for days to 50% flower and maturity. Standard heterosis from -23.1 – 4.6% for 50% flowering and -40.0 – 1.0% for days to maturity was reported by Khandalkar (2007). Dheva *et al* (2008 a) reported significant heterosis

over better parent for days to 50 % flower (-23.84 %) followed by days to maturity (-16.94 %) in desirable negative direction in the hybrids. Kumar *et al*. (2009a) found the highest significant negative heterosis over mid parent, better parent and standard check. Chandirakala *et al*. (2010) and Shoba and Balan (2010) reported the heterosis in desirable direction for earliness in the CMS-based hybrids of pigeonpea.

2.1.3 Plant height (cm)

Solomon *et al*. (1957) and Singh (1971) recorded positive heterosis over better parent for plant height. Sharma *et al*. (1973) recorded 80.50% heterosis over better parent. Maximum heterosis in five crosses was reported by Veeraswamy *et al*. (1973). Shrivastava *et al*. (1976) observed heterosis for plant height from -61.0 % to 14.01 % over better parent. Chaudhari (1979) recorded a range of heterosis from -31.44 to 10.67 and from -16.58 to 14.47% over better parent at two locations. Reddy *et al*., (1979) reported negative heterosis for plant height. Singh *et al*. (1983), Patel and Patel (1992) reported the maximum heterosis of 158.7 % for plant height over mid parent. Jain and Saxena (1990) and Patel *et al*. (1991) observed significant positive heterosis in all the hybrids for plant height, whereas highly significant negative standard heterosis for plant height in all 36 crosses reported by Pandey and Singh (2002). Wankhede *et al*. (2005) reported the mid parent heterosis of 9.35 % and standard heterosis of 18.7 % in the hybrid AKMS 2 x AKT 9221 for plant height. Khandalkar (2007) observed a large range of standard heterosis (-2.6 to 141.6%) in CMS based hybrids of pigeonpea for plant height. Dheva *et al*. (2008 b) and Kumar *et al*. (2009) reported the highest significant positive heterosis over mid parent, better parent and over check for plant height in their studies. Chandriakala *et al*. (2010) reported range of heterosis from -24.43 to 34.38 %, -47.86 to 38.25 % and -35.92 to 56.14 % over mid, better and standard parent respectively. Shoba and Balan (2010) revealed that high per se performance are associated with high heterosis in hybrid MS CO 5 x PA 128.

2.1.4 Number of primary and secondary branches plant^{-1}

Solomon *et al*. (1957) recorded heterosis over better parent for number of fruiting branches. Chaudhari (1979) recorded the range of heterosis over better parent from -53.70 to 4.71 % and from -30.43 to 20.75 % at two locations. Singh *et al* (1983) observed the highest significant positive heterosis over mid parent (8.6 %) and better parent (52.16 %) in an interspecific cross ICPW 159 x DA 11 for primary branches per plant. Narladkar and Khapre (1996) observed significant positive heterosis for primary branches. Paul *et al* (1996) observed the range of heterosis from -1.6 to 40.9 % for number of primary branches plant^{-1}. Pandey and Singh (2002) recorded highly significant positive heterosis for primary branches plant^{-1}; the range was from -7.59 to 51.50 %. Wankhede *et al*. (2005) observed significant positive heterosis of 32.60 % and 36.82 % for number of branches plant^{-1} over mid parent and standard check. Khandalkar (2007) reported -4.4 to 63.8% standard heterosis for number of primary branches in CMS based hybrids of pigeonpea. Kumar *et al*. (2009a) observed the highest significant positive heterosis (27.45 %, 24.40 % and 46.28 %) over mid-parent, better parent and standard check for number of primary branches plant^{-1}. For number of branches plant $^{-1}$, the range of heterosis over mid, better and standard parent was from -23.69 to 29.33 %, -42.83 to 28.87 % and -24.89 to 47.49 % respectively in GMS based hybrids of pigeonpea were reported by Chandirakala *et al*. (2010).

Veeraswamy *et al*. (1973) observed significant positive heterosis for number of secondary branches, while Srivastava *et al*. (1976) recorded 96.0% heterosis. Chaudhari (1979) reported that the heterosis over better parent was from -78.02 to 66.32% and -49.91 to 70.30%. Paul *et al*. (1996) observed the range of heterosis from -1.3 to 185.9 % for number of secondary branches plant^{-1}. Significant positive heterosis up to 205.78% for secondary branches was reported by Pandey and Singh (2002). Acharya *et al*. (2009) reported significant and positive heterosis for number of branches plant^{-1} in pigeonpea. Chandirakala *et al*. (2010) and Shoba and Balan (2010) reported the significant positive standard heterosis for number of secondary branches plant^{-1} in CMS based hybrids of pigeonpea.

2.1.5 Number of pods plant^{-1}

Singh (1971) reported 31.0% heterosis for number of pods plant^{-1}. Veeraswamy *et al*. (1973) recorded heterosis up to 188.50% whereas Srivastava *et al*. (1976) found up to 80% heterosis. Chaudhari (1979) reported a range of percent heterosis for pods plant^{-1} from -6.15 to 42.67 over better parent and from -49.44 to 50.54% over standard check. Reddy *et al*. (1979) recorded positive heterosis for this character. Patel and Patel (1992) recorded up to 169% heterosis. Tutesa *et al*. (1992) found 102.8 to 220.7% significant positive mid parent heterosis in six single cross hybrids for pods plant^{-1}. Narladkar and Khapre (1996) reported positive heterosis for grain yield and it was due to heterosis for total number of pods plant^{-1}. Paul *et al* (1996) reported a range of heterosis from 28.1 to 191% for number of pods plant^{-1}. Singh *et al* (1999) found the significant and positive heterosis over mid parent (25.54%) and better parent (18.86%) in cross ICPW 161 x ICPL 8719 for pods plant^{-1}. Pandey and Singh (2002) reported heterosis from -26.06 to 103.64%, and seventeen cross combinations showed significant positive heterosis for total number of pods plant^{-1}. Wankhede *et al*. (2005) and Dheva *et al*. (2008a and 2008b) reported significant positive heterosis in all the three basis of heterosis. Patel and Tikka (2008) showed significant and positive heterosis of 42.06, 25.45 and 98.26% on all the three bases of estimation viz; mid parent, better parent and standard parent, respectively. Acharya *et al*. (2009) reported significant and positive heterosis for number of pods plant^{-1}. they revealed that number of pods plant^{-1} was the most consistent yield attribute for seed yield plant^{-1}. Therefore, desired level of each component should be aimed in a selection programme. Kumar *et al*. (2009a) also observed positive heterosis from 18.62 to 58.31% over mid parent, 24.94 to 50.13% over better parent and 14.72 to 37.43% over the standard check for number of pods plant^{-1} in pigeonea. Chandirakala *et al*. (2010) estimated standard heterosis for pods plant^{-1} in GMS based hybrids of pigeonpea; they reported 3.34 to 48.86%, -3.88 to 32.84% and 5.41 to 98.26% over mid parent, better parent and standard control respectively. Shoba and Balan (2010) reported standard heterosis from 18.42 to 84.21 % in the CMS-based hybrids of pigeonpea.

2.1.6 Seeds pod^{-1}

Tutesa *et al*. (1992) reported significant positive mid-parent heterosis in 12 single cross hybrids and five three-way cross hybrids of pigeonpea; they found the maximum mid parent and better parent heterosis for seeds pod^{-1} in crosses ICPL 81 x EE 76 and (H77-208 x EE 76) x (UPAS-120). Paul *et al*. (1996) reported range of heterosis from -12.0 to 0.6% over winter Bahar and -6.4 to 7% over control for number of seeds pod^{-1}. Wankhede *et al*. (2005) reported heterosis from -8.13 to 22.45% over mid parent, from -11.93 to 14.29% over better parent and from -8.57 to 14.29% over standard check for number of seeds pod^{-1}.

2.1.7 100-Seed weight (g)

Solomon *et al*. (1957) reported negative heterosis for 100-seed weight (g). The range of heterosis was from -50.23 to -33.19% over better parent. Reddy *et al*. (1979) reported negative heterosis for this character. Chaudhari (1979) noted that the range of heterosis was from -16.35 to 22.73%. Manivel *et al*. (1999) recorded positive heterosis over better parent. Paul *et al*. (1996) reported range of heterosis from -44.1 to -18.0% over winter Bahar and -30.0 to 16.1% over control for 100-seed weight. Singh *et al* (1999) observed the higher significant heterosis for 100-seed weight. Wankhede *et al*. (2005) observed the highest significant positive heterosis for the cross AKMS-2 x ICP 8863 (15.16 %), AKMS-21 x BWR 171 (50.25 %) and AKMS-21 x BSMR 736 (28.44 %) over mid parent, better parent, and standard check respectively. Kumar *et al* (2009) observed the significant positive and negative heterosis over mid parent and better parent with cross LRG-38 x ICP-8836, and the highest significant positive heterosis with cross PRG-100 x ICP-8863. Chandirakala *et al*. (2010) revealed that among 30 hybrids, 10 crosses showed significant and positive heterosis over mid, better and standard control for 100 seed weight.

2.2 Combining ability

Combining ability analysis and the testing of significance of different genotypes was based on the procedure given by Kempthorne (1957). The

estimates of combining ability give the information about parents, which contribute more to the hybrids. This helps to develop the better performing cross combinations.

2.2.1 Grain yield plant^{-1} (g)

Jinks (1954) revealed that superior hybrids having poor x poor, average x poor general combiners as parents indicated dominance x dominance (epitasis) type of gene action. Higher magnitude of general combining ability (GCA) variance was observed by Singh (1972) and Sharma *et al*. (1973). Saxena (1976) reported the best combiners in late group; early parents had negative GCA effects. Reddy (1976) reported lowest GCA effects in large seeded group while medium maturity group showed high GCA effects. Significant and higher magnitude of specific combining ability (SCA) variances in F_1 generation was reported by Dahiya and Brar (1977) and Dahiya *et al*. (1978). Reddy (1978), Chaudhari (1979), Reddy (1979), Chaudhari *et al*. (1980) and Reddy *et al*. (1981) recorded higher magnitude of GCA variance. Vekanteswarlu and Singh (1982) reported that parents N R (W R) 15 and T_7 were the best general combiners for seed yield plant^{-1}. They further revealed that one good and one poor or even negative general combining parent can be involved in high significant specific combining ability effects of the crosses. Patel (1985) found the highly significant GCA and SCA variances in parents and hybrids. Lakhan *et al*. (1986) observed that most the crosses showing significant SCA effects due to one good and one poor general combiner. Narladkar and Khapre (1995) reported the variance for SCA was higher than GCA; among the parents the best general combiners were MS Hy-9, BDN-2, Daithna local and ICPL 87 for grain yield plant^{-1}. Best general combining ability of Daithna local for grain yield plant^{-1} was also reported by Aghav *et al*. (1998). Vanniarajan *et al*. (1999) reported that some of the cross combinations having parents with high x low and low x high GCA effects produced significant SCA effects. Srinivas *et al.* (1998) and Pandey and Singh (2002) observed desirable SCA effects for seed yield plant^{-1} and may thus be advanced to isolate desirable/transgressive segregants in advance generations. Jahagirdar (2003) reported the parents BDN-2, UPAS 120, ICPL 87, BSMR

736, and ICPL 87119 had positive significant GCA effects suggesting that they possessed desirable additive genes for increasing seed yield. Lohithaswa and Dharmaraj (2003) observed that parents BSMR 380, ICPL 87119 and TS 3 were the best general combiners for grain yield. Srinivas and Jain (2003) reported that genetic male-sterile line ICP MS 288 was good general combiner for seed yield. Among the males, LRG 30 showed good general combining ability for seed yield and for majority of yield components. Sekhar *et al*. (2004) studied the genetic analysis of 36 hybrids involving three male-sterile lines and 12 pollinator lines evaluated for 12 characters. The results revealed predominance of non-additive gene action for various characters studied. The parents QMS 1 and MS Prabhat (DT) among male-sterile lines, while Sel 90309, Sel 90306, Sel 90310, Sel 90311 and Sel 90307 among pollinators were identified as good general combiners. Hybrids utilizing three genetic male-sterile lines and 12 diverse elite genotypes of long duration group of pigeonpea were evaluated for general and specific combining ability, variance components and standard heterosis. Among the lines DA 32, DA 34, DA 37, DA46, DA 93-4, DA 93-2, DA 93-6 and Bahar mutant and testers DAMS 1 and ICPMS 3783 were found to be general combiners for seed yield plant^{-1} and other yield contributing characters (Pandey 2004). Phad *et al.* (2007) observed high specific combining ability of crosses which was due to high x high, high x low, low x high, low x low general combining ability of parents. Baskaran and Muthiah (2007) observed that the cross CORG 94 x ICPL 83027 had high SCA effects with high x low combinations indicating the operation of additive x dominance gene effects, and hence could be used in heterosis breeding. Yadav *et al*. (2008) observed high SCA effects in crosses ICP 12161 x ICP 9135, GT 100 x ICP 12116 and BANAS x ICP 9140 on the basis of per se performance. They revealed that the crosses expressed high SCA irrespective of the GCA effects of the parents, indicating involvement of dominance and epistatic gene effects in inheritance of traits. Acharya *et al*. (2009) compared the estimated GCA effects and *per se* performance of parents and revealed that GCA effects for seed yield plant^{-1} in general was related to *per se* performance. Therefore, it can be concluded that the choice of the parents on the basis of *per se* performance may be effective for improvement

of seed yield in pigeonpea. Sameer Kumar *et al.* (2009) revealed that high SCA resulted due to high x high GCA effects of parents in majority of the crosses.

2.2.2 Days to 50 % flowering and maturity

Singh (1972) reported high magnitude of GCA variances than SCA variances for days to flowering and maturity. Similar results were also observed by Sharma *et al*. (1973) and Chaudhari (1979). Highly significant GCA and SCA variances for both days to 50% flower and maturity and higher magnitude for GCA variances were observed by Reddy (1976), Dahiya and Brar (1977), Dahiya *et al*. (1978), and Reddy (1979). Higher magnitude of SCA variance was observed by Singh (1972). Reddy *et al*. (1979) and Pandey and Singh (2002) reported a predominant role of SCA than GCA variance for days to 50 % flowering. Significant GCA and SCA variances were observed by Chaudhari (1979) and Chaudhari *et al*. (1980). Hazarika *et al*. (1988) observed that early and determinate types were best combiners for days to flowering and maturity but were poor yielder. Patel *et al*. (1992) reported high estimate of SCA variance for days to flower and days to maturity. High GCA of Daithna local for early maturity reported by Aghav *et al*. (1998). Jahagirdar (2001) observed that, variances due to SCA were more than GCA variances. The significant negative GCA effects present in parents ICPL 87 and TV 1 which indicated their good general combining ability for earliness. Additive gene effects were reported for days to 50% flower by Lohithaswa and Dharmaraj (2003) and Sunil Kumar *et al*. (2003). Baskaran and Muthiah (2007) observed that the parents APK 1, CORG 9904 and ICPL 83024 exhibited negative GCA effect for days to maturity; they observed the presence of high x low and low x high GCA effects in the crosses VBN 1 x APK 1 for days to 50 % flowering and VBN 1 x ICPL 83024 for days to maturity. Phad *et al* (2007) observed the highest significant negative GCA effect in parental line BSMR 198 for days to 50 % flowering and days to maturity. Yadav *et al*. (2008) observed that the ratio of GCA to SCA genetic variance was greater than one, indicating additive type of gene actions in the expression of these traits. He observed the parents GT 10 and GT 101 as good general combiner for days to 50%

flowering and days to maturity. The parental lines ICPL 85034, LRG 38 and ICP 8863 had good general combining ability for days to 50% flowering and days to maturity reported by Sameer Kumar *et al*. (2009).

2.2.3 Plant height (cm)

Significant GCA and SCA variances for plant height were recorded by Sharma *et al*. (1973), Dahiya *et al*. (1978). Reddy (1978 and 1979), Reddy *et al*. 1979 and Reddy *et al*. (1996). Rao and Nagur (1979), Singh *et al*. (1983), Patel *et al.* (1987), Patel *et al.* (1992), Patel *et al.* (1993), Baskaran and Muthaiah (2007), Yadav *et al.* (2008), and Sameer Kumar *et al.* (2009) revealed that high SCA effects of high x low combinations indicating the operation of additive x dominance gene effects and hence could be used in heterosis breeding. Higher GCA variances were recorded by Sharma *et al*. (1973), Singh and Srivastava (2001); while higher SCA variances were reported by Dahiya *et al*. (1978) and Pandey and Singh (2002). Both GCA and SCA variances were important and equal according to Reddy (1979) and Reddy *et al*. (1979). Both general and specific combining abilities were found to be highly significant for plant height, as per Aghav *et al*. (1998). Phad *et al.* (2007) observed that the parents BSMR 175 and BDN 2010 were best general combiners for plant height.

2.2.4 Number of primary branches plant^{-1}

Significant GCA effects were reported by Reddy (1976) and Chaudhari (1979). For this character higher SCA variances than GCA variances in F_1 generations were recorded by Reddy *et al*. (1979). Ghodke *et al.* (1995) reported that the parental genotype ICPL 87119 was good general combiner for number of primary branches. Higher estimates of SCA variance than GCA reported by Singh *et al.* (1983), Patel *et al.* (1992), Singh and Srivastava (2001), Pandey and Singh (2002), Phad *et al*. (2007), Yadav *et al.* (2008) and Sameer Kumar *et al.* (2009).

2.2.5 Number of secondary branches plant^{-1}

Reddy (1976) and Chaudhari (1979) noted highly significant GCA variance for secondary branches plant^{-1}. Ghodke *et al*. (1995) reported that parental

genotype ICPL 87119 was good combiner for secondary branches. Pandey *et al*. (1998) reported genotypes Bahar and ICP 7035 were the best general combiners for number of secondary branches plant^{-1}, whereas DA-32, DA-37, DA-46, DA-93-1 and DA-93-2 were good general combiners for secondary branches plant^{-1} (Pandey and Singh, 2002). Phad *et al.* (2007) revealed that the crosses showing significant positive SCA effects for number of secondary branches per plant exhibited direct dependence of grain yield per plant on number of secondary branches plant^{-1}. Yadav *et al.* (2008) revealed high significant mean squares due to general and specific combining ability effects, indicating involvement of both additive and non-additive type of gene action.

2.2.6 Number of pods plant^{-1}

Dahiya and Brar (1977) and Dahiya *et al*. (1978) noted highly significant GCA and SCA variances for pod number. Reddy (1978) and Singh and Srivastava (2001) recorded significant GCA variances for pods plant^{-1}. Reddy (1979) recorded significant GCA and SCA variancees and higher GCA variance for this character. Reddy *et al*. (1979) reported that SCA variance was higher than GCA variance in F_1. Among the parents the best general combiners were ICPL 87119, (Ghodke *et al*. 1995), BDN 2 and Daithna local (Narladkar and Khapre, 1995) and Bahar (Pandey *et al*., 1998). Pandey and Singh (2002) reported 32 crosses with significant positive SCA effects against 36 total cross combinations for total pods plant^{-1}. The parents BDN-2, BSMR-736 and ICPL-87119 had positive significant GCA effects suggesting that they possessed desirable additive genes for increasing pod number Jahagirdar (2003). Baskaran and Muthiah (2007) observed that the cross VBN 1 x ICPL 83027 had high GCA effects and produced high SCA effects. These combinations involved high x high combiners indicating the major role of additive x additive (Amaranth and Subrahmanyam, 1992). Phad *et al.* (2007) observed that variances due to SCA were more than GCA variances indicating predominance of non-additive gene action. Similar results reported by Patel (1985) and Yadav *et al.* (2008). Sameer Kumar *et al.* (2009) revealed that the cross combinations of high GCA lines x high GCA testers manifested into higher SCA combinations.

2.2.7 100-Seed weight (g)

Highly significant GCA and SCA variances for 100-seed weight were reported by Sharma *et al*. (1973), Dahiya and Brar (1977), Dahiya *et al*. (1978), Reddy (1978) and Reddy (1979), Reddy *et al*. (1979) observed that SCA variances were several times higher than the GCA variances, whereas high GCA variance was reported by Singh and Srivastava (2001), also noted that cultivar Bahar as the best general combiner for 100-seed weight. Sunil Kumar *et al*. (2003) and Lohithaswa and Dharmaraj (2003) reported additive gene effects for 100-seed weight. Shrinivas and Jain (2003) reported predominance of non-additive gene actions for 100-Seed weight character. Baskaran and Muthiah (2007) observed that the variance due to SCA was higher than the variance due to GCA for this trait, they revealed that, the high SCA effects of high x low combinations indicating the operations of additive x dominance gene effects and hence could be used in heterosis breeding. Phad *et al.* (2007) observed higher SCA variance than GCA variance. The GCA estimated of BSMR 146 and BDN 2004 indicated their best general combining ability for 100-seed weight. Yadav *et al.* (2008) recorded non-additive type of gene action. They observed that the crosses selected on the basis of high *par se* performance possessed significantly desirable SCA effects. Sameer kumar *et al.* (2009) observed higher SCA variance indicating non-additive gene action. They revealed significant SCA effects were due to high x high GCA effects of parents in majority of the crosses.

2.3 Stability analysis

The stability analysis gives an idea about the homeostasis of the material tested. Here in this case we tried to evaluate the pigeonpea hybrids at various locations to test whether there is any environmental effect on the performance of these hybrids. At present there is no literature available on the stability of CGMS-based hybrids of pigeonpea. The literature related to earlier studies is given below.

2.3.1 Measurement of genotype × environmental interaction

The genotype x environment interaction is a major challenge in obtaining a complete understanding of genetic control of variability. The study of genotype x environment interaction in biometrical aspects is important from the genetically and evolutionary point of view. The phenotype has been conventionally defined as a linear function of the genotype, environment and interaction between the two.

Grafius (1956) emphasized that the studies of individual yield component can lead to simplification in genetic explanation of yield stability. If characters associated with yield stability could be found the plant breeder might effectively select for yield stability by selecting for these correlated characters. The genetic association of the component characters with yield should also be known.

Interaction will be absent when all the genotypes behave consistently in all environments or in other words their ranking does not change when subjected to different environments. Several workers (Finlay and Wilkinson, 1963, Perkins and Jinks, 1968 (a and b) and Johnson *et al.*, 1968) have attempted to measure the relationship between genotype and environment as well as interactions of genotype and the environment.

Finlay and Wilkinson (1963) developed a simple dynamic interpretation of varietal adoption to natural environments, which could provide a basis for formulation of broad biological concept of value to agronomist and the breeders. According to them an ideal variety may be defined as one with maximum yield potentials in the most favorable environment with maximum phenotypic stability measured by regression coefficient.

The approaches of Finlay and Wilkinson (1963), Eberhart and Russell (1966) and Tai (1971) are purely statistical and the components of this analysis have not been related to parameter in biometrical genetical model. Another approach is based on fitting of model, which specifies the contribution of genetic, environmental and genotype × environmental interactions to generation means and variances. This approach allows for contribution of

additive, dominance and epistatic gene actions to the genetic and interaction components, Mather and Jones (1958), Jinks and Stevens (1959), and Bucio Alanis and Hills (1966). This approach was used to investigate genotype × environment interactions in *Nicotiana rustica.*

Eberhart and Russell (1966) improved upon the model of Finlay and Wilkinson (1963) by adding another stability parameter namely the deviation from regression (S^2di). Later Breese (1969) applied this approach to data on grasses and has discussed the utility of this technique in predicting relative performance of genotype and hybrids over years, seasons and locations as well as to deduct differences in stability. He has shown that a major part of genotype × environment interaction could be explained by difference between linear responses as estimated by regression.

Perkins and Jinks (1968a) attempted to fill the gap between the two approaches by expressing the expectation of the statistical analysis in terms of standard model of genes, environmental action and genotype × environmental interactions and have extended the analysis to cover many inbred lines and crosses among them. Perkins and Jinks (1968 b) have mentioned that prediction of the sole parameters can be made both across the environments and across the generations.

Breese (1969), Samuel *et al.* (1970) and Paroda and Hays (1971) stated that the linear regression should simply be considered as a measure of response of genotype, whereas deviation around the regression line is a measure of stability. They also pointed out that a genotype with a lowest deviation may be the most stable and vice-versa.

2.3.2 Selection for adaptability

The general accepted theory of selection for wide adaptation is that selection should be made under the environmental conditions where the genotype is expected to grow.

The results of the experiment of St. Pierre *et al.* (1967) supported this theory and emphasized the importance of the practical use of genotype × environment interactions for getting varieties with wide adaptation and increasing the efficiency of selection work. They also indicated that genotype with wide

adaptation should come from a selection programme which permits the best expression of gene for wide adaptation.

Mehra and Pahuja (1980) reported that variation due to varieties, environments and variety × environmental interactions was highly significant in pigeonpea. BS 1 gave the highest mean yield but its performance was not stable over the range of environments. UPAS 120 was high yielding, more stable and was responsive to favorable environments. Higher yields tended to be associated with instability. Sharma *et al.* (1981) investigated 10 agronomic characters in 100 genotypes grown in five environments. Pod length and seeds pod^{-1} were stable across environments. Six lines were suitable for better conditions while three others proved promising for poor environments. Shoran *et al.* (1981) reported significant genotype × environment interactions for days to 50% flower, days to maturity, plant height, pods plant^{-1}, primary branches plant^{-1}, 100-seed weight and grain yield plant^{-1}. The linear component of genotype × environment was found to be significant only for days to maturity and grain yield plant^{-1}. However, its non-linear component was significant for almost all the characters. Jadhav (1983) observed that the genotype × environment (linear) variance components were significant for days to 50% flower, plant height, number of primary branches plant^{-1}, grain yield plant^{-1} and 100-seed weight. Singh *et al.* (1983) observed that the genotype × environment interactions were significant and its major portion was due to the non-linear component. Considering the mean square deviation as the measure of stability, it was found that high yielding lines like BS 58, K 28 and Bahar were unstable. The varieties SB 3 and Basant showing medium yield performance were found stable and most desirable. Singh (1984) reported that the magnitude of linear portion of genotype × environment interaction was higher as compared to non-linear portion for all the characters except plant height and pods plant^{-1}. Significant genotype × environment interactions for plant spread, number of secondary branches and pods plant^{-1}, days to 50% flower, days to maturity and grain yield ha^{-1} were observed by Ghodke (1985). Further the interactions were non-significant for plant height, number of primary branches, grain yield plant^{-1}, number of seeds pod^{-1}, 100-Seed weight and harvest index. The significant variances due to pooled deviation for plant

height, plant spread, secondary branches, pods plant^{-1}, 100-seed weight, days to 50% flower, days to maturity and grain yield indicated that differences in stability for these traits were due to both linear (bi) and non-linear (S^2di) parameters. Non-significant differences of pooled deviation for primary branches, seeds pod^{-1}, grain yield and harvest index suggest that main component for difference in stability for these traits was linear regression only. Shoran (1985) reported that, the magnitude of association between mean performance and regression coefficients was positively high for the majority of characters, viz. days to 50% flower, plant height, primary branches, pods plant^{-1}, 100-seed weight and seed yield plant^{-1}. The genotypes with poor performance for days to 50% flower, plant height, primary branches, pods plant^{-1}, 100-Seed weight and grain yield plant^{-1} had above average stability (bi<1.0). Balakrishnan and Natarajaratnam (1989) observed that none of the six pigeonpea cultivars over three different seasons could be indentified for yield stability. However SA 1 and PLS 361/1 were identified for the stability of number of branches, number of pods per plant, number of seeds per pod and 1000-seed weight. The genotype-environment interaction is highly significant for all the yield components except number of seeds per pod. This study also suggests that these two cultivars can be used for crop improvement studies in pigeonpea. Gartan *et al.* (1989) the pooled analysis of variance revealed significant differences among 30 genotypes for the characters under study. The genotypes interacted significantly with different environmental conditions and major portion of the interactions was attributable to linear component. Holkar *et al*. (1991) stated that the magnitude of regression coefficient and deviation from regression varied from genotype to genotype indicating that they were responsive towards environmental variation. In the present study, three hybrids viz., MS Prabhat DT / VAMBAN1, QMS1 / ICPL 161 and MST21 / ICPL 161 were stable for seed yield per plant with high mean performance. Apart from this character, the hybrid MS Prabhat DT / VAMBAN 1 possessed stability with desirable mean values for seeds per pod and QMS 1 x ICPL 161 for pods per plant and 100 seed weight. These stable hybrids can be further tested in different environments to test their yield potentiality. Ghodke *et al.* (1992) evaluated the newly developed pigeonpea

genotypes with national checks under sole cropping, intercrop with sorghum hybrid and intercrop with pearl millet during 1988. For phenotypic stability of yield and its components, both linear and non-linear components of G x E interactions were non-significant for all the characters except number of pods per plant indicating the importance of both of these components for stability performance of genotypes. The newly developed genotypes showed average stability performance of grain yield per plant. Genotype PBNA -511 was found good for grain yield under different cropping systems. Khapre *et al.* (1996) reported stability on yield components in 23 pigeonpea genotypes. BDN 681 showed average stability for seed yield, plant height, secondary branches plant^{-1} and pods plant^{-1}. BSMR 736 showed above average stability for seed yield plant^{-1}. BDN 686 and BDN 7 showed average stability for secondary branches plant^{-1} and harvest index respectively. PBNA 47-1, BDN 681 and PBNA 47-1 were considered to be the most promising for use in pigeonpea improvement programmes. Murugan *et al.* (1997) recorded stability for 17 pigeonpea genotypes for seed yield. The linear component of regression was not significant against pooled error, indicating that the difficulty of predicting the performance of late maturing pigeonpea genotypes over environments. However, genotypes ICP 7991 and ICP 7346 were relatively high yielding with mean seed yields of 1470 and 1277 kg ha^{-1}, respectively with good stability.

Manivel *et al.* (1998) studied phenotypic stability of 54 genotypes of pigeonpea (40 hybrids and 14 parents) grown over three different environments for seed yield. Highly significant mean squares were observed for genotypes, genotype × environment interaction and environment (linear). The hybrids MS Prabhat NDT × Pant A2, MS Prabhat NDT × ICPL 161 and MS Prabhat NDT × DM-1-5-1/2 were stable genotypes under three fertility levels as they had high mean and regression coefficient, not deviated from unity and non-significant minimum deviation from regression. Pandey and Singh (1998) evaluated 10 hybrid genotypes of long duration pigeonpea over four years for seed yield. Mean difference between hybrids (H) and years (Y) were highly significant indicating substantial variability among hybrids and years for seed yield. Highly significant variance due to environment + (H × Y)

revealed that hybrids interacted considerably with environmental conditions that existed during different years. Significant H × Y interaction was observed for seed yield. Both linear and non-linear components of H × Y interaction played important roles in the expression of seed yield. However, the linear component was larger in magnitude. It was observed that RAUPH 9117 and RAUPH 9003 were adaptable to all environments, while the hybrid genotypes RAUPH 9122 and RAUPH 9127 were suitable for high yielding environments. Saxena and Raina (2001) studied environmental interaction effects for seed weight and grain yield of twelve pigeonpea genotypes. They found that for grain yield of hybrids and pure lines responded differently as separate groups and hierarchical separations reflected the mean performance of the genotypes. Hybrids and controls showed specific adaptation to particular environments, emphasizing the need to breed for location specific hybrids and select testing sites and controls carefully.

Muthiah and Kalaimagai (2005) found that the G x E interaction linear was significant for plant height, branches per plant, pods per plant, seeds per pod, hundred seed weight and seed yield per plant. Patel *et al*. (2005) reported stable hybrid developed on cytoplasmic-genic male-sterile lines of pigeonpea. They stated that these hybrids have good adaptability over seasons. Rao *et al*. (2007) significant genotype x environment (GE) interaction for yield can seriously limit efforts in selecting genotypes (Kang1990). The AMMI analysis has clearly indicated its usefulness to have greater insight into magnitude and nature of G x E interaction. This model is effective in identifying the genotypes that have specific adaptation (interacting) and those which are adaptable non-interacting. It is also useful in characterizing the environments/ locations which are suitable for growing specific hybrids/varieties. Vanniarajan (2007) found that entries which showed unstable performance for one character also, showed the same for yield. The was present in the characters days to 50 % flowering, days to maturity, plant height, branches per plant, and pods per plant with seed yield per plant. Hence from the foregoing points, it is seen that seeds per pod were stable over environments along with seed yield, which gains support from the study of Shoran *et al*. (1981). Patel *et*

al. (2009) 11 early maturing pigeonpea genotypes were evaluated along with a national check (ICPL 87) for their yield performance during four years. Significant genotypic differences for yield and majority of the component characters were observed. Highly significant genotype-environment interaction indicated differential response of the genotypes to the environmental changes. The stability analysis was carried out, which showed significance of linear component. In other words, selection of genotypes with high mean performance is not possible without a sacrifice in the ability to perform well in every environment. Sreelakshmi *et al*. (2010) found stable genotypes ICPL 98008, ICPHAL 4979-2 and ICP 77303 for days to maturity and ICPL 20036 and ICPL 20058 for seed yield and were found to be suitable for low input cultivation.

2.4 Genetics of fertility restoration and stability of cytoplasmic-genetic male sterile (CGMS) lines

Oka (1974) suggested that the genetic background of a female parent could influence pollen and spikelet fertility of F_1 hybrids in inter-varietal rice hybrids. Tikka *et al*. (1997) reported development of cytoplasmic-genic male-sterility in pigeonpea with the help of wide hybridization. They used *Cajanus scarabaeoides* as female parent. The F_1 was partially fertile, while they got completely sterile plants in the F_2 generation, to which they used as female parent and made crosses with four genotypes. They got 100% sterile plants in the BC_1F_2 generation. Rathnaswamy *et al*. (1999) crossed two wild species *C. cajanifolius* and *C. acutifolius* to the genic male-sterile lines of *Cajanus cajan* (ms co 5). All the F_1s of ms co 5 × *C. cajanifolius* were found to be fully fertile. The F_1s of ms co 5 × *C. acutifolius* were found to be partially sterile and they were backcrossed to ms co 5. They further found that the frequency of male-sterility varied from 40 – 90% and more plants were in 60–70 % range. Wanjari *et al*. (2000) reported that male-sterility derived from *Cajanus sericeus* × *Cajanus cajan* is actually a single dominant gene possibly acting in concert with a single recessive gene to mimic cytoplasmic male-sterility. They found a segregation 1:1 (fertile: sterile) in the F_3 sibs while a ratio of 3:1 (fertile: sterile) in the selfed progenies, which shows that this male-sterility is

governed by monogenic recessive gene and that the male-sterile plants are homozygotes (ss). The fertile counterpart in the segregating sibs is heterozygotes (Ss). Zhang and Stewart (2001) and Feng *et al*. (2005) found the multiple, independent mechanisms of fertility restoration in cotton. They found that the Rf1 gene was responsible for fertility restoration for the D8 cytoplasm through a sporophytic mechanism and Rf2 gene was responsible for fertility restoration for the D8 cytoplasm through a gametophytic mechanism. Chauhan *et al*. (2004) studied the fertility restoration in cytoplasmic-genic male-sterile line of pigeonpea derived from *Cajanus scarabaeoides*. To identify perfect pollen fertility restorers, 543 derivative lines of F5 and F6 populations of *Cajanus scarabaeoides* × *Cajanus cajan* and other 1365 germplasm accessions were used as pollen parent. They could found good eighteen fertility restorers. Mallikarjuna and Kalpana (2004) reported two types of CMS plants in pigeonpea, which were distinguished by anther morphology. The type I CMS had partially or totally

brown and shriveled anthers and the process of microsporogenesis was inhibited at the pre-meiotic stage, while type II CMS plants had pale white shriveled anthers and the breakdown in microsporogenesis was at the post-meiotic stage after the formation of tetrads, which caused male-sterility of the plants. The cyto-genetic analysis between three cultivars of *Cajanus cajan* and four wild species of *Cajanus* showed normal meiosis in the parents but some meiotic abnormalities were observed in the F_1s indicating varying degrees of chromosomal and genetic differences between *C. cajan* and *C. acutifolius* (Jogendra Singh *et al*., 2004).

Jogendra Singh and Bajpai, (2005) studied the relative pollen fertility in interspecific crosses. They found that, *C. cajan* × *C. acutifolius* hybrid showed low pollen fertility in F_1 generation, where as high pollen fertility was found in crosses utilizing *C. cajanifolius* and *C. scarabaeoides*. They also noticed moderate variation in size of pollen grains among the parents and their hybrids. Mallikarjuna and Saxena (2005) reported development of cytoplasmic-genic male-sterility from cultivated pigeonpea cytoplasm. Here the wild species *C. acutifolius* has been used as one of the parents maintained

complete male-sterility. Cytological analysis revealed that both in the male-sterile as well as the fertile floral buds, meiosis proceeded normally till the tetrad stage. However, in the male-sterile genotypes during the formation of tetrads, the pollen mother cell (PMC) wall did not dissolve to release the tetrads unlike in the fertile genotypes and this major event was found to be responsible for male-sterility.

The tool of inter-specific hybridization can be used for the development of stable cytoplasmic-genic male-sterility system in pigeonpea (Saxena *et al*., 2005b). They designated the CMS system as A_4, which is developed by an inter-specific cross between *Cajanus cajanifolius*, a wild relative of pigeonpea and a cultivar ICP 11501. Also they tested various testers for knowing fertility restoration and maintenance reaction. They found ICPH 2470 as a promising short-duration experimental hybrid, which exhibited 77.5% advantage over the control cultivar UPAS 120. Lad and Wanjari (2005) reported that there may be many genes governing the fertility restoration in pigeonpea. They observed in segregating progenies a monogenic segregation pattern of 3 good: 1 poor dehiscence for pollen fertility percent. These progenies produced plants with 50-80% pollen fertility. Shinde *et al*. (2006) computed the photo-thermo-sensitivity on the basis of photoperiod sensitivity and seed setting percentage in sorghum. The male sterile that differed by lower magnitude of photoperiod sensitivity and recorded higher seed set percentage were considered as photo-thermo-insetitive. On the other hand the male steriles that differed by higher magnitude of photoperiod sensitivity and recorded lower seed set percentage was considered as photo-thermo-sensitive. They found that male sterile line 1409A was found to be most photo-thermo-insensitive for all seasons. Chaudhary *et al*. (2006) a higher order of sterility was noticed in the hybrids of A_3 cytoplasm when cornered to other cytoplasmic hybrids. Fertility status of A_4 cytoplasm hybrids were in between A_2 and A_3. From the fertility restoration studies it was concluded that the order of sterility in the diverse cytoplasm increased from A1 to A2 to A4 to A3. These results were in accordance with kishan and Borikar (1989) and Elkonin *et al*. (1995).

Dalvi *et al*. (2008) studied the fertility restoration of the three CMS lines *Cajanus seriseus* (A_1), *Cajanus cajanifolius* (A_4) and *Cajanus scarbaeoides*

(A_2) by using seven pigeonpea cultivars in three environments. They concluded that there was no effect of environments on the expression of fertility restoration. Pigeonpea cultivar ICPL 129-3 restored fertility in A_1 cytoplasm and maintained male sterility in the other two (A_2 and A_4) cytoplasms. Among crosses involving CMS lines (of A_4 cytoplasm) ICPA 2039 one hybrid combinations was male sterile and another as male fertile. Singh *et al*. (2009) reported that in long duration pigeonpea, formation of fertile pollen and its involvement in fertilization, pod formation and seed development was seriously affected or less in winter season (December – January). An increase in temperature in spring season (February – March), however resulted in normal pod and seed development. Again in summer (April – May) fertilization, pod formation and seed development were seriously affected due to high temperature i.e. $>35^0$C. Natenapit *et al*. (2009) showed that low temperatures (5^0C, 3 or 5 days) were not effective to restore pollen fertility of 'Ventimiglia'. Because the growth rate of flower buds under low temperature conditions was slower than those of high-temperature treatment, longer treatment might be necessary to cover all meiosis stages. They showed that high temperatures is the cause of pollen fertility in triploid interspecific hybrid lilies.

Sasikala *et al*. (2009) studied pollen fertility of 10 *Jatropha* species and an interspecific backcrossing hybrid between *Jatropha curcas* x *Jatropha integerrima* (BC_3F_1). Totally nine species had more than 84 per cent of pollen fertility. BC_3F_1 hybrid recorded the highest pollen fertility percentage of 97.54, while *Jatropha tanjorensis* had 16 per cent of pollen fertility which amounts to near sterility. Lakshmana *et al*. (2010) revealed that there is reduction in proportion of lines showing high restoration and mean seed set percentage from *kharif* to summer. This effect was noticed in all the cytoplasmic sources of pearlmillet.

Saxena *et al*. (2010) studied the genetics of fertility restoration in A_4 based diverse maturing hybrids in pigeonpea. They found that in extra-early group the pollen fertility was controlled by a single dominant gene; while in early and late maturing parents the male fertility was governed by two duplicate dominant genes. It was also observed that the hybrids with two dominant

genes produced greater amount of pollen grain as compared to those carrying a single dominant gene, and it was concluded that for breeding hybrids with stable fertility restoration the presence of two dominant genes was essential. Umadevi *et al*. (2010) evaluated a total of 74 CMS lines in rice and their maintainers for morphological and floral characters influencing out crossing rate. Out of these CMS lines, 42 CMS lines were completely pollen sterile. For all the CMS lines spikelet fertility ranged from 0.51 to 4.55 %. The medium duration CMS lines *viz.,* COMS 13, COMS 15, IR 68281, ICR 6626, DRR 7, RTN 6, RTN 13 and PMS 17 were found promising for the characters *viz*., pollen sterility (%) and medium duration favorable for out-crossing during seed production of A x B and A x R combinations. These CMS lines offer scope for utilizing in the development of three line hybrids with high yield in rice.

2.5 Study of Quality Parameters

Argikar (1970) has reported that growing season per location affects some of the quality parameters in cereals as well as in legumes. Kurien *et al.* (1972 a) reported average dal yield of 68 to 75%, i.e. 10 to 17% less than the theoretical average value of 85% from traditional commercial dehulling methods. In small-scale milling, dal yield was 50 to 80% with a mean of 62% (Singh and Jambunathan, 1981a). However, Ehiwe and Reichert (1987) reported less variation (79-83%) in dal yield of pigeonpea cultivars compared to other legumes. They found the cooking time of various grain legumes from 30 minutes to one hour. In this study the cooking time for CO1 was 40 minutes, whereas for other varieties it was 50 to 60 minutes. Swaminathan and Jain (1972) and Singh *et al*. (1974) have reported significant location effects on protein content of pigeonpea genotypes. Rathinaswamy *et al*. (1973) found that there was a significant negative correlation (r = 0.93) between the time taken for cooking and the protein content of the redgram varieties.

Singh *et al*. (1973) reported varietal differences for protein content in pigeonpea. They reported the average cooking time of 24.3 min and range of 23.3 to 25.3 min in improved varieties of pigeonpea.

Tripathi *et al*. (1975) found that late varieties gave significantly higher dal recovery (%), protein content (%) and lesser loss in processing than the early varieties. Early varieties gave significantly higher protein % than the late ones, while they did not showed significant difference in respect of husk (%), broken dal recovery (%,) and cooking characteristics. They reported that in early varieties, husk (%) varied from 9.2 to 12.4%, while in late it ranged from 5.0 to 13.6%. However, there was no significant difference between early and late varieties. Dal recovery (%) varied from 68.0 to 77.0% in early varieties while in late it varied from 76.0 to 85.2%. Dal recovery (%) was significantly higher in late varieties as compared to early ones. Broken dal content in early and late varieties varied from 7.0 to 12% and from 4.0 to 16%, respectively and no significant difference was observed between the two groups. Loss in processing was significantly higher in early varieties as compared to late ones. Protein content in early and late varieties ranged from 20.62 to 25.54% and 19.38 to 21.81%. Dahiya and Brar (1976) observed that germplasm lines P 1862, P3761, P 978, H13 and H18 had protein contents above 24% with seed sizes 6.50, 8.00, 8.75 and 10.00 g, respectively. Parbhat and Pant A9 cvs, with the smallest seed sizes of 5.50 and 5.75 g, respectively, has protein contents of 17.15 and 22.32%. While the genotypes Hyb. 3A and Hyb. 3C with the largest seed sizes of 19.50 and 20.00 g had protein contents of 20.56 and 19.68%, respectively.

Siegel and Fawcett (1976) studied the processing of grain legumes and revealed that in many countries of the world, grain legumes are initially processed by removing the hull and splitting the seed into its dicotyledonous components. They revealed that home-level processing of pigeonpea into dal is a fairly difficult task compared to other common pulses because of the tight bond between the seed coat and the cotyledons. Tripathi and Singh (1979) found the significant differences in varieties and locations for protein content (%), dal recovery (%) and cooking time (min). They reported range of protein content (%) from 19.9 to 21.5%, dal recovery (%) from 83.6 to 84.5% and cooking time from 18.8 to 21.1 min in pigeonpea varieties. Narasimha and Desikachar (1978) conducted the cooking quality test with four varieties of pearled tur (*Cajanus cajan*). They observed that cooking beyond 30 minutes

led to progressively higher dispersion of solids into the cooking water. Water uptake (in the initial phase of cooking) and dispersion of solids into the cooking medium (in the later stages of cooking) under standard conditions of cooking could be considered as objective indicators of cooking quality.

Singh *et al*. (1990) reported that the protein content in wild relatives belonging to the sub-tribe *Cajaninae* of tribe phaseoleae and the cultivated species of pigeonpea. The protein content in wild relatives ranged between 28.3% and 30.5%; whereas *Cajanus cajan* had 24.2%. Non protein nitrogen ranged between 9.0% and 13.4% among the wild species as compared to the cultivated species, which had 11.0% protein. Singh and Jambunathan, (1981 a) studied the process of dehulling of pigeonpea and reported that in dehulling of pigeonpea the first steps involves loosening the husk from the cotyledons, and the second removing the husk from the cotyledons and splitting them using a roller machine of stone chakki. A survey of dehulling methods in India indicated that pigeonpea is traditionally dehulled in two ways depending on the magnitude of operation. one is the large-scale commercial dehulling of large quantities of pigeonpea into dal in mechanically operated mills, and the others is the small-scale home-processing method adopted by villagers using a stone chakki. The husk or seed coat content of pigeonpea cultivars ranged between 13.2 and 18.9%, with a mean of 15.6% of the whole seed mass.

Singh and Jambunathan (1981 b) reported the highest protein content of 23% in pigeonpea dal. Analyses of germplasm accessions of pigeonpea seed revealed that the protein content was ranged from 15.5 to 28.6%. The cooking time of 25 pigeonpea dal samples showed a variation from 24 to 68 minutes. They found the negative and highly significant co-relation coefficients between the cooking time and water absorption characteristics of dal. They reported that white pigeonpea seed gave higher dal yields than others. They also reported that village-level home processing appeared to give lower dal recoveries about 62% as compared to 71% obtained in a mechanically operated mill. Ramakrishnaiah and Kurien (1983) reported a large variation (72.3-82.0%) in the dal yield of various pigeonpea cultivars, and suggested that the environment could influence dal yield. The abrasive action of the dehulling machine, no doubt, has a significant influence on dehulling losses,

but if dehulling conditions are the same the environmental influence among the cultivars can be eliminated. Ramkrishnaiah and Kurien (1983) studied the milling (dehusking and splitting) characteristics of eighteen cultivars and one commercial variety of pigeonpea. They found the variations in dehusking characteristics, which were independent of size or husk content of the grain; but were influenced by other varietal factors such as adherence of husk to cotyledons and moisture content. The yield of dehusked split dal and pearled grains also do not depend on the size of grains or the proportion of the cotyledons, but are influenced by splitting and scouring losses in dehusking machines. Splitting during dehusking appears to be a varietal character which is also influenced by moisture. Moisture has an adverse effect on dehusking. The husk content of the cultivars varied from 10.5 to 15.5 %. They reported that husk content was not influenced by the size of grain. However, smaller grains have relatively higher husk and germ contents. Dehusking was complete in variety 'T-21', it was 87% whereas in commercial variety, it was only 62 %.

Singh *et al*. (1993) observed that the cooking time of ICPL 87, ICPL 270, ICPL 366 and ICPV1 ranged between 18 and 21 min. They reported a positive correlation between cooking time and seed size. Similar results reported in chickpea by Williams *et al.* (1983) and in lentils Erskine *et al*. (1985). Further they reported range of dal protein content range of 20.5 and 23.9% of newly developed genotypes.

Singh and Eggum (1984) reported the protein content range of 17.3 to 24.1% in pigeonpea. Singh *et al*. (1984) revealed that although there were no clear-cut differences present in cooking time and water absorption of different protein maturity groups of pigeonpea, the cooking quality of early cultivars appeared to be better than those of the medium and late ones. They found that water absorption was significantly correlated with the cooking time. Norton *et al*. (1985) reported that proteins present in legume seeds can be broadly classified into metabolic proteins, which are involved in normal cellular activities, and storage proteins, which are synthesized during seed development. The major storage proteins in legume seeds are globulins which usually account for about 70% of the total protein. Jain *et al*. (1987) reported

that presence of highly significant reciprocals differences were mainly due to the maternal effect. They observed that when high-protein lines were used as female parents, the protein content of all their F_1's approximated the high-protein parents. Similarly, when low-protein percentage of all the F_1's approximated their maternal parent. Rangaswamy (1991) noted high seed protein of 30.8 % in *Cajanus cajanifolius* and from 26.1 to 29.6% to its hybrids. They reported 23.19 to 24.29% heterosis for protein content in pigeonpea. Yi and Cheng (1991, 1992) found that different types of cytoplasm affect some cooking and nutrient quality traits of rice. Saxena *et al*. (1992) reported that pigeonpea is potentially an economical substitute for most other imported dals like chickpea and lentil on which the country spends a considerable amount of foreign exchange annually. Singh *et al.* (1992) used oil and water pretreatments to loosen the seed coat. Raghuvanshi *et al*. (1994) observed the correlation of cooking time with protein and seed weight. The cooking quality was positively correlated with seed weight (r = 0.120) while negatively correlated with protein content (r = 0.193). Jayasekera (1996) used oil and water treatments to process pigeonpea into good quality dal with available domestic dehullers in Srilanka and concluded that both oil and water treatments gave dal yields over 66%.

Gupta *et al*. (2000) studied the pigeonpea genotypes for cooking quality and found that the less cooking time for pigeonpea genotypes UPAS 120 and Bahar. They reported the cooking time in range of 37 to 53 minutes. Panigrahi *et al*. (2002) revealed that protein content of *C. cajanifolius* (30.8%) was much higher than the two pigeonpea cultivars, AKT 9013 (22.8%) and AKPH 1156 (21.6%). The F_1 hybrids from both the crosses had much higher protein content than the mid-parental values and were very close to the wild species *Cajanus cajanifolius* evidencing for positive heterosis (Rangaswamy *et al*. 1991). Hariprasanna *et al*. (2006) revealed that the milling recovery in rice hybrids was not influenced by the sterile cytoplasm. For kernel dimensions before and after cooking there were both favorable and unfavorable cytoplasmic effects, which varied in magnitude depending upon the sterile cytoplasm and parental combinations. Similar results were obtained for kernel elongation and gelatinization temperature. In general, the cytoplasmic

influence was found to be highly cross-specific and depended on the nuclear background of CMS line and fertility restorer.

Wankhade and Wanjari (2008) determined protein content of hybrids and their parents by crossing three genetic male sterile lines (AKms 2, AKms 11 and AKms21) and eight testers (ICP 8863, ICPL 87119, BSMR 175, BSMR 736, BWR 171, AKT 9221, C 11 and BDN 2). They found that out of 24 crosses evaluated only AKms 2 x BDN 2 exhibited positive significant heterobeltiosis as well as useful heterosis for protein content over standard check BDN 2. The study of combining ability for protein content revealed that two parents, BDN 2 and ICP 8863 showed positive significant general combining ability effect and one cross AKms 11 x ICPL 87119 showed significant specific combining ability effect in positive direction. Murali *et al*. (2009) studied the effect of bore well water and ground water on cooking quality of pigeonpea dal. They reported that when dal cooked in bore well water required greater time (77.33 min) for cooking, where as when dal cooked in distilled water had taken less time (32.80 min) for cooking. The increase in time consumption of dal cooked in bore water was twice than that observed in tap and well water, indicating that when dal was cooked in distilled, tap and well water, around 50 per cent of time was saved.

Chapter III

MATERIALS AND METHODS

3.1 EXPERIMENTAL MATERIALS

The present investigation was carried out to derive information on heterosis, combining ability, stability and quality parameters in CGMS-based pigeonpea hybrids. A line x tester mating design was used to develop F_1 hybrids using three CGMS lines ICPA 2043, ICPA 2047 and ICPA 2092 developed at ICRISAT. All three A-lines were derived from *Cajanus cajanifolius* (A_4) cytoplasm (Saxena *et al.* 2005b). The tester materials comprised of 13 genotypes (ICP 3525, ICPL 20106, ICP 12749, ICP 13991, ICP 10934, HPL 24-63, ICP 10650, ICP 3963, ICP 3407, ICP 11376, ICP 3514, ICP 3475 and ICP 3374) obtained from International Crops Research Institute for the Semi Arid Tropics (ICRISAT), Patancheru (Andhra Pradesh); 10 genotypes (BSMR 198, BSMR 846, BSMR 175, BSMR 2, BSMR 203, BWR 164, BWR 154, BDN 2001-6, BSMR 571 and BSMR 736) from Agricultural Research Station, Badnapur, M.A.U., Parbhani, genotypes (Phule-T-00-5-7-4-1, Phule-T-04-3-1, Phule-T-00-4-11-6-2, Phule-T-00-1-25-1 and VIPULA) from MPKV Rahuri, and six genotypes(AKT-9913, AKT-222521, AKT 8811, AKT-00-12-6-4, TV 1, and AKT-9915) from Pulses Research Unit, PDKV, Akola (Table 3.1). All these materials were evaluated at four selected environments viz., Patancheru, Parbhani, Latur and Badnapur (Table 3.2).

3.1.1 Hybridization

All the 102 cross combinations were made during *kharif* 2008 in a line (3) × tester (34) mating design and sufficient number of hand pollinated seeds was produced during 2008 rainy season at the Department of Agricultural Botany, Marathwada Agricultural University, Parbhani.

3.2 Experimental design and sowings

The experimental materials consisted of 102 hybrids developed with known restorer as described earlier. These crosses were used to study heterosis, combining ability, stability and quality parameters of hybrids. The

Table 3.1: Descriptions of parental lines used in crossing

Sr. No.	Parents	Selection/ pedigree	Maturity (days)	Plant height (cm)	100-Seed mass (g)	Seed color	Disease reaction (%) in Nursery	
	CMS Lines						**Wilt**	**SM**
1.	ICPA 2043	ICPA 2043 [ICPA 2039 x ICPL 20176) x ICPL 20176 x ICPL 20176 x ICPL 20176 x ICPL 20176 x ICPL 20176	162	161	10.7	Light Brown	19.00	0.00
2.	ICPA 2047	ICPA 2047 [ICPA 2039 x ICPL 995050) x ICPL 99050 x ICPL 995050 x ICPL 99050 x ICPL 99050 x ICPL 99050	167	179	11.0	Brown	0.00	0.00
4.	ICPA 2092	ICPA 2047 [ICPA 2039 x ICPL 96058) x ICPL 96058 x ICPL 96058x ICPL 96058 x ICPL 96058 x ICPL 96058	174	187	10.0	Light Brown	11.0	0.00
	Testers							
1.	ICP 3525	Selection from PI-395257	176	190	10.7	Brown	0.00	0.00
2.	ICP 11376	Field collection from Nepal	168	165	10.7	Brown	0.00	0.00
3.	ICP 3514	N.A.	175	188	11.7	Brown	0.00	0.00
4.	ICP 3475	Selection from 1141 TANKASI, Bihar, India	175	165	10.7	Brown	0.00	0.00
5.	ICP 3374	N.A.	173	189	11.8	Brown	0.00	0.00
6	ICP 10934	Field collection, Assam,	172	110	7.5	Brown	NA	NA
7.	ICPL 20106	IPH 487 Inbred 120	182	283	11.9	Cream	04	01
9.	ICP 12749	Selection from IC-WRSel. C.No 74360; C.No74360-ICP 7065x7035-F4B-S218X-	218	205	17.4	Brown	NA	NA
10.	ICP 13991	Field collection from Bangladesh	180	222	8.0	Cream	24	0.00
11.	HPL 24-63	ICPL 20205	179	162	8.5	Brown	07	21
12.	ICP 3963	ICPL 96053	179	155	11.2	Cream	0.00	0.00
13.	ICP 10650	PI 396940; P 3819	175	180	8.5	Brown	21	29
14.	ICP 3407	ICPL 20123	182	170	11.6	Brown	0.00	0.00
15.	BSMR-198	Selection from plant A-3 x ICP-7035	145	203	11.4	Brown	0.00	0.00
16.	BSMR-846	ICP-8767 x BDN-1	155	200	10.7	Brown	0.00	0.00

Where N.A. = Data not available

Table 3.1 continue…

Sr. No.	Parents	Selection/ pedigree	Maturity (days)	Plant height (cm)	100-Seed weight (g)	Seed color	Disease reaction (%) in Nursery	
							Wilt	SM
17.	BSMR-175	Selection from (Plant A-3 x ICP-7035) x BDN-2 [ARS, Badnapur 1991]	170	210	10.5	White	0.00	0.00
18.	BSMR-2	N.A.	176	210	11.0	Brown	0.00	0.00
19.	BSMR 203	N.A.	176	200	11.5	Brown	0.00	0.00
20.	BSMR 164	N.A.	178	195	11.7	Light Brown	0.00	0.00 00
21.	BWR 154	N.A.	176	202	11.8	Light Brown	0.00	0.00
22.	BDN 2001-6	N.A.	173	215	10.2	Brown	0.00	0.00
23.	BSMR 571	N.A.	175	205	11.5	Brown	0.00	0.00
24.	BSMR-736 (C)	(ICP-7217 x No.148) x BDN-1	180	182	10.9	Brown	0.00	0.00
25.	PHULE-T-00-5-7-4-1	N.A.	175	215	10.6	Cream	0.00	0.00
26.	PHULE-T-04-3-1	N.A.	168	222	10.6	Brown	0.00	0.00
27.	PHULE-T-00-4-11-6-2	N.A.	170	210	11.5	Brown	0.00	0.00
28.	PHULE-T-00-1-25-1	N.A.	170	192	11.4	Brown	0.00	0.00
29.	VIPULA	N.A.	171	215	11.5	Brown	0.00	0.00
30.	AKT 9913	N.A.	165	215	11.4	Brown	0.00	0.00
31.	AKT 222521	N.A.	168	203	11.5	Brown	0.00	0.00
32.	AKT-8811	Mass selection from bulk of segregating population of four crosses 1. ICPL-6 x DA-6 2. ICPL-6 x AL-57 3. ICPL-95 x H-80-110 4. ICPL-84008 x AL-57	150	190	9.2	Brown	0.00	0.00
33.	AKT 00-12-6-4	N.A.	166	195	11.6	Brown	0.00	0.00
34.	TV 1	N.A.	170	190	11.5	Dark Brown	0.00	0.00
35.	AKT 9915	N.A.	175	185	10.00	Brown	0.00	0.00
36.	ICPH 2671 (C)	ICPA 2043 x ICPR 2671	176	260	11.8	Brown	0.00	0.00

Where N.A. = Data not available

Table 3.2: Details of each environment is given below

Sr. No.	Particulars	Environments			
1.	Location	ICRISAT, Patancheru	Department of Agricultural Botany, MAU, Parbhani	Oilseed Research Station, Latur	Agriculture Research Station, Badnapur
2.	Latitude	17° 53'N	19° 16'N	18° 24'N	19° 50'N
3.	Longitude	78° 27'E	67° 47'E	76° 36'	47° 53'
4.	Altitude	545.0 m	409.0 m	633.8 m	519.6 m
5.	Soil type	Medium black	Heavy black	Medium to heavy black	Medium black
6.	Climatic zone	Moderate rainfall zone (997.59 mm)	Assured rainfall zone (865.3 mm)	Moderate to assured rainfall zone (652.4 mm)	Assured rainfall zone (585.3)
7.	Temperature (°C) Min. Max.	 10.24 36.5	 08.5 35.0	 11.0 38.3	 07.5 39.5
8.	Humidity (%) Min. Max.	 20 100	 50 100	 15 91	 12 100
9.	Date of sowing	25-06-2009	11.7.2009	7.7.2009	17.07.2009
10.	Date of harvesting	20-12-2009	10-01-2010	20-01-2010	26-02-2010

102 F_1s and parents in all the four environments were planted in α-lattice design with two replications. Each replication consisted of 162 entries (102 F_1s + 37 parents (2 checks repeated nine times (2 x 9 =18) and 5 dummy entries). Each genotype was represented by single row in each replication and each check was repeated once in one plot. In between the two checks 16 genotypes were sown. The row length was 4.0 m. The inter and intra row spacing was kept at 75 cm and 30 cm, respectively. Only one plant was maintained after thinning at each hill. At Patancheru, protective irrigation was given during the crop season while it was maintained under rainfed conditions at Parbhani, Latur and Badnapur. The other agronomic practices were followed as per recommendations (Ramkrishna *et al*. 2005) to grow a good crop.

3.2.1 Observations

3.2.1.1 Yield and yield components

Observations were recorded on randomly selected five competitive plants on each parent and crosses in each replication in all the environments. The summary of observations recorded is as follows.

a) Days to 50% flowering

Number of days taken from sowing to flowering of 50% plant in a plot was recorded.

b) Days to maturity

Days required from sowing to 75% maturity were recorded.

c) Plant height (cm)

Height of plant from ground level to the tip of the plant was recorded at the time of maturity.

d) **Number of primary branches plant^{-1}**

Total number of pod bearing branches on the main stem of a plant was counted.

e) Number of secondary branches plant^{-1}

Total number of pod bearing branches per plant on primary branches of a plant was counted.

f) Total number of pods plant^{-1}

Total number of pods on the sampled plant was counted at the time of harvesting.

g) Seeds pod^{-1}

Seeds from randomly selected ten pods from each plant were counted and the average seeds pod^{-1} was calculated.

h) Pod weight (g)

Total weight of the pods harvested from the sampled plant was weighed on electronic balance and measured in grams.

i) 100-Seed weight (g)

Fully grown 100 seeds of each entry were collected randomly and weighed on electronic balance.

j) Grain yield plant^{-1} (g)

Grains of the selected plants were harvested and threshed separately. Grain weight was taken after thorough drying in the sun.

3.2.1.2 Cyto-histological observations

3.2.1.2.1 Assessment of pollen fertility of hybrids

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

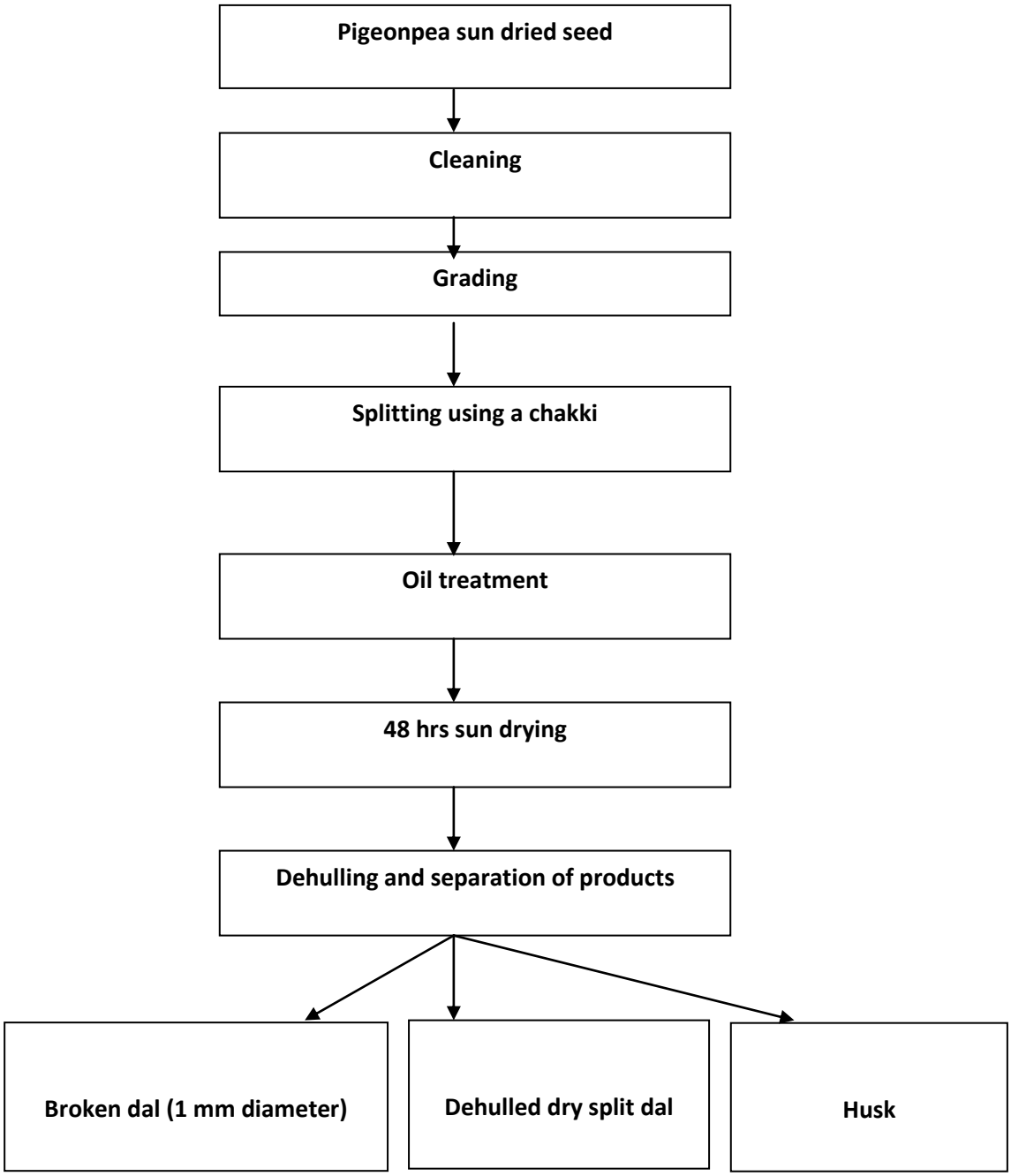
$$\text{Pollen fertility (\%)} = \frac{\text{Number of fertile pollens}}{\text{Total number of pollens}} \times 100$$

3.2.1.3 Qualitative observations (parameter of dal quality)

The dal was prepared by traditional small-scale processing method adopted by villagers using a stone chakki. It consists of splitting of seed with the help of stone chakki. The half split seed samples were then sun dried by spreading in a thin layer on a mat or gunny bag for 48 hrs. Finally the material was dehusked with a stone chakki. Various products i.e. dehusked dal, broken dal (1 mm diameter) and husk were obtained. These products were separated, and weighed separately on electronic balance to calculate the recovery percent (Flow chart: 1). The observations were recorded for four parameters of dal quality on randomly selected five plants of each parent, crosses and checks in two replication at Parbhani. The details of observations recorded are as follows **(**Singh and Jambunathan 1981 (a) and Jayasekera 1996).

Flow chart 1: Dehulling pigeonpea using the traditional stone chakki

(Singh and Jambunathan 1981 (a) and Jayasekera 1996)



a) Time taken for cooking (minutes)

Cooking time was determined by boiling the 10 gm of dal in distilled water in test tube on heater and total time required for cooking of dal were recorded in minutes by using stopwatch.

b) Protein (%)

Protein (%) of parents and hybrids was estimated following Micro-Kejaldahals Method. The estimated nitrogen content in each genotype was multiplied by constant multiplyer of 6.25 to obtain protein (%).

c) Dal recovery (%)

Dal recovery percent was calculated by using formula.

$$\text{Dal recovery \%} = \frac{\text{Total weight of dehusked dal (split dal, and broken dal)}}{\text{Total weight of seed used for dehusking}} \times 100$$

d) Water absorption (gg^{-1})

It was calculated by using formula

$$\text{Water absorption } (gg^{-1}) = \frac{\text{Weight of dal after cooking} - \text{Initial weight of dry dal}}{\text{Weight of dry dal}}$$

3.3 Statistical procedures

The data were subjected to analysis of variance as per the method described by Fisher and Yates (1974) and Panse and Sukhatme, (1985).

3.3.1 Pooled analysis of variance

The analysis of variance table was set out as per Panse and Sukhatme (1985).

3.3.2 Line x tester analysis

The analysis was carried out for L x T mating design as suggested by Kempthorne (1957). Statistical analysis was performed using SAS software available at ICRISAT, Patancheru. Test of significance was applied as per Panse and Sukhatme (1985).

Standard Error of mean (S.E. m) = (Error mean square/ No. of replications) ^{½}

Critical difference (C.D.) = S.E. of difference x ‘t’ value at 5%

3.3.2.1 Combining ability analysis

Combining ability analysis and the testing of significance of different genotypes was carried out according to the procedure given by Kempthorne (1957). Expected mean sum of squares of all the variance components of two way table and form of analysis of variance is given below.

Analysis of variance for combining ability

Source	df	M.S.S.	Expectation of mean squares
Replications	(r-1)		
Crosses	(mf-1)		
Males (m)	(m-1)	M_1	σ^2 + r (Cov Fs-2 Cov Hs) + (fr CovHs)
Females (f)	(f-1)	M_2	σ^2 + r (Cov Fs-2 Cov Hs)+ (mr Cov Hs)
Females x males (fm)	(m-1) (f-1)	M_3	σ^2 + r (Cov Fs-2 Cov Hs)
Error	(r-1) (mf-1)	M_4	σ_e^2

Where,

m = males

f = females

fr = Female x replication

mr = Male x replication

Cov Hs = Covariance of half sibs

Cov Fs = Covariance of full sibs

3.3.2.2 Estimation of general combining ability (gca) and specific combining ability (sca) effects

The half-sib and full-sib analysis was used to estimate the general and specific combining ability variances due to parents and hybrids respectively. The half sibs are those which have one common parent and full sibs are the individuals having both the parents common. The estimated covariances for half sib and full sibs were obtained by the following relations.

1. $$\text{Cov Hs } (\sigma^2 \text{ GCA}) = \frac{(M_1-M_3) + (M_2-M_3)}{r\ (l \times t)}$$

$$2.\quad \text{Cov Fs} = \frac{(M_1-M_4) + (M_2-M_4) + (M_3-M_4) + 6r\ (\text{Cov Hs}) - r(l+t)\ \text{Cov Hs}}{3r}$$

$$3.\quad \sigma^2 sca = \text{Cov Fs} - 2\ \text{Cov Hs}$$

General and specific combining ability effects were estimated as follows.

$$i)\quad \hat{u} = \frac{X\ldots}{m.f.r.}$$

Where,

X … = total of all hybrids

m = number of males

f = number of females

r = number of replications

$$ii)\quad gi = \frac{Xi..}{f.r} - \hat{u}$$

Where,

Xi.. = total of i^{th} male parent over all females and replications.

$$iii)\quad gj = \frac{\sum Xj..}{m.r.} - \hat{u}$$

Where,

Xj.. = total of j^{th} female parent over all male parents and replications.

$$iv)\quad Sij = \frac{\sum Xj(ij).}{r} - \frac{\sum (Xj)..}{f.r.} - \frac{\sum Xj..}{m.r.} + \hat{u}$$

Where,

$\sum Xj\ (ij)..$ = $(ij)^{th}$ combination total over all replications.

The restriction $\sum gj = 0$; $\sum Sij = 0$ is imposed on the elements of model.

The standard errors for GCA and SCA effects were calculated as follows:

$$\text{S.E. (GCA lines) gi} = \left[\frac{Me}{r.t.}\right]^{1/2}$$

$$\text{S.E. (GCA tester) gj} = \left[\frac{Me}{}\right]^{1/2}$$

r.l.

$$S.E.(Sij - Sk1) = \left[\frac{2Me}{r}\right]^{1/2}$$

Where,

Me = Error mean sum of squares

r = replication

t = testers

l = lines.

gi = standard error for lines

gj = standard error for testers

Pooled analysis of variance for data obtained from four locations (El-Itriby *et al*., 1981)

Source of variation	df	MSS	Expectation of mean squares
Location	(l-1)		
Replications within locations	l(r-1)		
Crosses	(mf-1)		
Females	(f-1)	M_1	$\sigma^2 e + r\sigma^2 fml + rm\sigma^2 fl + rl\sigma^2 f m + rml\sigma^2 f$
Males	(m-1)	M_2	$\sigma^2 e + r\sigma^2 fm1 + rf\sigma^2 ml + rl\sigma^2 fm + rf1\sigma^2 m$
Female x male	(m-1) (f-1)	M_3	$\sigma^2 e + r\sigma^2 fm1 + r1\sigma^2 fm$
Crosses x location	(mf-1)(l-1)		
Male x location	(m-1)(l-1)	M_4	$\sigma^2 e + r\sigma^2 fml + rf\sigma^2 ml$
Female x location	(f-1) (l-1)	M_5	$\sigma^2 e + r\sigma^2 fm1 + rm\sigma^2 fl$
Female x male x location	(m-1) (f-1) (l-1)	M_6	$\sigma^2 e + r\sigma^2 fm1$
Error	1(r-1)(mf-1)	M_7	$\sigma^2 e$

Where,

f = number of female parents

m = number of male parents

MSS = mean sum of square

Contribution of lines, testers and crosses

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

1. Contribution of males = $\frac{\text{S.S. (m)}}{\text{S.S. (crosses)}} \times 100$

2. Contribution of females = $\frac{\text{S.S. (f)}}{\text{S.S. (crosses)}} \times 100$

3. Contribution of male x female (interaction) = $\frac{\text{S.S. (m x f)}}{\text{S.S. (crosses)}} \times 100$

Where,

S.S. = Sum of squares

3.3.2.3 Pooled analysis for combining ability (line x tester)

Combining ability analysis was based on the procedure developed by Kempthorne (1957) related to Design II of Comstock and Robinson (1952). The estimates of variances were obtained by equating mean sum of squares to expectations and solving for the components.

σ^2 e = genetic variance among individuals from the same mating.

σ^2m = the variance of male effects.

σ^2f = the variance of female effects.

σ^2fm = the variance due to interaction between females and males.

σ^2fl = the variance due to interaction between female effects and environments (location).

σ^2ml = the variance due to interaction between male effects and environments.

σ^2fml = the variance due to interaction among females, male and environments.

The test of significance for females x males x environment interaction is F = M_6/M_7 and for females x males interaction is F = M_3/M_6. If M_3 is non-significant then M_3 will be tested against pooled error. The variance σ^2 m and σ^2 f will be tested against σ^2 ml and σ^2 fl, respectively.

'F' test for σ^2m = $(M_2 - M_3 + M_6) / M_5$

'F' test for σ^2f = $(M_1 - M_3 + M_6) / M_4$

In case, M_4 and M_5 are non-significant σ^2 f and σ^2m will be tested against corresponding pooled error.

The estimates of components of variance were obtained as follow :

σ^2 m over locations = $(M_2 - M_5 - M_3 + M_6) / rfl.$

σ^2 m over location = $(M_1 - M_4 - M_3 + M_6) / rfl.$(Environment)

σ^2ml = $(M_5 - M_6)/fr.$

σ^2fl = $(M_4 - M_6)/mr.$

σ^2fml = $(M_6 - M_7)/r.$

The estimates of σ^2gca and σ^2sca were based on covariance of full sibs and half-sibs.

Cov Hs = $(f\sigma^2m + m\sigma^2f)/(f+m)$

= $1/r\ 1(f+m) = \sigma^2fm + 2$ Cov (Hs)

From the above equations variances due to general and specific combining ability were estimated as:

σ^2gca = Cov (Hs)

σ^2sca = σ^2fm = Cov (Fs) - 2 Cov (Hs)

3.3.2.4 Estimation of hybrid vigour

The mean values over replications for various traits were used for estimation of heterosis. It was expressed as percent increase (+) or decrease (-) of F_1 hybrid over standard checks (standard heterosis) were measured for all the characters. The heterosis was calculated as per the formula given by Fonseca and Patterson (1968) and Meredith and Bridge (1972).

$$\text{Standard heterosis (\%)} = \frac{\overline{F_1} - \overline{SC}}{SC} \times 100$$

Where,

$\overline{SC}$ = mean of standard check

Test of significance

Significance of heterosis was tested by least significant differences (LSD) as follow:

L.S.D. for S.C. = (2 x pooled error mean square of the RBD/ no. of replication)$^{1/2}$ at p = 0.05 and 0.01

3.4 Stability analysis

Stability analysis of parents and crosses was carried out for 21 characters under study. Two different approaches were adopted for estimating the stability parameters (a) conventional pooled analysis of variance (G x E interactions) and (b) regression analysis, developed by Finlay and Wilkinson (1963) and subsequently modified by Eberhart and Russel (1966).

3.4.1 Pooled analysis of variance

The pooled analysis of variance was carried out as per the standard procedure reviewed by Singh and Chaudhari (1985).

The form of analysis of variance is given below.

Analysis of variance for mean data

Source	df
Environments	(n-1)
Genotypes	(v-1)
Genotypes x Environment	(n-1) (v-1)
Pooled error	n (r-1) (v-1)

Where, n, v and r stand for number of environments, genotypes and replications respectively. The mean sums of squares due to genotypes and environments were tested against mean sum of squares due to genotype x environment. The mean sum of squares due to genotype x environment were tested against mean sum of squares for pooled error.

3.4.2 Stability model of Eberhart and Russel (1966)

The stability parameters are defined with the following model:

$Yij = m + biIj + dij$

$i = 1, 2 .. t$ and $j = 1, 2 \ldots s.$

Where,

Yij = mean of i^{th} variety in j^{th} environment

m = mean of all the varieties over all the environments

bi = the regression coefficient of the i^{th} variety on the environmental index which measure the response of this variety to varying environments.

Ij = the environmental index which is defined as the deviation of the mean of all the varieties at a given location from the overall mean.

dij = the deviation from regression of the i^{th} variety at j^{th} environment.

$$Ij = \frac{\sum_i Yij}{\sum v} - \frac{\sum_i \sum_j Yij}{n}$$

With $\sum_i Ij = 0$

3.4.3 Environmental index (Ij)

$Ij = [(\sum_i Yij/ g) - (\sum_i \sum_j Yij/ge)]$ With $\sum Ij = 0$

Where,

Ij = environment index

Yij = summation of all the genotypes for j^{th} environment

g = number of genotypes

$\sum_i \sum_j Yij$ = summation of all the genotypes overall the environments.

ge = number of genotypes x number of environments

3.4.4 Regression coefficient (bi)

The first stability parameter is a regression coefficient. The regression coefficient of the varietal mean on environmental index is estimated as :

$bi = \sum jYij \; Ij / EI^2 j$

Where,

$\sum jYij \; Ij$ = sum of the i^{th} genotype x environmental index in j^{th} environment

$\sum I^2j$ = as for environmental index

The appropriate analysis of variance is given in following table. With this model the sum of squares due to environment and genotype x environment partitioned in environment (linear), genotype x environment (linear) and deviation from regression.

Analysis of variance for stability parameter

Source of variation	df	Expectations of mean squares
Total	(ge-1)	$\sum i \sum j Y^2$ ij – C.F.
Genotype (G)	(g-1)	1/e $\sum i$ Y - C.F. = $\sum Y^2 j$
Environment (E)	(e-1)	1/g $\sum j$ Y^2 – C.F. = $\sum Y^2 j$
Genotype x Environment	(g-1) (e-1)	$\sum i \sum j Y^2$ ij – C.F. = $\sum j - Y^2 j$
Environment (linear)	1	1/g $(\sum j$ YijIj$)^2 / \sum j I^2 j)$ Ms_2
Genotype x Environment (linear)	(g-2)	$\sum i$ $(\sum j$ YijIj$)^2 / \sum j I^2 j)$- Env. (linear)
Pooled deviation	g(e-2)	$\sum i \sum j S^2 ij$ Ms_3
Genotype-1	(e-1)	$[(\sum j Y^2 ij - Yi^2/e - (\sum j$ YijIj$)^2 / (\sum j I^2 j)]$
Genotype-g	(e-2)	$(jY^2 g - Y^2 g/e) - (jYg I^2 j) / jI^2 j = j^2 g)$
Pooled error	(r-1) (g-1)	

3.4.5 Deviation from regression (S^2di)

The performance of each genotype can be predicted by using estimate of parameter.

Yij = Xi + bi Ij

Where,

Xi is the estimate of mean.

The deviations (Sij = Yij = Yij) are squared to provide an estimate of another stability parameter (S^2di).

S^2di = $[\sum \sigma 2$ij$/(e-2) - S^2$ e/r]

Where,

S^2 e/r = Estimate of the pooled error.

$\sum \sigma 2$ij = $[\sum Y^2 ij = Y^2$ i/e – $(\sum j$Yij Ij$)^2$ / $jI^2 j]$

3.4.6 Test of significance

(a) In order to test the significance of the difference among the variety means, i.e. $H_0 = \mu_1 = \mu_2 = \mu_3 = \ldots \mu_n$

The appropriate 'F' test is defined as:

$F = Ms_1 / Ms_3$

(b) To test that the varieties do not differ for their regression on the environmental idex, i.e. $H_0 = b_1 = b_2 = \ldots b_n$,

$F = Ms_2 / Ms_3$

Thus all the variances can be tested against pooled deviation means square (Ms3).

(c) An appropriate test of the deviation from regression for each genotype can be obtained.

$F = [\sum i \sum j \sigma 2ij / e-2] /$ Pooled error.

The test of significance carried for the stability parameter, for phenotypic index and regression coefficients are as follows:

$S.E. = \sqrt{\text{Error M.S.} / r\ e}$

$F = Ij - \mu / S.E.$

Thus,

L.S.D. for Ij = S.E. x't' at 0.05 per cent.

The hypothesis that any regression coefficient does not differ from unity can also be tested by 't' test. The S.E. and 't' for regression coefficient were calculated as follows :

S.E. (b) $= [\text{deviation Ms} / \sum j\ Ij^2]^{1/2}$

't' $= b - 1 / S.E.(b)$

Thus, L.S.D. for b-1 = S.E. (b) x 't' at 0.05 per cent.

3.5 Study of genetics of fertility restoration

3.5.1 Genetics of fertility restoration

During 2006 rainy season, the parental lines were planted at Department of Agricultural Botany, Marathwada Agricultural University, Parbhani to undertake crossing program. The four male sterile lines viz. ICPA 2043, ICPA 2047, ICPA 2048 and ICPA 2092 were crossed with 12 male parents to obtain 48 crosses. Selfed seeds of parental lines were also produced for next season. These crosses were planted at experimental farm of Department of Agricultural Botany, Marathwada Agricultural University, Parbhani during 2007 rainy season. The backcrossing program was undertaken in selected four fertile crosses to produce BC_1F_1 population. These four backcrosses were selected for the study of genetics of fertility restoration (Table 3.3).

Table 3.3 Selected crosses for study of genetics of fertility restoration

Sr. No.	Selected F_1	BC_1F_1
1	ICPA 2043 x ICPR 2766	ICPA 2043 x (ICPA 2043 x ICPR 2766)
2	ICPA 2047 x ICPR 3513	ICPA 2047 x (ICPA 2047 x ICPR 3513)
3	ICPA 2048 x ICPR 3477	ICPA 2048 x (ICPA 2048 x ICPR 3477)
4	ICPA 2092 x ICPR 2766	ICPA 2092 x (ICPA 2092 x ICPR 2766)

3.5.2 Testing of parents, F_1, F_2, and test crosses

Materials involving parents (P_1 and P_2), F_1, F_2 and test crosses (A x F_1) listed in Table 3.3 were planted at Parbhani, during 2008 rainy season.

Two rows (4m) with inter-row spacing 75 cm were used for planting of parents and hybrids (F_1). Populations of 500 plants were maintained for each F_2 and 200-300 for each testcross. The sowing was done on 15th July 2008.

3.5.3 Recording of observations

Pollen fertility

Mature pollen grains were collected and stained with 2 percent acetocarmin solution to distinguish sterile and fertile pollen grains under light

microscope. Completely stained pollen grains were classified as fertile, and the pollen grains out of sample of two hundred pollen grains were counted and sterility percent was calculated. Pollen fertility counts were taken on individual plants of F_1 and their parents. Microscopic observations for pollen fertility were taken for all those plants of F_2s and testcrosses, whose fertility cannot be judged manually/phenotypically. The slides were examined under the microscope at three microscopic fields to avoid all sources of error.

Statistical analysis

The goodness of fit in F_2 ratios and test cross ratio was tested using a chi-square test (Panse and Sukhatme, 1985). The confirmation of ratios obtained in F_2 segregating population was done by the ratios obtained in test crosses.

$$\chi^2 = \frac{(O - E)^2}{E}$$

Where,

O = observed value

E = Expected value

Goodness of Fit

When the calculated value of χ^2 is less than the table value the fit is said to be good or the assumed ratio is correct. Conversely, when the calculated value is more than the table value, the fit is not good and assumed ratio is not correct. Probability was tested for two ratios (Deokar, 1964) and their respective testcross ratios (Table 3.4).

Table 3.4: Segregation ratios for F_2 and test crosses

Genetic control	F_2 ratio	Test cross ratio	Inferences
Monogenic	3:1	1:1	One basic dominant gene
Digenic	15:1	3:1	Two duplicate genes

CHAPTER IV

RESULTS

The results obtained from the present investigation on "Heterosis, combining ability, stability, and quality parameters in CGMS-based pigeonpea hybrids" are presented under the following sub-headings.

4.1 Analysis of variance

The mean performance of genotypes (parents and hybrids) for each of the characters studied was analyzed statistically, and the genotypic differences were found to be highly significant for all the characters for individual location as well as pooled data (Table 4.1).

4.2 Mean performance of parents and hybrids

The location wise as well as pooled *per se* performance of parents, hybrids, and controls are given in Table 4.2 - 4.11 and were compared by using respective critical difference at 5% and 1% level of significance. The results are described below.

4.2.1 Days to 50% flowering

In pigeonpea early flowering is a desirable character. At all the four locations the control BSMR 736 flowered earlier as compared to control ICPH 2671. Therefore the present results were compared and described by means of early maturing control BSMR 736.

Parents

The female parent ICPA 2043 was significantly earlier at Patancheru, while at Parbhani, Latur and Badnapur it was at par with the control BSMR 736. The ICPA 2047 and ICPA 2092 were at par to the control BSMR 736 at all the four locations. At Patancheru, 4 out of 34 male parents were significantly earlier over the control BSMR 736. Parents ICP 11376 was significantly earlier (107 days) followed by ICP 3514 (108 days) and AKT 9913 (110 days) as compared to the control BSMR 736 (117 days). At Parbhani, none of the male parents showed significant superiority for days to flower over the control BSMR 736 (120 days).

At Latur, 3 male parents were significantly earlier as compared to the control BSMR 736 (111 days). AKT 9915 (101 days), ICPL 20106 (106 days) and TV 1 (108 days) were significantly earlier to the control BSMR 736 (111 days). At Badnapur, only one male parent VIPULA (115 days) was significantly earlier over the control BSMR 736 (117 days). The *per se* performance over pooled mean basis revealed that female parent ICPA 2043 was at par with control BSMR 736, whereas all the male parents were flowered later than the control BSMR 736 (116 days).

Hybrids

At Patancheru, six out of 102 hybrids were significantly superior for days to flower, while three were at par with control BSMR 736. Hybrid ICPA 2043 x ICP 3475 (110 days) was significantly earlier followed by ICPA 2047 x ICP 3475 (110 days) and ICPA 2043 x AKT 8811 (111days) as compared to control BSMR 736 (117 days). At Parbhani and Badnapur, none of the hybrids showed superiority for days to flower with control BSMR 736. At Latur, 12 hybrids were significantly earlier while one was at par with control BSMR 736. Hybrids ICPA 2043 x HPL 24-63 (103 days), ICPA 2043 x BSMR 736 (104 days) and ICPA 2092 x BDN 2001-6 (104 days) were significantly earlier over the control BSMR 736 (111 days). The estimates of *per se* performance on pooled basis revealed that none of the hybrids showed superiority for days to flower with control BSMR 736 (116 days), whereas 16 hybrids were significantly earlier over the control ICPH 2671 (121 days).

4.2.2 Days to maturity

In pigeonpea early maturity is a desirable character. At all the four locations the control BSMR 736 recorded early maturity as compared to the control ICPH 2671 and therefore, the results are discussed in relation to control BSMR 736.

Parents

The female parents ICPA 2043 and ICPA 2047 were significantly earlier than the control BSMR 736 at Patancheru, Parbhani, Latur and Badnapur; while ICPA 2092 (171 days) was significantly earlier to the control BSMR 736 (173 days) for days to maturity at Parbhani only. Twelve male parents showed significant superiority for maturity over the control BSMR 736 at Patancheru.

Likewise, at Parbhani 21 male parents; at Latur five male parents, and at Badnapur seven male parents showed significant superiority over the control BSMR 736. TV 1 (166 days), PHULE T-00-4-11-6-2 (166 days) and AKT 8811 (167 days) were significantly earlier as compared to the control BSMR 736 (174 days) at Patancheru. At Parbhani, male parent ICP 10650 (157 days) was significantly earlier, followed by ICP 13991 (159 days) and BSMR 198 (160 days) as compared to the control BSMR 736 (173 days). At Latur, the male parent VIPULA (156 days) was significantly earlier as compared to the control BSMR 736 (165), while at Badnapur ICP 3407 (168) matured significantly earlier as compared to the control BSMR 736 (180 days). The *per se* performance on the basis of pooled data revealed that out of three, two female parents ICPA 2043 (166 days) and ICPA 2047 (167 days) registered significantly earlier maturity as compared to the control BSMR 736 (173 days). The female parent ICPA 2092 was similar to the control BSMR 736 in maturity. The male parents showed varied responses to maturity in different environments. ICP 10934 (164 days), ICP 13991 (167 days), ICP 11376 and ICP 10650 (168 days) were significantly earlier in maturity as compared to the control.

Hybrids

Out of 102 cross combinations studied, only six showed significant superiority over the control BSMR 736 at Patancheru. Similarly, 24 hybrids at Parbhani; 50 hybrids at Latur; and 26 hybrids at Badnapur recorded significant superiority for maturity over the control. At Patancheru, hybrid ICPA 2043 x BSMR 2 (170 days) was significantly earlier in maturity over the control BSMR 736 (174 days). The same hybrid registered significant earliness at Parbhani. At Latur, hybrids ICPA 2043 x ICP 10934, ICPA 2047 x BSMR 846 and ICPA 2043 x ICP 13991 were significantly earlier in maturity (158 days) as compared to the control BSMR 736 (165 days). At Badnapur, hybrid ICPA 2043 x AKT-00-12-6-4 (167 days) was the earliest in maturity followed by ICPA 2092 x ICP 13991 (168 days) and ICPA 2092 x AKT 9915 (170 days) than the control BSMR 736 (171 days). The pooled data showed that 25 hybrids were significantly superior for days to maturity over the control BSMR 736. Hybrids ICPA 2043 x BSMR 2 (166 days), ICPA 2043 x ICP 10934 and ICPA 2043 x PHULE T-00-4-11-6-2 (167

days) and ICPA 2043 x AKT 8811 (168 days) were significantly earlier for maturity as compared to the control BSMR 736 (173 days). At Patancheru, it was observed that the five hybrids from ICPA 2043 male-sterile line and one from ICPA 2047 recorded significantly earlier maturity over the control. Similarly, at Parbhani 16 hybrids were from ICPA 2043, three from ICPA 2047 and five from ICPA 2092; at Latur, 26 from ICPA 2043, nine from ICPA 2047 and 15 from ICPA 2092; and at Badnapur 10 from ICPA 2043, 10 from ICPA 2047 and six from ICPA 2092. In general, it was observed that the hybrids made on male-sterile line ICPA 2043 matured earlier followed by on ICPA 2047 and ICPA 2092.

4.2.3 Plant height (cm)

Parents

Plant height is one of the important characters considered for plant selection. At Patancheru, control BSMR 736 (206 cm) showed more plant height than ICPH 2671 (202 cm). Therefore, *per se* performance of parents and hybrids were compared with BSMR 736. Out of 37 parents studied, 16 were significantly superior over the control BSMR 736. Parents ICP 3514 (243 cm), HPL 24-63 (234 cm) and ICP 3525 (233 cm) recorded greater plant height, and showed positive significant superiority over the control BSMR 736. At Parbhani, Latur and Badnapur, the control ICPH 2671 recorded maximum plant height as compared to the control BSMR 736. Hence, *per se* performance was compared over the control ICPH 2671. At Parbhani, out of 37 parents, nine parents recorded significant superiority over the control ICPH 2671. ICP 3374 (231 cm), HPL 24-63 (220 cm) and BSMR 175 (219 cm) recorded highest plant height as compared to the control ICPH 2671 (200 cm). At Latur, only two parents ICP 3525 (177 cm) and BDN 2001-6 (174 cm) recorded more plant height than the control ICPH 2671 (160 cm). Likewise, at Badnapur, five out of 37 parents showed significant superiority over the control ICPH 2671. TV 1 (172 cm), ICP 3963 (169 cm) and AKT 9915 (164 cm) registered more plant height as compared to control. The control ICPH 2671 (176 cm) recorded maximum plant height on pooled data. Out of 37, nine parents showed positive significant superiority over the control. BSMR

175 (191 cm), ICP 3525 (190 cm) and ICP 3374 (189 cm) recorded significant superiority over the control ICPH 2671 (176 cm).

Hybrids

At Patancheru, out of 102 hybrids evaluated, 71 exhibited significant superiority over the control BSMR 736. Hybrids ICPA 2047 x ICP 13991 (262 cm), ICPA 2047 x BSMR 164 (259 cm) and ICPA 2092 x PHULE T-00-1-25-1 (257 cm) were three hybrids which registered the highest significant superiority for greater plant height. At Parbhani, 54 hybrids showed significant superiority over the control ICPH 2671 (200 cm). Hybrids ICPA 2092 x BSMR 175 (248 cm) and ICPA 2047 x ICP 3963 (242 cm) recorded more plant height as compared to control ICPH 267 (200 cm). At Latur, hybrids ICPA 2043 x PHULE T-00-1-25-1 (197 cm), ICPA 2043 x AKT 8811 and ICPA 2043 x AKT 9913 (196 cm) performed better for plant height as compared to the control ICPH 2671 (160 cm). The *per se* performance on pooled data basis showed that hybrids ICPA 2047 x TV 1 (204 cm), ICPA 2047 x AKT 9913 (203 cm), and ICPA 2047 x PHULE T-00-5-7-4-1 (201 cm) were significantly superior and registered greater plant height as compared to control ICPH 2671 (191 cm).

4.2.4 Number of primary branches plant^{-1}

At Patancheru, more number of primary branches plant^{-1} recorded by control BSMR 736 (12) than ICPH 2671 (10). Therefore the *per se* performance of parents and hybrids were compared over the control BSMR 736. At Parbhani, Latur and Badnapur as well as on pooled data basis more number of primary branches plant^{-1} recorded by the control ICPH 2671 as compared to control BSMR 736. Therefore *per se* performance of parents and hybrids were compared over the control ICPH 2671.

Parents

At Patancheru, all the female parents ICPA 2043, ICPA 2047 and ICPA 2092 were at par to control BSMR 736. Among the male parents, ICP 10934 (19), ICPL 20106 (19), VIPULA (16) and ICP 3963 (16) showed highly significant superiority for number of primary branches plant^{-1} as compared to control BSMR 736 (12). ICPA

2043 was significantly superior over the control ICPH 2671 only at Badnapur. At Parbhani, Latur and Badnapur the *per se* performance of ICPA 2047 and ICPA 2092 was similar to the control ICPH 2671. At Parbhani, three out of 34 male parents were significantly superior over the control ICPH 2671. ICP 3525 (21), ICPL 12749 (19) and ICP 10934 (19) were significantly superior to the control for number of primary branches plant^{-1}. At Latur, only one parent BWR 164 (9) recorded significant superiority over the control ICPH 2671 (7). At Badnapur, 11 out of 37 parents registered the significant superiority over the control ICPH 2671. Parents AKT 9913 (17) and AKT-00-12-6-4 (17) were significantly superior over the control ICPH 2671 (13). The pooled analysis revealed that, seven male parents had significant superiority as compared to control the ICPH 2671 (11). ICP 10934, AKT 9915 and ICP 10650 had 13 number of primary branches plant^{-1} each was significantly superior as compared to the control.

Hybrids

At Patancheru, 22 hybrids showed significant superiority for number of primary branches plant^{-1} over the control BSMR 736. Hybrids, ICPA 2047 x ICPL 20106 (22), ICPA 2092 x ICP 3514 (22) and ICPA 2092 x AKT 222521 (19) showed significant superiority as compared to control BSMR 736 (12). At Parbhani, eight hybrids were significantly superior over the control ICPH 2671. Hybrids ICPA 2092 x BDN 2001-6 (21), ICPA 2043 x ICP 13991 (20) and ICPA 2092 x BWR 154 (20) were significantly superior for number of primary branches as compared to the control ICPH 2671 (15). At Latur, 10 hybrids exhibited significant superiority for number of primary branches plant^{-1} over the control ICPH 2671. The hybrid ICPA 2043 x HPL 24-63 (12) showed the highest significant superiority for number of primary branches plant^{-1} as compared to control ICPH 2671 (7). At Badnapur, three hybrids registered significant superiority over the control ICPH 2671. Hybrids ICPA 2043 x BSMR 736, ICPA 2047 x AKT 9915, and ICPA 2092 x BSMR 2 (15) were significantly superior as compared to the control ICPH 2671 (13). The analysis of pooled data revealed that, five hybrids ICPA 2043 x TV 1, ICPA 2047 x ICPL 20106, ICPA 2092 x ICP 3525, ICPA 2092 x BSMR 2 and ICPA 2092 x ICP 3514 had 13 number of primary branches

plant^{-1} each of which was significantly superior as compared to control ICPH 2671 (11).

4.2.5 Number of secondary branches plant^{-1}

At all the four locations higher numbers of secondary branches were borned by the control ICPH 2671 than BSMR 736. Therefore the *per se* performance of parents and hybrids were compared by using control ICPH 2671.

Parents

At Patancheru, five parents recorded significant superiority over the control ICPH 2671 (45) for number of secondary branches plant^{-1}. ICP 3525 (67), AKT 8811 (66), ICPL 20106 (57) and HPL 24-63 (53) were significantly superior to the control ICPH 2671 (45) for number of secondary branches plant^{-1}. At Parbhani, three parents ICP 13991 (40), HPL 24-63 (33) and ICP 3514 (29) registered significant superiority over ICPH 2671. At Latur, five parents showed significant superiority over the control ICPH 2671 (20) of which PHULE T-00-1-25 (29), AKT 9915 (25) and AKT 9913 (23) recorded the more number of secondary branches plant^{-1} than control. At Badnapur, five parents showed significant superiority for number of secondary branches plant^{-1} over the control ICPH 2671 (24). Parent ICP 3374 (31) ranked first for number of secondary branches plant^{-1} and was significantly superior as compared to the control. The analysis of pooled data revealed that only one parent ICP 3525 (33) was significantly superior for number of secondary branches plant^{-1} over the control ICPH 2671 (28).

Hybrids

At Patancheru, four hybrids recorded significant superiority over the control for number of secondary branches plant^{-1}. Hybrids ICPA 2043 x ICP 3514 (56), ICPA 2092 x ICP 3514 (55), ICPA 2092 x ICP 3514 (53) were superior for number of secondary branches plant^{-1} as compared to the control ICPH 2671 (45). At Parbhani, nine hybrids showed significant superiority over the control. The hybrids ICPA 2047 x ICPL 20106 (35), ICPA 2043 x ICP 13991 (34) and ICPA 2047 x PHULE T-00-4-11-6-2 (34) performed well for large number of secondary branches plant^{-1} as compared to the control ICPH 2671 (25). At Latur, 34 hybrids showed significant superiority over the control ICPH 2671. Hybrids ICPA 2043 x

ICP 3374 (30), ICPA 2047 x BWR 154 (30) and ICPA 2043 x HPL 24-63 (29) were found to have more number of secondary branches plant^{-1} than ICPH 2671 (20). At Badnapur, seven hybrids were significantly superior for number of secondary branches plant^{-1} over the control ICPH 2671. The hybrid ICPA 2043 x ICP 3525 (32) ranked first for number of secondary branches plant^{-1}, and showed significant superiority as compared to control ICPH 2671 (24). The pooled analysis revealed that out of 102 cross combinations studied three were significantly superior to the control ICPH 2671. The hybrid ICPA 2092 x ICP 3407 (31) ranked first across the locations for number of secondary branches plant^{-1} as compared to control ICPH 2671 (28). It was followed by ICPA 2043 x ICP 3374 (30) and ICPA 2043 x ICPL 20106 (30).

4.2.6 Number of pods plant^{-1}

At all the four locations, the control ICPH 2671 recorded more number of pods plant^{-1} as compared to control BSMR 736. For this reason the *per se* performance of parents and hybrids was compared over the control ICPH 2671.

Parents

This is a very important character that directly contributes to seed yield. The *per se* performance of all the three female parents ICPA 2043, ICPA 2047 and ICPA 2092 were similar to control ICPH 2671 for number of pods plant^{-1} at Patancheru, Parbhani, Latur, and Badnapur. At Patancheru, ICP 3525 (538), TV 1 (437), HPL 24-63 (393), BSMR 198 (385) were significantly superior for number of pods plant^{-1} over the control ICPH 2671 (309). The same male parents showed significant superiority at Latur. At Parbhani, TV 1 (409) ranked first for number of pods plant^{-1} followed by ICP 3525 (398) and HPL 24-63 (353) over the control ICPH 2671 (183). At Badnapur, the highest pods plant^{-1} observed with parents ICP 3525 (379), followed by HPL 24-63 (234) and TV 1 (208) over the control ICPH 2671 (172). Over pooled data nine out of 37 parents showed significant superiority over the control ICPH 2671 (232). ICP 3525 (432), TV 1 (342) and BSMR 198 (283), and these were significantly superior as compared to control.

Hybrids

At Patancheru, out of 102 hybrids studied, 24 had significant superiority for number of pods plant^{-1} as compared to control ICPH 2671 (309). Hybrids ICPA 2047 x HPL 24-63 (528), ICPA 2092 x ICPL 20106 (525), ICPA 2092 x ICP 10934 (518) showed higher number of pods plant^{-1} as compared to control. The same hybrids showed superior performance for number of pods plant^{-1} at Badnapur. At Badnapur, 17 hybrids showed significant superiority to the control ICPH 2671. Similarly, at Parbhani and Latur, 24 hybrids exhibited significant superiority over the control ICPH 2671. The analysis of pooled data revealed that only three hybrids were significantly superior for number of pods plant^{-1} as compared to the control ICPH 2671 (232). ICPA 2092 x ICPL 20106 (472), ICPA 2092 x ICP 10934 (424) and ICPA 2047 x HPL 24-63 (384), and these had higher number of pods plant^{-1} as compared to the control.

4.2.7 Pod weight (g)

At Patancheru, Parbhani, Latur and Badnapur the control ICPH 2671 recorded more pod weight as compared to the control BSMR 736. Hence, the *per se* performance of parents and hybrids were compared over the control ICPH 2671.

Parents

At Patancheru, Parbhani, Latur and Badnapur, the female parent ICPA 2043 exhibited significant superiority over the control ICPH 2671, whereas ICPA 2047 and ICPA 2092 were similar in pod weight as compared to the control ICPH 2671. At Patancheru, out of 34 male parents evaluated, only four showed significant superiority over the control ICPH 2671. At Parbhani and Latur six parents and at Badnapur four parents were significantly superior to control ICPH 2671. At Patancheru, ICP 3525 (250.8 g), BSMR 198 (194.3 g), HPL 24-63 (192.5 g) and TV 1 (185.6 g) exhibited significant superiority for pod weight to the control. The same male parents showed significant superiority for pod weight at Parbhani, Latur and Badnapur. On the pooled data basis, the control ICPH 2671 (138.9) recorded more pod weight as compared to control BSMR 736 (130.4). Seven out of 37 parents exhibited significant superiority as compared to the control. ICP 3525 (232.7 g), HPL 24-63 (174.3 g), and TV 1 (167.5 g) were significantly superior for pod weight as compared to control.

Hybrids

Out of 102 hybrids examined, 24 registered significant superiority over the control ICPH 2671 (162.6 g) for pod weight at Patancheru. Similarly, 29 hybrids at Parbhani as well as at Latur, and 30 hybrids at Badnapur showed significant superiority over the control ICPH 2671. At Patancheru, hybrids ICPA 2047 x HPL 24-63 (313.1 g), ICPA 2043 x ICP 3374 (245.7 g), ICPA 2092 x ICP 10934 (241.4 g) and ICPA 2092 x ICPL 20106 (236.4 g) performed significant superiority for pod weight to the control. The same hybrids exhibited significant superiority over the control at Latur. At Parbhani, ICPA 2043 x ICP 3374 (253.2 g), ICPA 2092 x ICP 10934 (248.9 g) and ICPA 2092 x ICPL 20106 (243.9 g) exhibited significant superiority for pod weight over the control (166.08 g). Hybrids ICPA 2092 x ICPL 20106 (196.4 g) and ICPA 2092 x ICP 10934 (195.4 g) were significantly superior to the control ICPH 2671 (166.08 g) at Badnapur. The *per se* performance over pooled mean basis revealed that 28 hybrids registered significant superiority over the control ICPH 2671 (138.9 g) for pod weight. The highest pod weight was recorded by the hybrids ICPA 2047 x HPL 24-63 (234.0 g), followed by ICPA 2092 x ICP 10934 (221.8 g) and ICPA 2043 x ICP 3374 (220.2 g).

4.2.8 Seeds pod^{-1}

Parents and hybrids

There were no significant differences observed for seeds pod^{-1} among the controls BSMR 736 (4) and ICPH 2671 (4). Both control showed four number of seeds pod^{-1}. Therefore *per se* performance was compared over both the controls. It was observed that there was no significant difference observed for seeds pod^{-1} in parents as well as in hybrids at Patancheru, Parbhani, Latur and Badnapur. At Patancheru, out of 37 parents evaluated, 32 borned four number of seeds pod^{-1} while five had three number of seeds pod^{-1}. Among 102 hybrids examined, 97 recorded four number of seeds pod^{-1} whereas five registered three number of seeds pod^{-1}. At Parbhani, the *per se* performance of all the parents and hybrids were similar to control except four parents and seven hybrids recorded three number of seeds pod^{-1}. Similarly at Latur 30 parents and 94 hybrids recorded four number of

seeds pod^{-1} while seven parents and eight hybrids showed three number of seeds pod^{-1}. At Badnapur, 31 parents borned four number of seeds pod^{-1} while six showed three seeds pod^{-1} whereas among hybrids 95 recorded four number of seeds pod^{-1} while seven with three number of seeds pod^{-1}. The analysis of pooled data showed that 31 parents had four number of seeds pod^{-1} where as six parents registered three seeds pod^{-1}; while 94 hybrids showed four number of seeds pod^{-1} while only eight showed three seeds pod^{-1}.

4.2.9 100-Seed weight (g)

At Patancheru, the highest 100-seed weight recorded by the control ICPH 2671 (10.6.0 g) as compared to control BSMR 736 (10.3 g). At Parbhani, Latur and Badnapur, controls ICPH 2671 and BSMR 736 recorded similar 100-seed weight. The control ICPH 2671 used for comparison at these three locations.

Parents

At Patancheru, parents, 29 out of 37 showed significantly greater 100-seed weight than the control ICPH 2671 (10.6 g), whereas 20 at Parbhani, 15 at Latur and 11 at Badnapur exhibited significant superiority over the control ICPH 2671. At Patancheru, PHULE T-04-3-1 (12.8 g) recorded more 100-seed weight as compared to the control ICPH 2671 (10.6 g) followed by ICP 3374 (12.5 g) and ICP 3514 (12.4 g). At Parbhani, BSMR 2 (13 g) and VIPULA (12 g) showed more 100-seed weight as compared to the control ICPH 2671 (11.6 g). At Latur ICP 10934 (12.2 g); and at Badnapur PHULE T-04-3-1 (12.1 g) registered significant superiority for 100-seed weight over control ICPH 2671 (10.64 g). On pooled data, 23 parents exhibited significant superiority as compared to the control ICPH 2671. PHULE T-04-3-1 (12.2 g), ICP 10934 (12 g), and ICP 3374 (11.8 g) were significantly superior for 100-seed weight as compared to the control ICPH 2671 (10.64 g).

Hybrids

At Patancheru, hybrids, 79 out of 102 showed significant superiority over the control ICPH 2671. Similarly, 14 hybrids at Parbhani, 48 at Latur, and 28 at Badnapur exhibited significant superiority over the control ICPH 2671. At Patancheru, hybrids ICPA 2043 x ICP 11376 (13.3 g) and ICPA 2047 x PHULE

T-00-1-25-1 (13.2 g) were significantly superior for 100-seed weight as compared to the control. At Parbhani, hybrids ICPA 2092 x BSMR 736 (15 g), ICPA 2092 x VIPULA (13.7 g), ICPA 2043 x BSMR 2 (13.1 g) recorded significantly more 100-seed weight than the control ICPH 2671. At Latur ICPA 2047 x BSMR 175 (12.5 g); while, at Badnapur ICPA 2043 x BSMR 2 (12.3) had more 100-seed weight as compared to control ICPH 2671. Out of 102 hybrids studied, 56 recorded significant superiority for 100-seed weight than the control ICPH 2671 on pooled data basis. ICPA 2092 x BSMR 736 (12.4 g), ICPA 2043 x ICP 11376 (12.3 g) and ICPA 2043 x BSMR 2 (12.1 g) were first three hybrids which recorded the significant superiority for 100-seed weight as compared to the control ICPH 2671.

4.2.10 Pollen fertility (%)

Parents

At Patancheru, 31 out of 37 parents showed 100% pollen fertility and were found superior as compared to the controls BSMR 736 (97%) and ICPH 2671 (99%). Likewise, 22 parents at Parbhani and at Latur; and 14 at Badnapur exhibited 100% pollen fertility. The analysis of pooled data revealed that only four parents viz., BSMR 846, BSMR 164, HPL 24-63, and PHULE T-00-1-25-1 showed 100% pollen fertility.

Hybrids

At Patancheru, 27 out of 102 hybrids showed 100% pollen fertility and were superior as compared to the controls BSMR 736 (97%) and ICPH 2671 (99%). Likewise, 36 hybrids at Parbhani, 42 at Latur, and 50 at Badnapur exhibited 100% pollen fertility. The analysis of pooled data revealed that seven hybrids viz., ICPA 2043 x ICP 3525, ICPA 2043 x BSMR 175, ICPA 2043 x BSMR 203, ICPA 2043 x ICP 10934, ICPA 2043 x ICP 3407, ICPA 2043 x TV 1, and ICPA 2092 x ICP 3514 exhibited 100% pollen-fertility across four locations.

4.2.11 Grain yield plant^{-1} (g)

At all the four locations, the highest grain yield plant^{-1} was recorded by the control ICPH 2671 (133.5 g) than BSMR 736 (122.5 g). For this reason the present results of hybrids and parents were compared and discussed using the highest yielding

control ICPH 2671. The control ICPH 2671 is the world's first CGMS-based pigeonpea hybrid, which showed 30% yield advantage over local check varieties in on-farm trials conducted in five states of India (Saxena and Nadarajan, 2010).

Parents

Out of 34 male parents evaluated, five exhibited significant superiority over the control ICPH 2671 at Patancheru and Parbhani. Similarly, six at Latur and one at Badnapur showed significant superiority for grain yield plant^{-1} over the control ICPH 2671. At Patancheru, ICP 3525 (232.7 g), TV 1 (153.6 g), and HPL 24-63 (150.8 g) were significantly superior to the control ICPH 2671 (133.5 g) for grain yield plant^{-1}. The same male parents showed significant superior *per se* performance for grain yield plant^{-1} at Parbhani and Latur. At Badnapur, the male parents ICP 3525 (159.7 g), HPL 24-63 (87 g) and ICP 3963 (71.9 g) were superior in grain yield plant^{-1} as compared to the control ICPH 2671 (75.9 g). The pooled mean data revealed that the male parents ICP 3525 (232.7 g), TV 1 (153.6 g) and HPL 24-63 (150.8 g) were significant and showed superior *per se* performance as compared to the control ICPH 2671 (133.5 g).

Hybrids

At Patancheru, 27 out of 102 hybrids were superior to the control ICPH 2671. At Parbhani, 24 hybrids, at Latur 26 hybrids and at Badnapur four hybrids showed significant superiority over the control ICPH 2671. At Patancheru. the high *per se* performance for grain yield plant^{-1} was recorded by hybrid ICPA 2047 x HPL 24-63 (219.4g) and ICPA 2043 x ICP 3374 (159.29 g) over the control ICPH 2671 (133.5 g). At the same time same hybrids showed high *per se* performance at Latur and Badnapur. At Parbhani, hybrids ICPA 2092 x ICPL 20106 (174.8 g), ICPA 2043 x ICPL 20106 (171.0 g) and ICPA 2043 x ICP 3374 (169.1 g) were superior for grain yield plant^{-1} as compared to control ICPH 2671 (111.6 g). The pooled analysis revealed that 12 hybrids were significantly superior over control ICPH 2671 for grain yield plant^{-1}. The high significant *per se* performance for grain yield plant^{-1} was recorded by the hybrids ICPA 2043 x ICP 3374 (164.9 g), followed by ICPA 2047 x HPL 24-63 (164.4 g), ICPA 2092 x ICPL 20106 (153.3 g), ICPA 2092 x ICP 10934 (148.7 g) and ICPA 2043 x ICPL 20106 (144.5 g).

4.3 Heterosis

In the present experiment, heterosis is reported over standard controls (BSMR 736 and ICPH 2671) for individual locations are presented in tables 4.12 to 4.15.

4.3.1 Days to 50 % flowering

Early flowering is a desirable feature of a genotype. Therefore, negative heterosis for days to flower is considered as desirable.

Heterosis over control BSMR 736

Out of 102 hybrids evaluated significant and negative heterosis registered by six hybrids at Patancheru and 12 at Latur. At Parbhani and Badnapur none of the hybrids showed significant superiority for earliness over the control BSMR 736. At Patancheru, hybrid ICPA 2043 x ICP 3475 recorded significant and negative heterosis (-5.98%), followed by ICPA 2043 x AKT 8811 (-5.56%) and ICPA 2047 x ICP 3475 (-5.13%). At Latur, the hybrid ICPA 2043 x HPL 24-63 recorded significant and negative heterosis (-7.21%) followed by ICPA 2092 x BDN 2001-6 (-6.31%) and ICPA 2043 x BSMR 736 (-6.31%).

4.3.2 Days to maturity

Early maturity is a desirable feature of a genotype. Therefore, negative heterosis for maturity is considered as desirable.

Heterosis over control BSMR 736

At Patancheru, out of 102 hybrids evaluated, only six registered significant and negative heterosis for days to maturity. The hybrid ICPA 2043 x BSMR 2 (-2.3%) was the earliest with highest significant and negative heterosis. At Parbhani, 24 hybrids exhibited significant and negative heterosis. Hybrids ICPA 2043 x BSMR 2 (-8.67%), ICPA 2043 x BSMR 198 (-6.65%) and ICPA 2043 x HPL 24-63 (-6.07%) registered the high significant and negative heterosis for maturity. At Latur, 44 hybrids recorded significant and negative heterosis. Of these, ICPA 2043 x ICP 10934 and ICPA 2047 x BSMR 846 recorded high significant and negative heterosis of -4.55%. At Badnapur, none of the hybrids exhibited significant and negative heterosis.

4.3.3 Plant height (cm)

The heterosis for plant height was estimated over the control which showed maximum plant height to the respective locations. At Patancheru, 71 hybrids showed significant and positive heterosis over the control BSMR 736 for plant height, while at Latur 35 hybrids registered significant and positive heterosis over the control ICPH 2671. At Parbhani and Badnapur none of the hybrids showed significant and positive heterosis over the control ICPH 2671. At Patancheru, the hybrid ICPA 2047 x ICP 13991 (27.01%) exhibited the highest significant and positive heterosis over BSMR 736. At Latur, hybrid ICPA 2043 x PHULE T-00-5-7-4-1 (23.13%) registered the highest significant and positive heterosis. Over pooled data 56 hybrids showed significant and positive heterosis over the control ICPH 2671.

4.3.4 Number of primary branches plant^{-1}

Heterosis over control BSMR 736

At Patancheru, heterosis for number of primary branches plant^{-1} estimated over the control BSMR 736; while at Parbhani, Latur and Badnapur, it was estimated over the control ICPH 2671. Twenty one hybrids registered significant and positive heterosis over the control BSMR 736 at Patancheru. The high significant and heterosis of 84.17% exhibited by the hybrid ICPA 2047 x ICPL 20106 over the control BSMR 736. Similarly, the estimates of heterosis over control ICPH 2671 revealed that out of 102 cross combinations evaluated eight hybrids at Parbhani, 11 at Latur, and three at Badnapur registered significant and positive heterosis over the control ICPH 2671. At Parbhani, ICPA 2092 x BDN 2001-6 (37.33), at Latur, ICPA 2043 x HPL 24-63 (72.86), and at Badnapur ICPA 2047 x AKT 9915 (17.31%) showed significant and positive heterosis over the control ICPH 2671.

4.3.5 Number of secondary branches plant^{-1}

Heterosis over control ICPH 2671

Four hybrids at Patancheru, nine at Parbhani, 34 at Latur; and seven at Badnapur recorded significant and positive heterosis for number of secondary branches plant^{-1} over the control ICPH 2671. At Patancheru, the highest (23.33%) significant and positive heterosis exhibited by the hybrid ICPA 2043 x ICP 3514

over the control ICPH 2671. Similarly, at Parbhani, ICPA 2047 x ICPL 20106 (40.80%); at Latur, ICPA 2047 x BWR 154 (49.00%); and at Badnapur ICPA 2043 x ICP 3525 (31.25%) registered the highest significant and positive heterosis for number of secondary branches plant^{-1} over the control ICPH 2671.

4.3.6 Number of pods plant^{-1}

Heterosis over control ICPH 2671

The number of pods plant^{-1} a principal component of yield exhibited higher magnitude of heterosis as compared to other traits. The magnitude of heterosis is generally positive for number of pods plant^{-1} in pigeonpea. A perusal of the data revealed that, at Patancheru, the significant and positive heterosis was exhibited by 24 out of 102 hybrids. Hybrids ICPA 2047 x HPL 24-63 (70.79%), ICPA 2092 x ICPL 20106 (70.05%) and ICPA 2092 x ICP 10934 (67.73%) registered highly significant and positive heterosis. At Parbhani, 24 hybrids registered significant and positive heterosis over the control ICPH 2671 for number of pods plant^{-1}. The highly significant and positive heterosis recorded by hybrids ICPA 2092 x ICPL 20106 (75.3%) followed by ICPA 2092 x ICP 10934 (57.55%). The same hybrids showed the significant and positive heterosis at Latur for number of pods plant^{-1}. At Badnapur, 23 hybrids showed significant and positive heterosis over the control ICPH 2671 for number of pods plant^{-1}. The hybrid ICPA 2047 x HPL 24-63 (67.38%) recorded the highest significant and positive heterosis.

4.3.7 Pod weight (g)

Heterosis over control ICPH 2671

At Patancheru, in respect of pod weight, 24 hybrids recorded significant and positive heterosis. The high value of hybrid vigour were observed with ICPA 2047 x HPL 24-63 (110.10%) followed by ICPA 2043 x ICP 3374 (64.9%) and ICPA 2092 x ICP 10934 (62.01%). At Parbhani, 29 hybrids exhibited high significant and positive heterosis for pod weight. The highest heterosis of 75.3% was recorded by hybrid ICPA 2092 x ICPL 20106, followed by ICPA 2092 x ICP 10934 (57.55%) and ICPA 2043 x ICP 3374 (52.32%). At Latur, 33 hybrids recorded significant and positive standard heterosis over the control ICPH 2671. The highest heterosis was registered by hybrid ICPA 2092 x ICPL 20106

(118.83%) followed by ICPA 2092 x ICP 10934 (114.92%) and ICPA 2047 x HPL 24-63 (106.28%). The simillar hybrids exhibited significant and positive heterosis at Badnapur also.

4.3.8 Seeds pod^{-1}

As there was no variation present among the controls and hybrids. None of the hybrids showed significant and positive heterosis for this character. For seeds pod^{-1} negative heterosis was observed among hybrids. Hybrids ICPA 2043 x BSMR 846 (-12.78%), ICPA 2092 x PHULE T-00-1-25-1 (-15.8%) and ICPA 2043 x ICP 3525 (-17.04%) exhibited the highest negative heterosis at Patancheru. The simillar hybrids recorded high negative heterosis at Parbhani, Latur and Badnapur.

4.3.9 100-Seed weight (g)

The 100-seed weight is an important yield component and heterosis in positive direction is desirable for this trait. Heterosis over both the control BSMR 736 and ICPH 2671 estimated and described over the highest yielding control ICPH 2671.

Heterosis over control ICPH 2671

The heterotic effects revealed that 79 hybrids at Patancheru, 13 at Parbhani, 48 at Latur, and 28 at Badnapur registered significant and positive heterosis over the control ICPH 2671. At Patancheru, the highest heterosis recorded by hybrid ICPA 2043 x ICP 11376 (25.47%) followed by ICPA 2047 x PHULE T-00-1-25-1 (24.53%). At Parbhani, hybrid ICPA 2092 x BSMR 736 (18.1%) recorded high heterosis. At Latur the highest heterotic effects registered by hybrids ICPA 2047 x BSMR 175 (20.89%) and ICPA 2043 x BSMR 2 (11.22%) over the control ICPH 2671. The same hybrid recorded highest heterosis at Badnapur.

4.3.10 Pollen fertility (%)

Heterosis over control ICPH 2671

At Patancheru and Badnapur none of the hybrids registered 100% pollen fertility. At Parbhani, 36 hybrids and at Latur 41 showed significant and positive heterosis over the control ICPH 2671.

4.3.11 Grain yield plant^{-1} (g)

The frequency of hybrids for the expression of heterotic effects showed that the maximum heterosis was observed over popular variety BSMR 736 as compared to popular hybrid ICPH 2671. In view of that the heterosis over highest yielding control ICPH 2671 reported as underneath.

Heterosis over control ICPH 2671

At Patancheru, significant and high positive heterosis was observed with hybrid ICPA 2047 x HPL 24-63 (64.31%) followed by ICPA 2043 x ICP 3374 (62.13%) and ICPA 2092 x ICP 10934 (47.38%). At the same time same hybrids exhibited significant and high positive heterosis at Latur and Badnapur. In a similar way hybrids ICPA 2092 x ICPL 20106 (48.09%), ICPA 2043 x ICPL 20106 (44.87%) and ICPA 2043 x ICP 3374 (43.31%) recorded significant and high positive heterosis at Parbhani. More number of heterotic hybrids (26) noticed for grain yield plant^{-1} at Latur, followed by 24 at Patancheru and Parbhani and 15 at Badnapur.

4.4 Line × tester analysis

Since genotypic differences found to be significant, the line x tester analysis was used for the estimation of combining ability for the 11 characters with respect of 102 hybrids developed by crossing three females (A-lines) and 34 males (testers). Location wise ANOVA and pooled ANOVA are given in Tables 4.16 to 4.20.

4.4.1 Analysis of variance

At Patancheru, the analysis of variance revealed that the mean sum of squares (MSS) due to lines x testers and hybrids versus parents were highly significant for all the 11 characters. The MSS due to hybrids was significant for days to flower, number of pods plant^{-1} and pod weight. The MSS due to lines was significant for eight characters while it was non-significant for number of primary branches plant^{-1}, pollen fertility (%) and seeds pod^{-1}. The MSS due to testers was significant for days to flower and maturity, Plant height, number of secondary branches plant^{-1}, number of pods plant^{-1}, pod weight and grain yield plant^{-1}, while for number of primary branches plant^{-1}, seeds pod^{-1}, 100 seed weight and pollen fertility (%) it was non-significant (Table 4.16).

At Parbhani, the analysis of variance revealed that the MSS due to lines x testers were highly significant for all the characters studied. The MSS due to hybrids were significant only for days to flower, number of pods plant^{-1} and seeds pod^{-1}. The MSS due to hybrids versus parents were significant for all the characters, except days to flower and number of pods plant^{-1}. The MSS due to lines were significant for eight characters, excluding pollen fertility (%), number of secondary branches plant^{-1}, and 100 seed weight (g). The MSS due to testers were significant for days to maturity, plant height, number of pods plant^{-1}, pod weight, 100-seed weight and grain yield plant^{-1} (Table 4.17).

At Latur, the analysis of variance revealed that the MSS due to line x testers were highly significant for all characters. The MSS due to hybrids was significant only for days to flower, number of pods plant^{-1}, and pollen fertility (%). The MSS due to hybrids versus parents were significant for nine characters, excluding days to flower and pollen fertility (%). The MSS due to lines was significant for all the traits, except seeds pod^{-1}. The MSS due to testers was significant only for days to maturity, pods plant^{-1}, pod weight (g) and grain yield plant^{-1} (Table 4.18).

At Badnapur, the analysis of variance revealed that the MSS due to line x testers and hybrids versus parents were highly significant for all the characters. The MSS due to hybrids were significant only for days to maturity, pollen fertility (%), and grain yield plant^{-1}. The MSS due to lines were significant for all the characters, except seeds pod^{-1} and number of primary branches plant^{-1}. The MSS due to testers were significant for plant height (cm), pods plant^{-1}, pod weight (g), pollen fertility (%) and grain yield plant^{-1} (Table 4.19).

Pooled analysis of variance for combining ability

The variance components due to lines were significant for all the characters except 100-seed weight (g). The MSS due to testers and hybrids were significant for eight characters, except number of secondary branches plant^{-1}, number of seeds pod^{-1}, and pollen fertility (%). The MSS due to locations x hybrids, locations x crosses, locations x lines, locations x testers and locations x lines x testers were highly significant for all the characters. The MSS due to location x line was significant for all the characters, except pod weight. The MSS due to locations x testers were

significant for days to flower and maturity, number of secondary branches plant^{-1}, number of pods plant^{-1}, seeds pod^{-1} and grain yield plant^{-1} (Table 4.20).

4.4.1.1 Days to 50 % flowering

At Patancheru and Latur the magnitude of variance due to hybrids versus parents was lower than hybrids and parents. At Parbhani magnitude of variance due to hybrids versus parents was greater than hybrids and parents. At Badnapur the magnitude of variance due to hybrids versus parents was lower than the magnitude of variance due to hybrids, while it was greater than variance due to parents. The magnitude of variance due to lines were higher than the magnitude of variance due to testers and line x tester at all the four locations.

4.4.1.2 Days to maturity

The magnitude of variance due to hybrids versus parents was higher than the magnitude of variance due to hybrids and parents at Patancheru, Parbhani, and Latur whereas, it was lower at Badnapur. The magnitude of variance due to lines was higher than the magnitude of variance due to testers and lines x tester at all the four locations for days to maturity.

4.4.1.3 Plant height (cm)

For plant height the magnitude of variance due to hybrids versus parents was higher than the magnitude of variance due to parents and hybrids at all the four locations. The magnitude of variance due to lines was higher than the magnitude of variance due to testers and lines x testers at all the four locations.

4.4.1.4 Number of primary branches plant^{-1}

The magnitude of variance due to hybrids versus parents was higher at all the four location than the magnitude of variance due to parents and hybrids. The magnitude of variance due to lines was higher than the magnitude of variance due to testers and lines x testers at all the locations.

4.4.1.5 Number of secondary branches plant^{-1}

The magnitude of variance due to hybrids versus parents was higher at Patancheru, Parbhani and Latur locations than variance due to hybrids and parents, where as it was lower at Badnapur. The magnitude of variance due to lines was greater at Patancheru and Latur, whereas at Parbhani and Badnapur it was lower than the magnitude of variance due to testers and lines x testers.

4.4.1.6 Number of pods plant^{-1}

The magnitude of variance due to hybrids versus parents was lower than variance due to parents and hybrids at all the four locations viz., Patancheru, Parbhani, Latur and Badnapur. The magnitude of variance due to lines was greater than the magnitude of variance due to testers and lines x testers at all the four locations.

4.4.1.7 Seeds pod^{-1}

The magnitude of variance due to hybrids versus parents was greater than variance due to hybrids and parents at Patancheru, Latur and Badnapur where as it was lower at Parbhani. The magnitude of variance due to lines was greater than variance due to testers and line x testers at Parbhani only.

4.4.1.8 Pod weight (g)

The magnitude of variance due to hybrids versus parents was greater than the variance due to hybrids and parents at Patancheru and Parbhani where as, it was lower at Latur and Badnapur. The magnitude of variance due to lines was greater than the magnitude of variance due to testers and line x testers at all the four locations.

4.4.1.9 100-Seed weight (g)

The magnitude of variance due to hybrids versus parents was greater than variance due to hybrids and parents at all the four locations. The magnitude of variance due to lines was greater than magnitude of variance due to testers and lines x tester's at all the locations for 100- seed weight.

4.4.1.10 Pollen fertility (%)

The magnitude of variance due to hybrids versus parents was greater than the magnitude of variance due to hybrids and parents at Patancheru and Parbhani, where as it was lower at Latur and Badnapur. The magnitude of variance due to lines was lower than the magnitude of variance due to testers and line x testers at Patancheru and Parbhani, while it was greater at Latur and Badnapur.

4.4.1.11 Grain yield plant $^{-1}$ (g)

For grain yield plant^{-1}, magnitude of variance due to hybrids versus parents was greater than magnitude of variance due to hybrids and parents at Patancheru, Parbhani and Latur where as it was lower at Badnapur. The magnitude of variance due to lines was greater at Parbhani, Latur and Badnapur than variance due to tester and lines x testers, whereas at Patancheru, variance due to testers was greater than variance due to lines and lines x testers.

4.4.2 General Combining Ability (GCA)

The general combining ability (GCA) effects of parents and hybrids for individual location as well as over pooled data are given in table 4.21-4.25 and described as below.

4.4.2.1 Days to 50% flowering

At Patancheru, 11 out of 37 parents exhibited significant and negative general combining ability (GCA) effects for days to flower. The female parent ICPA 2043 exhibited significant and negative GCA effects for days to flower at all the four locations, while ICPA 2092 recorded significant and negative GCA effects at Latur only. At Patancheru, the male parent ICP 3475 (-6.716) registered high significant and negative GCA effects followed by PHULE T-00-11-6-2, AKT 8811 and VIPULA each recorded -3.382 GCA effects for days to flower. Likewise at Parbhani, four parents registered significant and negative GCA effects for days to flower; ICPA 2043 (-4.985) recorded the least significant and negative GCA effects followed by BSMR 203 (-2.534) and HPL 24-63 (-2.201). At Latur, 11 parents showed significant and negative GCA effects. BSMR 736 (-7.221) recorded the high significant and negative GCA effects followed by ICP 13991 (-5.221), and HPL 24-63 (-4.721). At Badnapur, 21 parents exhibited significant

and negative GCA effects. The highest GCA effects in negative direction was registered by AKT 222521 and AKT 00-12-6-4 (-6.373), followed by AKT 8811 (-5.706) and TV 1 (-4.873). The GCA effects calculated on pooled data revealed that, 10 parents exhibited significant and negative GCA effects. ICP 3475 (-3.877), BSMR 736 (-3.502), and AKT 8811 (-3.211) registered high significant and negative GCA effects indicating their good general combining ability for earliness.

4.4.2.2 Days to maturity

The general combining ability effects of parents revealed that among the females, ICPA 2043 (-2.789) exhibited significant and negative GCA effect at Patancheru for days to maturity. The same parent showed significant and negative GCA effect at Parbhani and Badnapur for early maturity. Line ICPA 2047 (-1.951) exhibited significant and negative GCA effects only at Badnapur, while ICPA 2092 (-0.025) exhibited negative GCA effect at Latur only. The male parents HPL 24-63 (-4.088), ICP 3475 (-3.922), and ICP 13991 (-2.922) was exhibited significant and negative GCA effects for days to maturity at Patancheru. At Parbhani, PHULE T-00-4-11-6-2 the exhibited the least GCA effect (-9.338) followed by AKT 222521 (-7.505), and ICP 3374 (-7.172). At Latur, PHULE T-00-1-25-1 exhibited the highest GCA effect in negative direction (-2.578) in negative direction followed by BSMR 198 (-2.412), and AKT 8811 (-2.245). At Badnapur, AKT 9915 exhibited the highest least GCA effect (-5.951) followed by HPL 24-63 (-4.784), and BSMR 571. The GCA effects estimated using pooled data revealed that, ICPA 2043 had the highest significant and negative GCA effect (-3.371), followed by HPL 24-63 (-3.239) and PHULE T-00-4-11-6-2 (-2.989).

4.4.2.3 Plant height (cm)

The line ICPA 2043 exhibited significant and positive GCA effect (4.005) only at Latur. The another female parent ICPA 2047 recorded significant and positive GCA effect at all the four locations, while ICPA 2092 exhibited significant and positive GCA effects at Parbhani (7.282) and at Badnapur (0.857). At Patancheru, the male parents PHULE T-00-1-25-1 recorded the highest GCA effect (26.364) followed by AKT 9913 (19.347) and TV 1 (15.497). At Parbhani, male parents

AKT 9913 (19.103) and PHULE T-00-1-25-1 (17.642) registered the highest significant and positive GCA effects. The same male parents had significant and positive GCA effects at Latur. At Badnapur, male parents TV 1 (28.670) recorded highest significant and positive GCA effects followed by BSMR 2 (10.020), and HPL 24-63 (9.387). The pooled GCA effects showed that, 12 parents recorded significant and positive GCA effects at the same time another 12 parents showed significant and negative GCA effects. The GCA effects estimated on pooled mean basis revealed that line ICPA 2043 exhibited significant and negative GCA effect (-4.524). ICPA 2047 exhibited significant and positive GCA effect (4.477), whereas ICPA 2092 (0.047) exhibited positive GCA effect. The male parents AKT 9913 (103.931), PHULE T-00-1-25-1 (12.999), and TV 1 (12.856) exhibited significant and positive GCA effects.

4.4.2.4 Number of primary branches plant^{-1}

At Patancheru and Latur ICPA 2043 recorded significant and positive GCA effect, while ICPA 2047 recorded significant and positive GCA effect at Patancheru (9.710) and Badnapur (0.302), whereas ICPA 2092 recorded significant and positive GCA effect at Patancheru (0.622) and Parbhani (3.044). Out of 37 parents, 29 had significant and positive GCA effects at Patancheru. Similarly 30 parents at Parbhani, 22 at Latur, and 36 at Badnapur showed significant and positive GCA effects. The estimates of GCA effects over pooled data showed that 31 parents had significant and positive GCA effects. At Patancheru, male parent ICPL 20106 (6.360) exhibited the highest significant and positive GCA effect followed by ICP 3514 (3.847), and TV 1 (3.410). At Parbhani, BDN 2001-6 recorded the highest and significant and positive GCA effect (4.722) followed by ICP 13991 (4.372) and TV 1 (2.688). At Latur, parents ICP 3525 (1.957), ICPL 12749 (1.823) and HPL 24-63 (1.483) recorded significant and positive GCA effect, whereas at Badnapur, BSMR 2 (2.213), AKT 9915 (1.963), and BSMR 846 (1.429) had highly significant and positive GCA effect. The analysis of pooled data showed that TV 1 (1.576) recorded the highest significant and positive GCA effect followed by BDN 2001-6 (1.483), BSMR 2 (1.125) and ICP 3525 (1.033).

4.4.2.5 Number of secondary branches plant^{-1}

At Patancheru, significant and positive GCA effect (3.438) was recorded by ICPA 2092 for number of secondary branches plant^{-1}. Similarly, ICPA 2043 (2.330) at Latur, and ICPA 2047 (0.812) at Badnapur recorded significant and positive GCA effect. The positive GCA effect (0.110) was recorded by ICPA 2043 at Patancheru, ICPA 2047 (0.211) at Parbhani. The significant and positive GCA effects recorded by male parents ICP 3374 (17.455), ICP 3514 (14.239), and VIPULA (10.322) for number of secondary branches plant^{-1} at Patancheru. At Parbhani, male parents BSMR 2 (5.976), ICPL 20106 (5.376) and ICP 13991 (5.359) had significant and positive GCA effects. The male parents HPL 24-63 (7.743), AKT 8811 (6.476), and TV 1 (4.359) registered the significant and positive GCA effects at Latur. At Badnapur, ICP 10934 (3.433), AKT 9913 (3.266), and BSMR 175 (3.133) recorded the significant and positive GCA effects. The values pooled GCA effects revealed that ICP 3374 recorded the highest GCA effect (4.556), followed by ICP 3514 (2.935) and ICPL 20106 (2.756).

4.4.2.6 Number of pods plant^{-1}

The female parent ICPA 2092 recorded significant and positive GCA effect, while ICPA 2043 and ICPA 2047 exhibited significant and negative GCA effect at all the four locations for number of pods plant^{-1}. Among the male parents, significant and positive GCA effect was recorded by ICPL 20106 (140.052), ICP 10934 (135.835), and ICP 3374 (110.569) at Patancheru. The similar parents exhibited good GCA effects at Parbhani, Latur and Badnapur. The estimates of GCA effects over pooled data analysis revealed that ICPL 20106 (128.998) recorded the highest significant and positive GCA effect, followed by ICP 10934 (120.666), and ICP 3374 (103.231) for number of pods plant^{-1}.

4.4.2.7 Pod weight (g)

The estimates of GCA effects of parents revealed that ICPA 2092 was the only line that recorded positive GCA effects at all the four locations. Out of 34 male parents studied, 11 registered significant and positive general combining ability effects. The highest GCA effects exhibited by male parents ICP 3374 (66.517), followed by ICPL 20106 (65.950), and ICP 10934 (54.867) at

Patancheru. The similar male parents also had significant and positive GCA effects at Parbhani and Latur. At Badnapur, the highest significant and positive GCA effect was recorded by male parent ICPL 20106 (78.38). The analysis of pooled data showed that 17 parents exhibited significant and positive GCA effects. ICP 3374 recorded the highest GCA effect (69.420) followed by ICP 3374 (64.672), and ICP 10934 (57.252). It was found that the parents showing significant GCA effects also had good (medium to high) *per se* performance.

4.4.2.8 Seeds pod^{-1}

At Patancheru and Badnapur none of the female parent showed significant and positive GCA effect. The female parent ICPA 2043 recorded significant and negative GCA effect at Parbhani (-0.145) and Latur (-23.885). ICPA 2047 had significant and positive GCA effect (0.088) only at Parbhani; while ICPA 2092 recorded significant and positive GCA effect at Parbhani (0.057) and Latur (29.314). Eight out of 34 male parents recorded significant and positive GCA effect at Patancheru. Likewise nine parents at Parbhani and Latur and eight at Badnapur recorded significant and positive GCA effect. At Patancheru, ICP 3374 (0.301) showed high GCA effect followed by BDN 2001-6 (0.251) and ICPL 12749 (0.218). These parents had good general combining ability at Latur. At Parbhani, male parents ICP 3475 (0.371), ICP 3374 (0.287), and BDN 2001-6 (0.204) had high GCA effects. Likewise, at Badnapur BDN 2001-6 (0.254), ICPL 12749 (0.221), and BSMR 175 (0.204) registered significant and positive GCA effects. The estimates of GCA effects over pooled data analysis revealed that 11 out of 37 parents had significant and positive GCA effects. ICP 3374 recorded the highest significant GCA effect (0.264) followed by BDN 2001-6 (0.239), and ICP 3475 (0.228).

4.4.2.9 100-Seed weight (g)

At Patancheru and Latur, none of the lines registered significant and positive GCA effect. ICPA 2043 recorded significant and positive GCA effect (0.106) at Parbhani. The same line had significant and positive GCA effect (0.264) at Badnapur. ICPA 2047 (0.194) was the only line which recorded positive GCA effect at Parbhani, while at Parbhani and Badnapur ICPA 2092 recorded

significant and negative GCA effect. At Patancheru, among the male parents significant and positive GCA effects recorded by BSMR 175 (0.831), followed by ICPL 12749 (0.776), AKT 9913 (0.659), BSMR 164 (0.596) and TV 1 (0.521). The same male parents showed significant and positive GCA effects at Parbhani, Latur and Badnapur. The pooled GCA effects showed that the male parents BSMR 175 (0.929) recorded the highest significant and positive GCA effect, followed by ICPL 12749 (0.798) and AKT 9913 (0.639).

4.4.2.10 Pollen fertility (%)

ICPA 2043 (2.586) recorded significant and positive GCA effects at Patancheru. It also showed significant and positive GCA effect (3.738) at Badnapur. While, ICPA 2047 (0.014) and ICPA 2092 (0.807) recorded significant and positive GCA effects at Parbhani only. At Patancheru, the highest GCA effect was recorded by male parent TV 1 (17.360), followed by AKT 8811 (15.976), and ICPL 20106 (13.660). Similarly at Parbhani BSMR 2 (12.403); at Latur ICP 10650 (6.699); and at Badnapur BWR 154 (7.476) had significant and positive GCA effect. The pooled data analysis revealed that TV 1 (7.513) recorded the highest GCA effect, followed by AKT 8811 (6.697), and BSMR 846 (5.991).

4.4.2.11 Grain yield plant^{-1} (g)

Nature and magnitude of combining ability effects help in identifying superior parents and their utilization in breeding programme. The estimates of general combining ability effects (GCA effects) of the parents revealed that the female parent ICPA 2092 had significant and positive GCA effect, it was good general combiner for grain yield plant^{-1} at all the four locations as well as over pooled data. Another female parent ICPA 2047 recorded significant and positive GCA effect at Parbhani only, whereas ICPA 2043 recorded significant and negative GCA effect at all the four locations. Among 34 male parents evaluated 13 had significant and positive GCA effects and were good general combiner for grain yield plant^{-1} at Patancheru. Similarly, nine male parents at Parbhani, 12 at Latur and 11 at Badnapur registered significant and positive GCA effects. The significant and positive high GCA effects were recorded by male parents ICP 3374 (64.406), ICPL 20106 (60.424) and ICP 10934 (51.326) at Patancheru.

These male parents registered significant and positive GCA effects at Latur and Badnapur. At Parbhani, male parents ICPL 20106 (59.417), ICP 3374 (55.625) and ICP 3514 (43.675) recorded significant and positive GCA effect Over pooled data, ICP 3374 (54.490) showed significant and highest positive GCA effect, followed by ICPL 20106 (53.879), ICP 10934 (44.212), ICP 3514 (37.580) and BDN 2001-6 (37.276).

4.4.3 Specific combining ability (SCA)

The specific combining ability (SCA) effects of parents and hybrids for individual location as well over pooled data are presented in table 4.26- 4.30 and described as below.

4.4.3.1 Days to 50 % flowering

Out of 102 hybrids, 21 registered significant and negative specific combining ability (SCA) effects for days to flower at Patancheru. Likewise, eight hybrids at Parbhani; 37 at Latur; and 32 at Badnapur had significant and negative SCA effects. The hybrid ICPA 2092 x ICP 11376 (-6.162) had the highest significant and negative SCA effect, followed by ICPA 2092 x BDN 2001-6 (-5.995) and ICPA 2047 x ICP 3514 (-5.294) at Patancheru. Similarly, hybrid ICPA 2043 x BDN 2001-6 (-5.514) registered the highest significant and negative SCA effect at Parbhani. At Latur, hybrid ICPA 2047 x ICP 3963 (-13.897) exhibited significant and negative high SCA effects; whereas ICPA 2043 x PHULE T-00-4-11-6-2 (-33.26) was at Badnapur. The pooled data analysis suggested that 22 hybrids registered significant and negative SCA effects. The hybrids ICPA 2047 x PHULE T-00-4-11-6-2 (-9.194), ICPA 2043 x PHULE T-00-4-11-6-2 (-5.815), and ICPA 2092 x BDN 2001-6 (-5.241) had registered significant and negative SCA effects for days to flower.

4.4.3.2 Days to maturity

The values of SCA effects revealed that out of 102 hybrids examined, 19 had significant and positive SCA effects, while 23 hybrids exhibited significant and negative SCA effects at Patancheru. Hybrid ICPA 2047 x PHULE T-00-1-25-1 (-5.456) had the highest significant and negative SCA effects followed by hybrids

ICPA 2092 x ICP 3525 (-4.500) and ICPA 2043 x BSMR 198 and ICPA 2043 x BDN 2001-6 each with SCA effects -4.377. Similarly, at Parbhani hybrids ICPA 2092 x BDN 2001-6 (-9.103) and ICPA 2092 x AKT 9913 (-8.603); at Latur ICPA 2047 x BSMR 846 (-7.123); and at Badnapur ICPA 2043 x AKT 00-12-6-4 (-8.966) were recorded high significant and negative SCA effects. The analysis of pooled data revealed that significant and negative SCA effect was present in 30 hybrids and a significant and positive SCA effect was present in 29 hybrids. Hybrids ICPA 2043 x BSMR 175 (-4.754), ICPA 2092 x ICP 13991 (-3.349), and ICPA 2092 x ICP 10650 (-3.141) exhibited significant and negative SCA effects.

4.4.3.3 Plant height (cm)

Out of 102 cross combinations studied, 32 registered significant and positive SCA effects at Patancheru. Likewise at Parbhani 30 hybrids, at Latur 18 hybrids and at Badnapur 21 hybrids had significant and positive SCA effects. Significant and positive high SCA effects was registered by hybrid ICPA 2043 x PHULE T-00-4-11-6-2 (32.797) at Patancheru, ICPA 2092 x BSMR 2 (22.351) at Parbhani, ICPA 2092 x BDN 2001-6 (30.825) at Latur and ICPA 2092 x ICP 10934 (22.86) at Badnapur. The estimates of SCA effects over pooled data revealed that 24 hybrids had significant and positive SCA effects. The significant and positive SCA effects were observed with hybrids ICPA 2047 x HPL 24-63 (11.808), ICPA 2092 x BSMR 2 (11.185), and ICPA 2047 x ICP 13991 (10.086).

4.4.3.4 Number of primary branches plant^{-1}

At Patancheru, 39 hybrids exhibited significant and positive SCA effects. Similarly, 30 hybrids at Parbhani, 22 at Latur and 36 at Badnapur had significant and positive SCA effects. The highest SCA effects was exhibited by hybrid ICPA 2092 x ICP 3514 (6.761) at Patancheru. Likewise ICPA 2047 x ICPL 20106 (7.151) at Parbhani, ICPA 2047 x BWR 154 (5.135) at Latur and ICPA 2043 x BSMR 736 (2.987) at Badnapur recorded significant and positive high SCA effects. The estimates of SCA effects over analysis of pooled data revealed that 31 hybrids had significant and positive SCA effects. The highest significant and positive SCA effect was observed with hybrids ICPA 2047 x ICPL 20106 (3.281),

ICPA 2047 x AKT 00-12-6-4 (2.495) and ICPA 2092 x PHULE T-00-5-7-4-1 (2.171).

4.4.3.5 Number of secondary branches plant^{-1}

For number of secondary branches plant^{-1} , the hybrid ICPA 2092 x BSMR 571 recorded highest significant and positive SCA effects (12.46) at Patancheru. Similarly, hybrid ICPA 2043 x BSMR 164 (9.196) at Parbhani, ICPA 2047 x BWR 154 (9.235) at Latur and ICPA 2043 x ICP 3525 (10.174) at Badnapur exhibited the highest significant and positive SCA effects. The analysis of pooled data showed that the highly significant and positive SCA effects was present in hybrids ICPA 2043 x BSMR 175 (4.799), ICPA 2092 x BSMR 571 (4.723), and ICPA 2092 x PHULE T-04-1-3-1 (4.536). Significant and negative SCA effect was found in ICPA 2043 x PHULE T-04-1-3-1 (-5.622), ICPA 2047 x BSMR 175 (-4.168) and ICPA 2047 x BSMR 571 (-4.139). Overall, 23 hybrids recorded significant and positive SCA effect at Patancheru, 24 at Parbhani, 37 at Latur and 41 at Badnapur registered significant and positive SCA effects. The estimates of SCA effects on pooled data revealed that 27 hybrids recorded significant and positive SCA effect.

4.4.3.6 Number of pods plant^{-1}

Hybrid ICPA 2047 x HPL 24-63 (211.306) recorded the highest SCA effects for number of pods plant^{-1} at Patancheru. This hybrid also had good SCA effects at Parbhani, Latur and Badnapur. The analysis of pooled data revealed that significant and positive high SCA effects was present depicted by hybrids ICPA 2047 x HPL 24-63 (162.785), ICPA 2092 x BSMR 164 (87.325) and ICPA 2043 x ICP 3475 (82.391) for number of pods plant^{-1}. Out of 102 cross combinations 37 hybrids at Patancheru, 35 at Parbhani, 36 at Latur, and 37 at Badnapur had significant and positive SCA effects. The estimates of SCA effects over pooled data analysis indicated that 39 hybrids recorded significant and positive SCA effect for number of pods plant^{-1}.

4.4.3.7 Pod weight (g)

At Patancheru, among 102 hybrids evaluated, 37 had good SCA effects for pod weight. The hybrid ICPA 2047 x HPL 24-63 (135.862) recorded the highest SCA effects for pod weight followed by ICPA 2092 x BSMR 164 (47.728) and ICPA 2043 x ICP 3374 (42.309). At Parbhani, 36 hybrids had significant and positive SCA effects. The high SCA effect registered with the hybrid ICPA 2047 x HPL 24-63 (135.862). At Latur and Badnapur, the said hybrid also depicted the highest SCA effect. The estimates of SCA effects over pooled data analysis revealed that the highest SCA effect was recorded by ICPA 2047 x HPL 24-63 (97.042), followed by ICPA 2092 x BSMR 164 (48.674), and ICPA 2043 x ICP 3475 (40.568). On the contrary, significant and negative SCA effects were recorded by the hybrids ICPA 2092 x HPL 24-63 (- 50.152), ICPA 2043 x HPL 24-63 (-46.890), and ICPA 2092 x ICP 3475 (-38.594) for pod weight. Overall 45 cross combinations exhibited significant and positive SCA effects.

4.4.3.8 Seeds pod^{-1}

Out of 102 cross combinations studied, 26 hybrids at Patancheru, 35 at Parbhani, 23 at Latur and 27 at Badnapur had significant and positive SCA effects. The estimates of SCA effects over pooled data revealed that 39 hybrids had significant and positive SCA effects; while 37 registered significant and negative SCA effects. The high SCA effect registered by hybrid ICPA 2043 x ICPL 12749 (0.510) at Patancheru. The said hybrid also exhibited high SCA effects at Latur and Badnapur. At Parbhani, ICPA 2043 x BSMR 846 (0.44) had the highest SCA effect. The analysis of pooled data revealed that significant and positive SCA effect was present by hybrids ICPA 2043 x ICPL 12749 (0.429), ICPA 2092 x BSMR 846 (0.416), and ICPA 2043 x AKT 222521 (0.412). Likewise, significant and negative SCA effects was observed with ICPA 2043 x BSMR 846 (-0.530), ICPA 2043 x ICP 3525 (-0.479), and ICPA 2047 x AKT 8811(-0.413).

4.4.3.9 100-Seed weight (g)

Out of 102 cross combinations examined, significant and positive specific combining ability (SCA) effects were recorded by 34 hybrids at Patancheru, 30 at Parbhani, 31 at Latur and 34 at Badnapur. Likewise, significant and negative SCA effect was recorded by 39 hybrids at Patancheru, 32 at Parbhani, 33 at Latur and

39 at Badnapur. At Patancheru, hybrid ICPA 2047 x BSMR 846 (1.809) registered the highest SCA effect. These hybrid also registered high SCA effects at Latur and Badnapur. At Parbhani, hybrid ICPA 2092 x PHULE T-00-1-25-1 (1.467) had the highest significant and positive SCA effects. The SCA effect calculated over pooled data revealed that, 41 hybrids had significant and positive SCA effects; while significant and negative SCA effects were recorded by 41 hybrids. The highest significant and positive SCA effects was registered by ICPA 2047 x BSMR 846 (1.721) followed by ICPA 2047 x AKT 9913 (1.721) and ICPA 2047 x BSMR 2 (1.553). Similarly, the highest significant and negative SCA effect was recorded by ICPA 2092 x ICPL 12749 (-1.394) followed by ICPA 2043 x BSMR 175 (-0.997) and ICPA 2092 x BSMR 2 (-0.995).

4.4.3.10 Pollen fertility (%)

Out of 102 cross combinations evaluated, 42 at Patancheru, 46 at Parbhani, 32 at Latur and 30 at Badnapur recorded significant and positive SCA effects. At Patancheru ICPA 2047 x ICP 13991 recorded the highest SCA effect (33.763). Similarly at Parbhani ICPA 2092 x BSMR 203 (28.082), at Latur ICPA 2043 x AKT 222521 (19.899) and at Badnapur ICPA 2043 x BSMR 2 (15.428) recorded the highest SCA effects. The analysis of pooled data indicated that 39 hybrids recorded significant and positive SCA effect. The significant and positive SCA effect was present with hybrids ICPA 2043 x BSMR 175 (14.323), followed by ICPA 2092 x BSMR 203 (12.510), and ICPA 2047 x ICP 13991 (11.775).

4.4.3.11 Grain yield plant^{-1} (g)

The specific combining ability effects (SCA effects) were considered to be best criteria for selection of superior hybrids. In the present study, at Patancheru, 45 hybrids depicted significant and positive SCA effects for grain yield plant^{-1}. The hybrids ICPA 2047 x HPL 24-63 (86.82), ICPA 2092 x BSMR 164 (47.13) and ICPA 2043 x ICP 3374 (37.808) had high significant and positive SCA effects. The said hybrids registered significant and positive SCA effects at Parbhani, Latur, and Badnapur. Similarly at Parbhani, 33 hybrids had high significant and positive SCA effects, while at Latur and Badnapur 36 hybrids exhibited significant and positive SCA effects. The pooled locations data revealed that 45

hybrids exhibited significant and positive SCA effects. Of which first three hybrids were ICPA 2047 x HPL 24-63 (70.331), ICPA 2092 x BSMR 164 (41.696) and ICPA 2043 x ICP 3374 (31.637).

4.4.4 Per cent contribution of females, males and their interaction to hybrid sum of squares

The per cent contribution by females, males and females x males interaction to total variance due to hybrids for the 11 characters were estimated and are presented in Table 4.31 - 4.35.

At Patancheru, the per cent contribution due to female parents was found to be less than either male parents or female x male interaction for all the characters. The per cent contribution due to male parents was greater for days to 50 % flower, number of secondary branches plant^{-1}, total number of pods plant^{-1}, pod weight (g) and grain yield plant^{-1} (g); while, it was less for days to maturity, plant height (cm), number of primary branches plant^{-1}, seeds pod^{-1}, 100-seed weight (g) and pollen fertility (%) than female x male interaction. At Parbhani, the per cent contribution due to female parents was found to be less than either male parents or female x male interaction for all the characters except days to 50 % flowering, days to maturity and number of primary branches plant^{-1}. For number of primary branches plant^{-1} the per cent contribution due to female parents was greater than both males and female x male interaction. The per cent contribution due to male parents was greater for days to maturity, plant height (cm), number of pods plant^{-1}, pod weight (g) and grain yield plant^{-1}; while, it was found to be less for days to 50 % flower, number of primary branches plant^{-1}, number of secondary branches plant^{-1}, total number of pods plant^{-1}, 100-seed weight and pollen fertility (%) than due to female x male interaction. At Latur, the per cent contribution due to female parents was found to be less than either male parents or female x male interaction for all the characters except days to maturity and number of primary branches plant^{-1}. The per cent contribution due to male parents was greater for all the characters than due to female x male interaction except for total number of pods plant^{-1}, pod weight (g) and grain yield plant^{-1}. At Badnapur, the per cent contribution due to female parents was found to be less than either male parents or female x male interaction for all the characters. The per cent contribution due to

male parents was greater for all the characters than due to female x male interaction except for total number of pods plant^{-1}, pod weight (g) and grain yield plant^{-1}.

The analysis of pooled data revealed that the per cent contribution due to female parents was found to be less than either male parents or female x male interaction for the character studied except days to 50 % flowering and days to maturity. The per cent contribution due to male parents was greater for plant height (cm), total number of pods plant^{-1}, pod weight (g) and grain yield plant^{-1} (g).

4.5 Stability analysis of parents and hybrids

Genotype-environment interactions are of major importance to the plant breeder in developing stable genotypes that interact less with the environment in which they are to be grown. If stability of performance or the ability to show a minimum interaction with the environment is a genetic characteristic, then preliminary evaluation could be planned to identify the stable genotypes. Low and high plant population, and medium and high rates of fertilizers can be used to increase the number of environments possible from a fixed number of locations, and at the same time provide a greater range of environmental conditions (Eberhart and Russell, 1996). In the present study, the parents and their hybrids were tested under four environments i.e. Patancheru, Parbhani, Latur and Badnapur locations. The performance of different genotypes in respect to different characters i.e. days to 50 % flower, days to maturity, plant height (cm), number of primary branches, number of secondary branches, total pods plant^{-1}, seeds pod^{-1}, pod weight (g), 100-seed weight (g), pollen fertility (%) and grain yield plant^{-1} were studied for estimating stability and significance of genotype x environment interactions. Analysis of variance is presented in Table 4.36 - 4.37 and estimates of stability parameters (Eberhart and Russel, 1966) in Tables 4.38 - 4.55.

4.5.1 Analysis of variance

The data obtained on mean performance of genotypes from four environments for each of the 11 characters were analyzed statistically location wise as per α-lattice design and the genotypic differences were found to be highly significant for all the 11 characters in all the four environments (Table 4.1).

4.5.2 Stability analysis for individual characters

The mean data averaged over replications for the genotypes from the four locations were subjected to pooled analysis. The analysis of variance revealed that the MSS due to genotypes (G) were found to be significant for all the characters; and that due to locations were significant for all the characters when tested against MSS due to G x E. The mean sum of square due to G x E when tested against MSS due to pooled error, found highly significant for all the characters except seeds pod^{-1} and 100-seed weight, thus satisfying the requirement of stability analysis and as such stability analysis was carried out on these characters. The variance due to G x E when divided into its components viz., variance due to G x E (liner) and that due to pooled deviation (non-linear), revealed that linear component of G x E interaction as well as the non-linear component when tested against pooled error were highly significant for these nine characters (Table 4.36).

4.5.2.1 Days to 50 % flowering

In pigeonpea, low mean performance and non-significant values of regression coefficient (bi<1) and deviation from regression line (S^2di <0) are desirable for days to 50% flowering.

Stability of parents

The estimates of stability parameters for days to flower revealed that 21 out of 37 parents used in making hybrids recorded low mean performance for days to flower. These parents were classified in to three groups (Table 4.38 A-B). In first group, two parents ICPA 2047 (119 days) and BSMR 198 (122 days) had low mean days to flower with non-significant and unit regression coefficient (bi =1); and non-significant deviation from regression (S^2di = 0), thereby indicating their stable performance across the environments. In second group, nineteen parents had high mean with non-significant regression coefficient (bi =1) but significant deviation from regression line (S^2di >0), which indicated only linear component (bi) was responsible for the G x E interaction. The third group consisted of 16 parents with high mean for days to flower, non-significant bi =1, and significant S^2di>0, suggesting instability of the parents in different environments.

Stability of hybrids

For days to flower all the 102 hybrids were classified into three groups (Table 4.39 A-C). In the first group eight hybrids were included which showed low mean days to flower and non-significant bi =1 and S^2di =0. These hybrids were classified as stable for days to flower. Four stable hybrids were derived from ICPA 2043 and two each from ICPA 2047 and ICPA 2092. In second group 55 hybrids were included had low mean days to flower, non-significant values of bi =1 and significant value of S^2di >0. In third group one hybrid showed low mean and significant values of both bi>1 and S^2di >0 indicating their instability under favorable as well as adverse environmental situations. In the fourth group 15 hybrids were showed below average mean and non-significant values for bi =1 and S^2di = 0. These hybrids indicated stability under different environmental conditions. In fifth group 27 hybrids were showed low mean, non-significant value of bi =1 and significant value of S^2di>0, indicating suitability of these hybrids under favorable environmental conditions. Among controls, BSMR 736 (mean =121, bi = 0.457, S^2di = 2.404) and ICPH 2671 (Mean =122, bi = 0.622, S^2di = 1.9) were showed low mean with non-significant value of bi =1 and S^2di=0, which indicated stability across the environments (Table 4.39 D).

4.5.2.2 Days to maturity

Stability of parents

Out of 37 parents evaluated, 20 showed above average mean for days to maturity; while, 17 showed below average mean. These parents were classified in to three groups (Table 4.40 A-C). Parent ICPA 2043 was the earliest in maturity (166 days) with non-significant values of regression coefficient (bi = 0.54) and deviation from regression (S^2di = -0.633), which showed above average stability of this line. Nineteen parents showed above average mean with non-significant regression values (bi=1) and significant value of deviation from regression line (S2di>0) suggesting linear component of stability was responsible for stability of parents. Rest of 17 parents showed below average mean with non-significant value of bi and significant value of S^2di indicating instability of genotypes for maturity. The deviation from regression (S^2di) was significant for

36 parents illustrating preponderance of environment x genotype interaction. Parent ICP 3407 registered above average mean with significant value of both bi and S^2di indicating, instability under favorable as well as unfavorable environmental condition.

Stability of hybrids

A total of 27 hybrids recorded above average mean; while, the remaining 75 hybrids showed below average mean values for maturity. These hybrids were classified in to three groups (Table 4.41 A - C). Nine hybrids showed above average mean with non-significant value of both bi = 1 and S^2di = 0, indicated stable performance of hybrids under different environmental conditions. Six hybrids were derived from ICPA 2043 while three hybrids from ICPA 2047. Three hybrids showed below average mean with non-significant value of bi =1 and S^2di =0 which indicated stability of hybrids under stress environmental condition. In the second group, 18 hybrids showed above average meanwhile 44 showed below average mean days to flower with non-significant values of bi =1 but significant value of S^2di>0 indicating their instability under different environmental condition. The controls BSMR 736 (mean = 172, bi =0.898, S^2di =-0.189) and ICP H 2671 (mean = 175, bi =0.679, S^2di =1.572) showed non-significant value of both bi and S^2di thereby suggesting their above average stability (Table 4.41 D).

4.5.2.3 Plant height

Stability of parents

Out of 37 parents, 17 recorded the greater mean; while, 20 had low mean value for plant height. On the basis of stability parameters these parents were classified in to three groups (Table 4.42 A-C). In first group nine parents had non-significant values of bi =1 and S^2di =0 which indicated stability of parents across different environment. Five parents depicted greater mean; while, four parents had low mean for plant height. The stable parents were BSMR 175, BDN 2001-6, BSMR 2, BSMR 164 and ICPL 20106. In second group 15 parents had non-significant values of bi =1 and significant value of S^2di >0 indicating their specific adaptability to environmental conditions. Of these, 10 parents had greater plant height; while, 15 had lower plant height. In third group three parents

exhibited significant values of regression coefficient (bi>1) and deviation from regression line (S2di >0). It suggested that these parents were highly sensitive to changes in environmental conditions. Two parents had greater mean for plant height; while, one had lower mean.

Stability of hybrids

Out of 102 cross combinations evaluated for stability analysis, 49 exhibited above average mean and the rest of the 53 hybrids had below average mean for plant height. These hybrids were classified in to four groups (Table 4.43 A-D). In first group 17 hybrids included of which 12 were from above average mean; while, five from below average mean. These hybrids had non-significant values of bi=1 and S^2di=0; which revealed the stability of these hybrids under different environmental conditions. In second group 64 hybrids were there, of which 23 had above average meanwhile 41 had below average mean. These hybrids had non-significant values of bi=1, and significant values of S^2di>0, which suggested the instability of hybrids under different environmental conditions. In third group, two hybrids included of which ICPA 2092 x PHULE T-00-1-25-1 exhibited greater plant height; while, ICPA 2043 x BSMR 2 had low plant height with significant value of bi>1 and non-significant value of S^2di=0; which had the specific adaptability of hybrids. In fourth group three hybrids had significant values of bi>1 and S^2di>0, which revealed instability of hybrids under different environmental conditions. Of which, one hybrid had above average mean; while, two had below average mean for plant height.

4.5.2.4 Number of primary branches plant^{-1}

Stability of parents

In case of primary branches plant^{-1}, all the parents were classified in to two groups (Table 4.44 A-B). In the first group, 10 parents had non-significant values of regression coefficient (bi =1) and deviation from regression line (S^2di =0). Six parents had above average mean indicating stability under wide environments, while four parents had below average mean demonstrating stability under stress environments. In second group, 27 parents registered non-significant values of bi =1 and significant value of S^2di >0. Seventeen parents had above average mean; while 10 had below average mean.

Stability of hybrids

The stability analysis of 102 hybrids for number of primary branches plant^{-1} was classified into three groups (Table 4.45 A-C). In first group, 16 hybrids had non-significant values of bi =1 and S^2di =0, which indicated stability of hybrids for number of primary branches plant^{-1} under different environmental conditions. Eleven hybrids had more number of primary branches plant^{-1} indicating stability under different environmental conditions. In second group, 43 hybrids had above average meanwhile 41 had below average mean with non-significant values of bi =1 and significant value of S^2di >0. In third group, two hybrids had number of primary branches plant^{-1} equal to average mean with significant value of bi >1 and S^2di >0 indicating instability of hybrids under poor as well as favorable environments. Stability analysis of both the control BSMR 736 and ICPH 2671 registered above average mean for number of primary branches plant^{-1} with non-significant values of bi =1 and S^2di =0 indicating wide stability across the environments. (Table 4.45 D).

4.5.2.5 Number of secondary branches plant^{-1}

Stability of parents

The results of stability analysis of 37 parents classified in to four groups (Table 4.46 A-D). In the first group, five parents included which had non-significant values of regression coefficient (bi =1) and deviation from regression line (S^2di =0), suggesting the stability of parents for number of secondary branches plant^{-1}. Three parents exhibited above average mean for number of secondary branches plant^{-1} indicating stability across the environments, while two had below average mean suggesting stability under stress environments. In second group 20 parents included, of which, nine had above average meanwhile 11 exhibited below average mean. These all parents had non-significant value of bi =1 and significant value of S^2di >0, indicating instability of hybrids under different environments. In third group three parents had above average mean with significant value of bi >1 and non-significant value of S^2di = 0, indicating specific adaptability. In fourth group out of nine parents four had above average mean while five showed below average mean for number of secondary branches plant^{-1}, with significant value of

bi >1 and S^2di >0 indicating highly instability of parents under favorable as well as poor environmental condition . The stable parents BSMR 175, VIPULA and PHULE T-00-5-7-4-1 performed well under good as well as poor environment, whereas AKT 00-12-6-4 and TV 1 were stable and performed well under stress environmental condition.

Stability of hybrids

All the 102 hybrids were classified in to four groups on the basis of stability analysis for number of secondary branches plant^{-1} (Table 4.47 A-D). In first group 18 hybrids had non-significant values of bi and S^2di. These include 10 hybrids with above average mean for number of secondary branches plant^{-1} and considered as stable hybrids which can be grown under different environmental condition. Four hybrids were from ICPA 2043 male-sterile lines, four from ICPA 2047 male-sterile lines and two from ICPA 2092 male-sterile lines. The remaining eight hybrids had below average mean which showed stability under stress environments. In second group, 63 hybrids included of which 32 had above average mean for secondary branches plant^{-1} while 31 showed below average mean. These hybrids had non-significant value of bi =1 and significant value of S^2di >0 suggesting instability under different environments. In third group, six hybrids included of which five had above average mean for number of secondary branches plant^{-1} while one had below average mean with significant value of bi >1 and non-significant value of S^2di =0. In fourth group, 15 hybrids included of which seven had above average mean for number of secondary branches plant^{-1} while eight showed below average mean with significant value of bi >1 and S^2di >0. Both the controls BSMR 736 and ICPH 2671 exhibited above average mean for number of secondary branches plant^{-1} with significant value of bi =1 and S^2di=0 which indicate stability under different environment.

4.5.2.6 Number of pods plant^{-1}

Stability of parents

The stability analyses of all the parents for number of pods plant^{-1} were classified into three groups (Table 4.48 A-C). In first group, 25 parents included which had non-significant values of bi =1 and S^2di =0, indicating the stable performance of

parents for number of pods plant^{-1}. It consists of 15 parents with above average mean for number of pods plant^{-1} suggesting stability under different environments, whereas ten parents showed below average mean suggesting stability under stress environmental conditions. In second group, five parents included of which two exhibited above average mean while three had below average mean for number of pods plant^{-1} with non-significant value of bi =1 and significant value of S^2di >0, were categorized as unstable parent. In third group, seven parents included of which two had above average mean value for number of pods plant^{-1} while five exhibited below average mean with significant value of bi>1 and S^2di>0, which suggested instability under favorable as well as unfavorable environmental conditions. HPL 24-63, ICP 10934 and ICP 3963 were first three stable parents which had greater number of pods plant^{-1}, while, BDN 2001-6, ICP 3374 and BSMR 2 were stable parents but showed less number of pods plant^{-1}.

Stability of hybrids

The stability analysis of 102 hybrids for number of pods plant^{-1} classified into three groups (Table 4.49 A-C). In first group, 74 hybrids showed non-significant value of bi = 1 and S^2di = 0 suggesting stability for number of pods plant^{-1}. This group consists of 31 hybrids with above average mean indicating stability across the environments while 43 exhibited below average mean suggesting average stability under stress environments. In second group, 18 hybrids had non-significant value of bi =1 and significant value of S^2di >0, of which nine hybrids with above average mean while nine with below average mean suggesting instability under wide environmental conditions. In third group, ten hybrids included of which four had above average mean while six had below average mean with significant value of bi >1 and S^2di >0. This indicated instability of hybrids under favorable as well as poor environments. It was observed that 28 hybrids derived from ICPA 2092 male-sterile line whereas 26 from ICPA 2047 and 20 from ICPA 2043. In general more number of stable hybrids were identified for number of pods plant^{-1} on ICPA 2092 male sterile lines followed by ICPA 2047 and ICPA 2043. The first three stable hybrids derived from ICPA 2043 male-sterile line for number of pods plant^{-1} were ICPA 2043 x ICP 3514, ICPA 2043 x PHULE T-00-4-11-6-2, and ICPA 2043 x ICP 10934. Likewise, first three ICPA 2047 stable hybrids were ICPA 2047 x ICPL 20106, ICPA 2047 x ICP

10650 and ICPA 2047 x BSMR 198. Similarly, ICPA 2092 stable first three hybrids were ICPA 2092 x BSMR 164, ICPA 2092 x ICP 3963 and ICPA 2092 x ICP 3514. The estimation of stability parameters for controls found that BSMR 736 and ICPH 2671 had greater number of pods plant^{-1} with non-significant value of regression coefficient but significant value of deviation from regression line indicated specific adaptability.

4.5.2.7 Pod weight

Stability of parents

In case of pod weight, all the parents were classified in to three groups, of which 16 exhibited above average mean, while rest of 21 had below average mean (Table 4.50 A-C). In first group, 26 parents included which had non-significant value of both regression coefficient (bi = 1) and deviation from regression line ($S^2di = 0$), and thus were categorized as stable ones; of which eleven parents showed above average mean for pod weight suggesting stability under different environmental conditions, whereas 15 parents showed below average mean indicating stability under stress environments. In second group, five parents showed non-significant value of regression coefficient (bi = 1) and significant value of deviations from regression line ($S^2di > 0$), of which three parents showed above average mean for pod weight while two showed below average mean exhibiting unpredictable nature of varieties. In third group, five parents of which two with above average mean while three with below average mean for pod weight but significant value of regression coefficient (bi > 1) and mean square due to deviations ($S^2di > 0$), indicated instability of parents under poor as well as good environmental conditions. The stable parents identified for pod weight were ICP 3525, HPL 24-63, TV 1, ICPA 2043, ICP 13991, ICP 3963, PHULE T-00-1-25-1, PHULE T-00-4-11-6-2, ICP 10934, AKT 00-12-6-4 and ICPA 2092.

Stability of hybrids

On the basis of stability analysis all the 102 hybrids were categorized into three stability groups (Table 4.51 A-C). In first group 64 hybrids with non-significant value of bi = 1 and $S^2di = 0$, of which 32 had above average mean for pod weight. These hybrids were classified as stable hybrids. Eight hybrids each were derived

from ICPA 2043 and ICPA 2047 male-sterile line. Another, eight hybrids were from ICPA 2047 based male-sterile line and 16 hybrids were from ICPA 2092 based male-sterile line. While remaining 32 hybrids had below average mean for pod weight with non-significant values of bi and significant values of S^2di exhibiting stability under stress environments. In second group, 36 hybrids included which showed non-significant value of regression coefficient (bi = 1) and significant value of deviation from regression line (S^2di >0), indicated instability of hybrids under different environmental condition. It consisted, 12 hybrids which showed above average meanwhile 24 with below average mean. In third group, two hybrids included of which one showed above average mean while other showed below average mean with significant value of bi >0 and S^2di >0, which indicated instability of hybrids under good as well as poor environment. The control ICPH 2671 (136.1) showed high mean yield with non-significant value of bi = 1 and S^2di = 0, indicating stability under different environment, whereas control BSMR 736 (126.6) had above average mean, with non-significant value of bi =1 but significant value of S^2di >0, indicating only linear component responsible for genotype x environment interaction.

4.5.2.8 Seeds pod^{-1}

As there was no genotype x environment interaction for the parents and hybrids, hence stability analysis was not carried out. Of

4.5.2.9 100-seed weight

As there was no genotype x environment interaction for parents and hybrids, hence stability analysis was not carried out for 100-seed weight.

4.5.2.10 Pollen fertility (%)

Parents

The pollen fertility among the parents varied from 79 to 100%. The assessment of data for stability analysis divided the parents into three groups (Table 4.52 A-C). In first group, 10 parents included with non-significant value of regression coefficient (bi =1) and deviation from regression line (S^2di =0). Of which eight

parents had pollen fertility above average mean showing the stability of parents across the environments; whereas two were with below average mean showing stability under stress environments. The stable parents identified for pollen fertility were BSMR 846,

BSMR 164, HPL 24-63, PHULE T-00-1-25-1, ICP 3525, ICPL 20106, AKT 00-12-6-4 and ICP 11376. In second group 25 parents included of which 17 showed above average mean while eight showed below average mean with non-significant value of bi=1 and S^2di >0. In third group two parents showed pollen fertility below average mean with significant value of both regression coefficient (bi =1) and deviation from regression line (S^2di =0), indicating instability for pollen fertility under different environments.

Hybrids

In case of pollen fertility all the hybrids were classified into three groups (Table 4.53 A-C). In first group, 15 hybrids included which showed non-significant value of bi =1 and S^2di =0 indicating stability of hybrids for pollen fertility. Of which 14 hybrids recorded above average mean pollen fertility which indicated stability of hybrids across the environments whereas one hybrid had below average mean pollen fertility indicating stability under stress environments. Ten hybrids derived from ICPA 2043, three from ICPA 2047 and two from ICPA 2092. In second group, 72 hybrids included of which 43 had high pollen fertility while 29 had low pollen fertility with non-significant value of bi=1 and significant value of S^2di >0. This indicated only linear component was responsible for genotype x environment interaction. In third group, 14 hybrids included; of which, only one hybrid had above average meanwhile 13 had below average mean. All these hybrids showed significant value of bi>1 and S^2di >0, which indicated instability of hybrids under poor as well as good environment. Control BSMR 736 had high pollen fertility with non-significant value of bi =1 and significant value of S^2di =0, whereas control ICPH 2671 had high pollen fertility with non-significant value of bi =1 and S^2di =0. The stable hybrids derived from ICPA 2043 were ICPA 2043 x ICP 3525, ICPA 2043 x BSMR 175, ICPA 2043 x BSMR 2, ICPA 2043 x ICP 10934, ICPA 2043 x ICP 3407, ICPA 2043 x TV 1, ICPA 2043 x HPL 24-63, ICPA 2043

x AKT 8811and ICPA 2043 x VIPULA. Likewise, ICPA 2047 stable hybrids were ICPA 2047 x ICP 10650, ICPA 2047 x BSMR 846 and ICPA 2047 x AKT 00-12-6-4. Similarly, ICPA 2092 stable hybrids were ICPA 2092 x ICP 3514 and ICPA 2092 x PHULE T-04-1-3-1.

4.5.2.11 Grain yield plant^{-1}

Stability of parents

Stability analysis of parents for grain yield plant^{-1} classified in to three groups (Table: 4.54 A-C). In first group 26 out of 37 had non-significant value of regression coefficient (bi=1) and deviation from regression line (S^2di =0) thereby indicating their stable performance in the different environmental conditions. Of which 13 parents showed above average mean yield while 13 were below average mean yield. In second group, four parents depicted high mean; while, two parents with low mean yield with non-significant value of bi = 1 and significant S^2di >0, which indicated only linear component (bi) was responsible for the G x E interaction. In third group, five parents had significant values of both bi >1 and S^2di >0, thereby indicating instability under poor as well as favorable environmental conditions. The figures in parenthesis denote respective parents, hybrids and controls number as illustrated in Fig. 1 and Fig. 2. Out of 37 parents evaluated 12 Parents [118] HPL 24-63, [131] ICP 3963, [117] ICP 10934, [126] PHULE T-00-1-25-1, [125] AKT-8811, [109] ICPA 2043, [134] PHULE T-00-4-11-6-2, [141] ICPA 2092, [115] BSMR 571, [108] BDN 2001-6, [136] ICP 3514 and [111] BSMR 2 showed the general adaptability for grain yield plant^{-1}. While four parents ICP 3525, TV 1, ICP 13991 and BSMR 198 showed instability to poor as well as favorable environment.

Stability of hybrids

The stability analysis of 102 hybrids for grain yield plant^{-1} classified in to four groups (4.55). In first group, 73 hybrids showed non-significant value of regression coefficient (bi=1) and deviation from regression line (S^2di) thereby indicating their stable performance in the different environmental conditions. Of which, 29 hybrids had above average meanwhile 44 had below average mean. A hybrid showing above average mean yield consists of 16 from ICPA 2092, seven from ICPA 2047 and six from ICPA 2043. Likewise a stable hybrid showing

below average mean yield consists of 16 each from ICPA 2043 and ICPA 2047 and 12 from ICPA 2092. In second group, 12 hybrids had non-significant value of bi =1 but significant value of S^2di >0 indicating instability of hybrids under different environments. Eight hybrids had above average mean yield while four hybrids had below average mean yield. In third group, four hybrids had significant value of bi >1 and non-significant value of S^2di =0 indicating instability under different environments. Three hybrids showed above average mean yield while one showed below average mean yield. In fourth group, six hybrids showed both significant value of bi>1 and S^2di>0, indicating instability of hybrids under poor as well as favorable environments. The first three high yielding ICPA 2043 based stable hybrids were [34] ICPA 2043 x ICP 3514 (mean =123.3, bi = 1.212, S^2di = 5.117), [20] ICPA 2043 x ICP 3475 (mean = 115.7, bi = 1.173, S^2di = 13.758) and [15] ICPA 2043 x ICP 10934 (mean = 115.2, bi = 1.193, S^2di = 2.697). Likewise ICPA 2047 based stable hybrids were [70] ICPA 2047 x ICPL 20106 (mean = 120.5, bi = 1.071, S^2di = 0.386), [67] ICPA 2047 x ICP 11376 (108.3) and [53] ICPA 2047 x ICPA 10650 (mean = 106.2, bi = 1.118, S^2di = 2.793). Similarly, ICPA 2092 based stable hybrids were [73] ICPA 2092 x BSMR 164 (mean = 128.8, bi = 1.173, S^2di = -4.132), [94] ICPA 2092 x AKT 9913 (mean = 119.8, bi = 1.144, S^2di = -4.569) and [74] ICPA 2092 x BDN 2001-6 (mean = 114.4, bi = 1.21, S^2di = 0.912).

4.6 Genetics of Fertility Restoration

Cytoplasmic nuclear-male sterility (CGMS) is maternally inherited and is known to be associated with specific (mitochondrial) genes without otherwise affecting the plant (Budar and Pelletier 2001). The fertility restorer (*Rf* or *Fr*) genes in the nucleus suppress the male-sterile phenotype and allows commercial exploitation of the CGMS system for the production of hybrid seeds. In addition the CGMS-*Rf* system provides an excellent model for the study of nuclear-mitochondrial interaction in multicellular organisms. The gene action in F_1 generation and the nature of segregation in F_2 generation observed in this study are shown in the Table 4.60. A total of four F_1 hybrids were advanced to F_2 and backcross generations to study the segregation for fertility restoration. The F_1 plants were selfed with muslin cloth bags and also backcrossed to the male-sterile parent. The

parents, F_1, F_2, and BC_1F_1 populations were grown in field during 2008 rainy season. Data on segregation for male-sterility and fertility were recorded in each plant of these populations. Chi-square (χ^2) tests were applied for testing goodness of fit for each phenotypic ratio. In hybrid ICPA 2092 x ICP 2766 all the five F_1 plants were male-fertile indicating the dominance of fertility restoring genes. As expected, the F_2 and BC_1F_1 population of this hybrid segregated for male-sterility and fertility. Out of 458 F_2 plants grown, 350 were fertile while 108 were male-sterile. This segregation fit well to the expected ratio of 3 fertile: 1 sterile (χ^2 = 0.004; P = 0.952) ratio. In BC_1F_1 generation out of 123 plants, 64 were male-fertile and 59 had male-sterile anthers, which showed a good fit for a 1 fertile: 1 sterile (χ^2 = 0.146, P = 0.702) ratio. In ICPA 2048 x ICP 3477 hybrid, all the 9 F_1 plants were male-fertile. Among 417 F_2 plants, 318 were male-fertile and 99 were male-sterile. This segregation fit well to the expected ratio of 3 fertile: 1 sterile (χ^2 = 0.003; P = 0.958) ratio. In BC_1F_1 generation out of 114 plants, 53 were male-fertile and 61 had male-sterile anthers, which showed a good fit for a 1 fertile: 1 sterile (χ^2 = 0.430; P = 0.512) ratio. This suggested that the fertility restoration was controlled by a single dominant gene. In the other two hybrids (ICPA 2047 x ICP 3513 and ICPA 2043 x ICP 2766) all the F_1 plants were also male-fertile. But the observations in the F_2 generation revealed that in ICPA 2047 x ICP 3513 out of 424 total plants studied, 393 were male-fertile and 31 were male-sterile. This segregation fit well to a dihybrid ratio of 15 fertile: 1 sterile (χ^2 = 0.029, P = 0.865). While, segregation in BC_1F_1 generation revealed that 110 plants were male-fertile and 43 were male-sterile, which showed a good fit for a 3 fertile: 1 sterile (χ^2 = 0.231, P = 0.631) ratio. Similarly, in hybrid ICPA 2043 x ICP 2766 out of 315 plants studied, 292 plants were male-fertile while 23 were male-sterile, which showed a good fit for a 15 fertile: 1 sterile (χ^2 = 0.028, P = 0.866) ratio. In BC_1 F_1 generations 84 plants were male-fertile and 27 were male-sterile. This segregation fit well to a ratio of 3 fertile: 1 sterile (χ^2 = 0.327, P = 0.568) ratio. This suggested that a digenic inheritance with duplicate gene action for fertility restoration.

4.7 Stability of CGMS lines

The observations were recorded to study the stability of male sterile line

throughout the season. The objective was to study the genotype x environment interaction. In present experiment three male sterile lines ICPA 2043, ICPA 2047 and ICPA 2092 were sown during rainy season 2009 at Department of Agricultural Botany, Marathwada Agricultural University, Parbhani. These lines were planted in selfing cage and observations were recorded from initiation of flowering up to maturity at the interval of 15 days for male sterility and fertility. In case of ICPA 2043, five out of 32 plants were observed fertile on 25th October 2009 and remaining 27 plants were sterile. The number of male sterile plants increased 15th December, 30th December, and 15th January date of observations. Total fertile plants were five to eight. The remaining 24 plants were sterile throughout the season. In another male sterile line ICPA 2047 three out of 32 plants were observed as fertile. Out of these three fertile plants, two fertile plants were observed during early stage of flowering, whereas third plant converted from sterile to fertile during 15th December 2009. In third male sterile line, four out of 32 plants were recorded as fertile. Out of these four fertile plants, two fertile plants were reported during initial flowering whereas two sterile plants were converted into fertility during 15th December. In general out of three male sterile lines highest sterile plants were observed in ICPA 2047 (99.1%), followed by ICPA 2092 (98.7%), and ICPA 2043 (97.2%) Table 4.62-64.

4.8 Study of quality parameters

Pigeonpea is one of the oldest food crops. In present study the newly developed CGMS-based pigeonpea hybrids have been tested for some quality characteristics. However, at present no literature on the quality parameters of hybrids is available. The present study was undertaken to make a comparative assessment of hybrids and cultivars for four important quality parameters such as cooking time (min), protein (%), water absorption (gg-1) and dal recovery (%).

4.8.1 Analysis of variance

As a first step the data obtained on the mean performance of genotypes (parents and hybrids) for each of the characters were analyzed statistically as per randomized block design and the genotypic differences were found to be highly

significant for all the characters. The analysis of variance for quality parameters is given in table 4.56. The *per se* performance of parents, hybrids and controls for quality parameters are given in Table 4.57- 4.59. The estimate of critical difference was used to compare the significant differences between the parents and hybrids.

4.8.1.1 Cooking time (min)

The pigeonpea dal of hybrid ICPH 2671 cooked earlier (32.4 min.) than the control BSMR 736 (38.3 min). Therefore the present results were compared with ICPH 2671. Out of 37 parents tested, 14 were significantly earlier to cook over the control. The parents ICP 3525 (18.5 min), AKT 8811 (19 min), TV 1 (21 min) and PHULE T-00-5-7-4-1 (21.5 min) took significantly less time to cook than the control. Similarly, out of 102 hybrids evaluated, 36 recorded significantly less cooking time than the control. Hybrids ICPA 2047 x PHULE T-00-1-25-1 (13.5 min), ICPA 2092 x PHULE T-00-1-25-1 (13.5 min), ICPA 2043 x BSMR 736 (18.0 min) and ICPA 2047 x ICP 3514 (21.5 min) recorded significantly less cooking time as compared to the control.

4.8.1.2 Protein (%)

The highest protein content (%) was recorded in the control ICPH 2671 (20.7 %) than BSMR 736 (19.9 %). Therefore the present results were discussed with control ICPH 2671. Out of 37 parents evaluated significantly high protein content (%) was recorded by six parents than the control. ICPL 20106 (23 %), ICP 3525 (22.8 %), and ICP 3514 (22.6 %) recorded significantly high protein (%) than the control. Similarly, out of 102 hybrids evaluated significantly high protein (%) was recorded by five hybrids as compared to the control. Hybrids ICPA 2043 x BSMR 198 (23%), ICPA 2043 x BSMR 175 (23 %) and ICPA 2043 x ICP 3407 (23 %) recorded significantly more protein (%) than the control.

4.8.1.3 Water absorption (gg^{-1})

The more water absorption recorded by the control BSMR 736 (2.1 gg^{-1}) than the control ICPH 2671 (1.7 gg^{-1}). Therefore, the present results were discussed with

the control BSMR 736. Five out of 37 parents showed significantly more water absorption (gg^{-1}) over the control. BWR 154 (2.5 gg^{-1}), and BDN 2001-6, AKT-00-12-6-4, and ICPL 20106 each with 2.3 gg^{-1} recorded significantly more water absorption than the control. Similarly, out of 102 hybrids studied, 15 recorded more water absorption as compared to the control. ICPA 2043 x ICP 11376 (2.7 gg^{-1}), ICPA 2043 x ICP 3514 (2.6 gg^{-1}), and ICPA 2047 x PHULE T-005-7-4-1 (2.5 gg^{-1}) registered significantly more water absorption than the control.

4.8.1.4 Dal recovery (%)

The hybrid ICPH 2671 recorded 71 % of dal recovery as compared to BSMR 736 (69.4 %). Hence the present results are discussed in relation to ICPH 2671. Out of 37 parents used for making dal only PHULE T-00-11-6-2 (83.3 %) recorded significantly more dal recovery (%) as compared to the control ICPH 2671 (71.0 %); whereas ICP 11376 (75.1 %), AKT 9913 (73.3 %), ICP 12749 (71.9 %) and HPL 24-63 (71.9 %) were similar to the control. Similarly, among the hybrids ICPA 2047 x ICP 3374 and ICPA 2092 x ICP 3374 (77.9 %) recorded significantly greater dal recovery (%) than the control. Hybrids ICPA 2047 x BSMR 203 and ICPA 2092 x BSMR 203 (each with 75.6 %), ICPA 2043 x ICP 3525, ICPA 2047 x PHULE T-04-1-3-1, and ICPA 2092 x PHULE T-04-1-3-1 (each with 74.1 %) were similar to the control.

CHAPTER V

DISCUSSION

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

In the present investigation, hybrids derived by using CGMS lines were studied to estimate the magnitude of standard heterosis, (Fonesca and Paterson, 1968 and Meredith and Bridge (1972), the combining ability parameters, nature of gene action (Kempthorne, 1957), interaction with environment and stability parameters (Eberhart and Russel, 1966) for yield and yield components were also estimated in this study. Another major objective was to know quality of newly developed inter-specific hybrids and the genetics of fertility restoration. The results are discussed here under.

5.1 Analysis of variance

The analysis of variance carried out for all the characters revealed highly significant genotypic differences in all the four environments i.e. Patancheru, Parbhani, Latur and Badnapur for all the characters studied. It indicated the presence of substantial genetic variation among the selected parental lines and their cross combinations. Also, the analysis of variance showed significant genotypic differences in all the 16 cooking quality parameters studied.

5.1.1 Mean performance of parents and hybrids over environments

Maturity duration is a very important factor that determines the adaptation of varieties to various agro-ecological conditions and cropping systems (Sharma *et al.* 1981). A broad maturity classification of early (< 150 days), medium (151 to 180 days), and late (> 180 days) has been in vogue for a long time in India (Saxena, 2006). In the present investigation female lines ICPA 2043 flowered earlier followed by ICPA 2047 and ICPA 2092 whereas the testers were of medium to long-duration group. Considering early flowering and maturity as important attributes, among the parents, female lines exhibited earliness in days to flower as well as for maturity. *The per se* performance of parents as well as hybrids in all the environments are presented in Tables 4.2 - 4.11 for all the characters studied.

The parents ICPA 2043, TV 1, PHULE T-00-1-25-1 and VIPULA and the hybrids ICPA 2043 x HPL 24-63, ICPA 2043 x ICP-3475, ICPA 2043 x BSMR 736 were significantly superior for early flowering as compared to controls BSMR 736 and ICPH 2671. The parents ICPA 2043, ICP 10934, ICP 13991 and hybrids ICPA 2043 x BSMR 2, ICPA 2043 x ICP 10934, and ICPA 2043 x PHULE T-00-4-11-6-2 were significantly superior for days to maturity as compared to controls. The parents BSMR 175, ICP 3525 and ICP 3374 and hybrids ICPA 2047 x TV 1, ICPA 2047 x AKT 9913, and ICPA 2047 x PHULE T-00-5-7-4-1 were superior for plant height than the controls. The three parents ICP 10934, AKT 9915 and ICP 10650 and five hybrids ICPA 2043 x TV 1, ICPA 2047 x ICPL 20106, ICPA 2092 x ICP 3525, ICPA 2092 x BSMR 2 and ICPA 2092 x ICP 3514 recorded greater number of primary branches plant^{-1} over both controls. The parents ICP 11376, HPL 24-63, AKT 8811, and ICP 3514 and hybrids ICPA 2092 x ICP 3407, four hybrids ICPA 2043 x ICP 3514, ICPA 2043 x ICP 3374, ICPA 2043 x ICPL 20106, and ICPA 2047 x ICP 3374 were with first amongst parents and cross combinations showed higher number of secondary branches plant^{-1} over both controls. The parents ICP 3525, TV 1 and HPL 24-63 and the hybrids ICPA 2092 x ICPL 20106, ICPA 2092 x ICP 10934, ICPA 2047 x HPL 24-63 and ICPA 2092 x ICP 11376 borned higher number of pods plant^{-1} as compared to controls. The parents ICPA 2047, ICP 3525 and hybrids ICPA 2043

x ICPL 12749 and ICPA 2047 x ICPL 20106 borned higher number of seeds pod^{-1} than controls BSMR 736 and ICPH 2671. The parents ICP 3525, HPL 24-63 and TV 1 and the hybrids ICPA 2047 x HPL 24-63, ICPA 2092 x ICP 10934 and ICPA 2043 x ICP 3374 were superior for pod weight than controls. The parents PHULE T-00-3-1, AKT 00-12-6-4 and ICP 3514 and hybrids ICPA 2043 x ICP 3525, ICPA 2043 x BSMR 164 and ICPA 2043 x ICP 11376 were superior for 100-seed weight than controls. Four male parents BSMR 846, BSMR 164, HPL 24-63, and PHULE T-00-1-25-1 and seven hybrids ICPA 2043 x ICP 3525, ICPA 2043 x BSMR 175, ICPA 2043 x BSMR 203, ICPA 2043 x ICP 10934, ICPA 2043 x ICP 3407, ICPA 2043 x TV 1, and ICPA 2092 x ICP 3514 showed 100 % pollen fertility across the four locations. For grain yield plant^{-1} the parents ICP 3525, TV 1, HPL 24-63, ICP 13991, BSMR 198, ICP 3963, PHULE T-00-4-11-6-2 and ICP 11376 at par with the controls BSMR 736 and ICPH 2671; whereas hybrids ICPA 2043 x ICP 3374, ICPA 2047 x HPL 24-63, ICPA 2092 x ICPL 20106, ICPA 2092 x ICP 10934 and ICPA 2043 x ICPL 20106 were superior than controls.

Conclusion:

The success of any breeding programme depends on the choice of parents and a clear knowledge of genetic system of the traits. Combining ability is one of the most effective tools for selecting the appropriate parents for hybridization. Almost all the breeding methods for pigeonpea improvement are designated to exploit additive genetic variance to develop high yielding pure line varieties. As pigeonpea is an often cross pollinated crop and it has a substantial amount of non-additive genetic variance, hybrid vigour for yield can be profitably exploited through heterosis breeding, which is possible by using male-sterility systems. Similarly, it also helps in choosing suitable cross combination for recombination breeding. The magnitude of heterosis provides a basis for genetic diversity for developing superior combinations. Hence the main objective of this investigation was to identify good general and specific combiners and heterotic cross combinations for yield and its component in pigeonpea.

5.2 Heterosis

The 20th century will be recorded in the history of crop improvement programme for the development of superior varieties and hybrids, which has revolutionized the productivity making India self-reliance. The quantum jump in yield potential observed in some crops in the past was primarily due to commercial exploitation of a single genetic phenomenon, commercially known as "hybrid vigour" or "heterosis" (Saxena and Sharma, 1990). It has become amply clear that most self-pollinated crops also exhibit similar extent of heterosis as in case of hybrid pollinated crops. In pulses, for exploitation of heterosis or hybrid vigour either we have to use male sterility or in a normal bisexual flower, hybrids be made. In pigeonpea genetic male-sterility (GMS) was already exploited to produce hybrids. Several heterotic cross combinations were found in GMS-based hybrids. The range of commercial heterosis (standard heterosis) was 20 – 100%. This showed the potential of hybrid breeding technology in leguminous crop like pigeonpea. The development of CMS lines in pigeonpea made it easy to develop hybrids and exploit the hybrid vigour commercially. Heterosis over standard check is important than other types of heterosis, however, in some cases heterobeltiosis is also preferred. The primary data of experimental pigeonpea hybrids evaluated at ICRISAT and various ICAR centers showed that now the technology for exploiting heterosis at commercial level is available, which could be exploited effectively to breed heterotic hybrids (Saxena *et al*., 2006b).

In the present experiment, heterosis is reported over standard controls BSMR 736 and ICPH 2671 for individual locations data is presented in tables 4.12 to 4.15. Several workers reported substantial heterosis for grain yield and other economic characters. Solomon *et al.* (1957) were the first to report hybrid vigour in pigeonpea in 10 inter-varietal hybrids.

5.2.1 Grain yield plant^{-1} (g)

For yield, heterosis of 40% and above over the standard control is considered significant from practical point of view in most of the crop. In the present study, the heterosis over standard control BSMR 736 and ICPH 2671 was estimated in all the four locations. Fairly conspicuous vigour was noticeable in few hybrids which represents the best combinations of the two parents. The higher heterotic estimates were observed in the hybrids involving female parent ICPA 2092, followed by ICPA 2047 and ICPA 2043.

In the present study, the per cent heterosis over BSMR 736 ranged from -50.81 to 79.07% at Patancheru, from -58.54 to 66.34% at Parbhani, from -72.33 to 139.9% at Latur, and from -71.23 to 83.88% at Badnapur. Likewise, the per cent heterosis over ICPH 2671 ranged from -54.87 to 64.31% at Patancheru, from -63.09 to 48.09% at Parbhani, from -52.75 to 76.78% at Latur and from -73.71 to 68.04% at Badnapur. The standard heterosis calculated over both the controls BSMR 736 and ICPH 2671 showed that, 24 hybrids at Patancheru and Parbhani, 26 at Latur and 15 at Badnapur recorded significant and positive heterosis. At Patancheru, Latur and Badnapur the highly significant and positive heterosis were registered by hybrids ICPA 2047 x HPL 24-63, ICPA 2043 x ICP 3374 and ICPA 2092 x ICP 10934. At Parbhani, hybrids ICPA 2092 x ICPL 20106, ICPA 2043 x ICPL 20106 and ICPA 2043 x ICP 3374 recorded the highly significant and positive heterosis over control ICPH 2671.

From the studies of heterosis, it was observed that the parents who had high *per se* performance produced higher heterotic values for grain yield plant^{-1} in hybrids ICPA 2043 x ICP 3374, ICPA 2047 x HPL 24-63 and ICPA 2092 x ICPL 20106. The parents ICP 3374, HPL 24-63, ICPL 20106 were found to be the most promising and need to be assessed for their utility in combination with existing promising male sterile lines. The *per se* performance and specific combining ability effects of above mentioned hybrids were matching with the heterosis. The parental lines involved in these heterotic cross combinations were from medium to high *per se* performance.

The hybrids with high heterotic effects for yield also showed good specific combining ability for one or the other related characters. It was observed in the hybrid ICPA 2047 x HPL 24-63 for plant height, number of secondary branches plant^{-1}, number of pods plant^{-1}, pod weight (g) and pollen fertility (%) on pooled

data. In harmony the hybrid ICPA 2092 x ICPL 20106 showed high heterosis and good specific combining ability for the number of pods plant^{-1}, pod weight (g) and pollen fertility (%). On the contrary, the hybrid ICPA 2043 x ICP 3374 had high heterosis and good specific combining ability with characters like primary and secondary branches plant^{-1}, number of pods plant^{-1}, pod weight and 100-seed weight. Further perusal of the data revealed that the hybrids expressed high SCA effects irrespective of the GCA effects of the parents, indicating involvement of dominance and epistatic gene effects in inheritance of traits. Better hybrids having poor x good, poor x average and average x good general combiners as parents indicated dominance x additive (epistasis) type of gene action (Jinks, 1954). Such hybrids could be utilized in the production of high yielding recombinant homozygous lines following diallel selective mating design or recurrent selection. Similar results in pigeonpea previously observed by Yadav *et al*. (2008). Additive and additive x additive (epistasis) gene effects are important in pigeonpea for breeding stable lines since these components of genetic variation are fixable. Most of the promising hybrids for different traits involved at least one good general combiner as parent. These hybrids were likely to throw desirable transgressive segregants in advance generations and may be utilized for selecting better and high yielding genotypes.

The heterosis over standard controls were in consonance with the findings of Solomon *et al.* (1957), Singh (1971), Sharma *et al.* (1973 a), Reddy (1976), Saxena (1977), Chaudhari (1979), Jain and Saxena (1990), Narladkar and Khapre (1996), Verulkar and Singh (1997), Hooda *et al.* (1999), Pandey (1999), Pandey and Singh (2002) and Yadav and Singh (2004). Sekhar *et al.* (2004) reported heterosis of 40% over standard check in pigeonpea. Saxena *et al*. (2006) and Wanjari *et al*. (2007) reported the heterosis over standard check in positive direction. Kandalkar (2007) reported significant highest positive heterosis of 155.7% over standard check for grain yield in CMS based hybrids of pigeonpea. Dheva *et al*. (2008 a,and b) observed the desirable range of heterosis 0.72 to 57.35% and 5.12 to 28.20% over the standard check for grain yield plant^{-1}. CGMS based hybrids in extra short, short and medium maturity groups have recorded grain yield superiority of 61% over the best control cultivar in different locations across India (Saxena, 2008). Dheva *et al.* (2009) reported heterosis in positive

direction from 0.97% to 59.68% over the check for grain yield plant^{-1}. Kumar *et al.* (2009) observed the highest significant and positive heterosis of 51.38% for the hybrid LRG-30 x ICP-8863 over standard check for seed yield plant^{-1}. Chandirakala *et al*. (2010) and Shoba and Balan (2010) reported the significant and positive standard heterosis for yield plant^{-1} in their studies. Saxena and Nadarajan (2010) reported 30% yield advantage of pigeonpe**a** hybrid ICPH 2671 over local check varieties in on-farm trials conducted in five states of India.

5.2.2 Days to 50 % flowering

Indeterminate growth and early flowering are considered desirable trait in pigeonpea. The heterosis for days to flower over BSMR 736 ranged from -5.98 to 10.68% at Patancheru; from -0.37 to 12.92% at Parbhani; from -7.21 to 17.12% at Latur; and from -0.85 to 15.81% at Badnapur. In general more heterosis for early flowering was observed over control BSMR 736 at Latur, followed by at Patancheru. At Parbhani and Badnapur, none of the hybrids showed significant and negative heterosis over the control BSMR 736. The significant and negative heterosis for days to flower was reported earlier by Chaudhari (1979), Singh *et al*. (1989) and Pandey and Singh (2002). The significant and negative heterosis in hybrids for days to 50% flower on all the three bases of estimation in pigeonpea reported by Hooda *et al*. (1999), Khorgade *et al*. (2000), Kalaimagal and Ravikesavan (2003), Patel and Tikka (2008), Chandirakala *et al*. (2010) and Shoba and Balan (2010). The hybrids having negative significant heterosis does have both parents with significant and negative general combining ability effects. Wankhade *et al*. (2005) reported significant and negative heterosis for days to 50% flowering in the hybrids based on genetic male-sterility system where as Kandalkar (2007) reported negative heterosis in CMS based hybrids showing preference for the early flowering hybrids.

5.2.3 Days to maturity

In the present study, the heterosis over early maturing control BSMR 736 was estimated at all the four locations. The per cent heterosis over BSMR 736 ranged from -2.30 to 6.03% at Patancheru; -8.67 to 11.27% at Parbhani; -4.55 to 6.97% at Latur; and -8.01 to 5.52% at Badnapur. In general, high heterotic estimates for

days to maturity were observed in the crosses involving female parent ICPA 2043, followed by ICPA 2047 and ICPA 2092. Hybrid ICPA 2043 x BSMR 2 recorded highest significant and negative heterosis for maturity at Patancheru as well as Parbhani. At Latur, two hybrids ICPA 2043 x ICP 10934 and ICPA 2047 x BSMR 846 exhibited the highest negative heterosis for maturity over the control BSMR 736. At Badnapur, cross ICPA 2043 x AKT 00-12-6-4 recorded significant and negative heterosis over the control BSMR 736. The cross ICPA 2043 x BSMR 2 followed by ICPA 2047 x BSMR 846 and ICPA 2043 x ICP 10934 were among the top ranking crosses which showed superiority over the control BSMR 736 for maturity. It was observed that, early maturing crosses included both early maturing parents. The high heterosis exhibiting hybrids also showed GCA and SCA effects in negative direction for maturity. The high heterosis of ICPA 2043 x BSMR 2 for days to maturity also showed high heterosis, negative GCA effects of parents and negative SCA effect of hybrid for 100-seed weight and pollen fertility. In pigeonpea the significant and negative heterosis for days to maturity was reported earlier by Chaudhari (1979) and Pandey and Singh (2002). The similar results for early maturing hybrids having at least one or both early maturing parents were reported by Phad (2003) and Kandalkar (2007). Hooda *et al.,* (1999), Khorgade *et al.,* (2000), Kalaimagal and Ravikesavan (2003), Patel and Tikka (2008), Chandirakala *et al.,* (2010) and Shoba and Balan (2010) registered significant and negative heterosis in crosses on all the three bases of estimation in their studies.

5.2.4 Plant height (cm)

It was observed from the present data that out of 102 hybrids generated, 59 exhibited significant hybrid vigour over the control BSMR 736, and 56 over the control ICPH 2671. The overall range of variation in the percentage increase in height of the various F_1 hybrids over that of the taller control BSMR 736 had been from -15.85 to 27.01% at Patancheru; -9.89 to 31.91% at Parbhani; -29.96 to 28.76% at Latur; and from -19.64 to 34.29% at Badnapur. Similarly, the percentage increase in height of the various F_1 hybrids over that of the taller control ICPH 2671 had been from -14.18 to 29.53% at Patancheru, from -15.30 to 24.00% at Parbhani, from -33.02 to 23.13% at Latur and from -23.99 to 27.03% at

Badnapur. The maximum increase being noticed in hybrid ICPA 2047 x TV 1 followed by ICPA 2047 x AKT 9913 and ICPA 2047 x PHULE T-00-5-7-4-1. The hybrid ICPA 2047 x TV 1 showed positive SCA effects for both the parents. The same hybrid showed positive SCA effects for secondary branches plant^{-1}, seeds pod^{-1}, pod weight and pollen fertility (%). Hybrid ICPA 2047 x AKT 9913 had the desirable heterosis for 100-seed weight and number of secondary branches plant^{-1}. The parents of the hybrid ICPA 2047 x AKT 9913 showed good GCA effects and desirable SCA effects for days to maturity. The same hybrid also showed good SCA effects for primary and secondary branches plant^{-1}. The hybrid ICPA 2047 x PHULE T-00-5-7-4-1 had good GCA effects for both the parents and desirable SCA effects for plant height. This hybrid also had the desirable SCA effects for number of pods plant^{-1}, seeds pod^{-1}, pod weight, 100-seed weight and grain yield plant^{-1}. The significant and positive heterosis for plant height has been reported by several workers including Solomon *et al*. (1957), Singh (1971), Sharma *et al*. (1973a), Veeraswamy *et al*. (1973), Chaudhari (1979) and Jain and Saxena (1990). Most of the hybrids, particularly those with high standard heterosis also had the best F_1 *per se* performance and the parents of these hybrids were good general combiners with high *per se* performance. Pandey and Singh (2002) reported negative standard heterosis for plant height in pigeonpea. As indeterminate growth habit is preferred over determinate, the plant height signifies its importance in yield. Significant and positive heterosis was reported by Wankhade *et al*. (2005) for plant height. As there is positive correlation between plant height and number of branches plant^{-1} (Phad, 2003), it is desirable to have hybrids with higher plant height. Pandey (2004) and Chandirakala *et al*. (2010) reported significant and negative heterosis for plant height on all the three bases of estimation.

5.2.5 Number of primary branches plant^{-1}

The number of branches favorably contributed to increasing the yield of the hybrid. At Patancheru, heterosis was estimated over the control BSMR 736 while at Parbhani, Latur and Badnapur heterosis was estimated over the control ICPH 2671. Hybrids, ICPA 2047 x ICPL 20106 (84.17%), ICPA 2043 x HPL 24-63 (72.86%), ICPA 2092 x BDB 2001-6 (37.33%) and ICPA 2047 x AKT 9915

(17.31%) registered the highly significant and positive heterosis over the control ICPH 2671 at Patancheru, Latur, Parbhani and Badnapur respectively. The hybrid ICPA 2047 X ICPL 20106 showed significant and positive heterosis for number of secondary branches plant^{-1}, plant height, pods plant^{-1}, pod weight, 100-seed weight and grain yield plant^{-1} at all the four locations. These results are in agreement with author Solomon *et al.* (1957), Gupta *et al*. (1978), Chaudhari (1979), Batta *et al.* (1986), Lakhan *et al.* (1986), Patel *et al*. (1992), Narladkar and Khapre (1996), Pandey and Singh (2002) and Wankhade *et al.* (2005). They also showed non-additive type of gene action for primary branches plant^{-1}. Singh *et al*. (1989) reported that the hybrids which showed heterosis for primary branches also had heterosis for pods plant^{-1} and seed yield. Narladkar and Khapre (1996) and Pandey and Singh (2002) also reported significant and positive heterosis for number of primary branches plant^{-1}. Aher *et al*. (2006) reported the range of heterosis over mid parent and better parent for number of primary branches plant^{-1} from -1.10 to 3.15% and from -2.9% to 2.4% respectively. They revealed that the presence of significant heterosis over better parent in hybrid BDN-2 x BDN-2010 may be due to presence of dominance and additive x additive gene effects. Similar findings were also reported in pigeonpea by Patel and Tikka (2008) for number of branches plant^{-1}. Chandirakala *et al*. (2010) reported the range of heterosis from -23.69 to 29.33% over mid parent, from -42.83 to 28.87% over better parent and from -24.89 to 47.49% over standard check. The parents of heterotic hybrids had high *per se* performance as well as high general combining ability for number of primary branches.

5.2.6 Number of secondary branches plant^{-1}

The highest number of heterotic hybrids observed at Latur followed by at Parbhani, Badnapur and Patancheru. At Patancheru, the highly significant and positive heterosis exhibited by hybrid ICPA 2043 x ICP 3514 and ICPA 2092 x ICP 3514 over the control ICPH 2671. Similarly, at Parbhani, ICPA 2047 x ICPL 20106, at Latur, ICPA 2047 x BWR 154, and at Badnapur, ICPA 2043 x ICP 3525 registered significant and positive heterosis over the control ICPH 2671. Also the parents of heterotic hybrids ICPA 2092 x ICP 3407, ICPA 2043 x ICP 3374 and ICPA 2043 x ICPL 20106 had high x low, high x medium and high x medium *per*

se performance respectively. Veeraswamy *et al.* (1973), Chaudhari (1979), Pandey and Singh (2002), and Phad (2003) observed positive heterosis for number of secondary branches plant^{-1}.

5.2.7 Number of pods plant^{-1}

Most of the hybrids proved to be heterotic for the number of pods plant^{-1}. The high heterosis registered by hybrids ICPA 2047 x HPL 24-63 at Patancheru and Badnapur; ICPA 2092 x ICPL 20106 at Parbhani and Latur. Most of the parents among the heterotic cross combinations had high *per se* performance and good general combining ability effects. It was observed that the hybrids which showed high heterosis also showed SCA effects in desirable direction. These observations are in agreement with Singh (1971), Veeraswamy *et al.* (1973), Chaudhari (1979), Patel and Patel (1992), Pandey and Singh (2002) and Kandalkar (2007). Tutesa *et al*. (1992) reported the highest heterosis of 116.2% in hybrid H73-20 x EE-76 x UPAS-120 for pods plant^{-1}. Narladkar and Khapre (1996) reported that heterosis for grain yield was due to total number of pods plant^{-1}. Wanjari *et al*. (2007) reported that positive heterosis could be useful for further exploitation. Patel and Tikka (2008) and Chandirakala *et al*. (2010) showed the heterosis for this trait ranged from 3.34 to 48.86%, -3.88 to 32.84% and 5.41 to 98.26% over mid, better and standard parent respectively. Hybrid MS CO 5 x ICPL 88009 showed the highest significant and positive heterosis of 42.06, 25.45 and 98.26% on all the three bases of estimation viz., mid parent, better parent and standard parent respectively.

5.2.8 Pod weight (g)

The expression of heterotic effects for pod weight revealed that 24 hybrids had significant and positive standard heterosis over ICPH 2671 at Patancheru; 29 at Parbhani; 33 hybrids at Latur and Badnapur. The hybrids ICPA 2047 x HPL 24-63, ICPA 2092 x ICP 10934 and ICPA 2043 x ICP 3374 exhibited significant and positive heterosis. It was also observed that the hybrids with more pod weight revealed positive heterosis for pod weight which directly correlated with grain yield plant^{-1}. Dalvi (2007) observed positive heterosis for pod weight in pigeonpea.

5.2.9 Seeds pod^{-1}

At Patancheru, none of the hybrids were showed significant and positive heteosis over both the controls, whereas three hybrids at Parbhani, seven at Latur, and eight at Badnapur recorded significant and negative heterosis for seeds pod^{-1}. The hybrids ICPA 2043 x BSMR 846, ICPA 2092 x PHULE T-00-1-25-1 and ICPA 2043 x ICP 3525 showed negative heterosis at Patancheru, Parbhani, Latur and Badnapur. Whereas, hybrid ICPA 2047 x AKT 8811 and ICPA 2092 x ICP 3963 showed negative heterosis at Patancheru, Latur and Parbhani. Sinha *et al*. (1994) and Patel (1990) reported very less heterosis for seeds pod^{-1} in pigeonpea. Patel and Patel (1992) revealed that heterotic response for seeds pod^{-1} was marginal with negative effect. Phad (2003) reported seeds pod^{-1} as an important character, which is positively correlated with grain yield.

5.2.10 100-Seed weight (g)

It was observed that hybrid ICPA 2043 x BSMR 2, ICPA 2092 x BSMR 736, and ICPA 2043 x ICP 11376 had high *per se* performance for 100-seed weight. The same hybrid also showed heterosis and SCA effects in desirable direction for days to maturity, pollen fertility and grain yield plant^{-1}. Chaudhari (1979), Reddy *et al*. (1979), Manivel *et al*. (1999), Wankhade *et al*. (2005), Kandalkar (2007) and Dalvi (2007) recorded positive standard heterosis in pigeonpea for 100-seed weight. Sameer Kumar *et al*. (2009) estimated heterosis on three bases i.e. mid parent, better parent and standard check. They reported highest heterosis of 10.11% over standard check.

5.2.11 Pollen fertility (%)

At Patancheru and Badnapur none of the hybrids registered 100% pollen fertility; while, at Parbhani 36 hybrids and at Latur 41 hybrids showed significant and positive heterosis over the control ICPH 2671. The positive heterotic hybrids identified over all the four locations were ICPA 2043 x ICP 3525, ICPA 2043 x BSMR 175, ICPA 2043 x BSMR 2, ICPA 2043 x ICP 10934, ICPA 2043 x ICP 3407, ICPA 2043 x TV1 and ICPA 2092 x ICP 3514. The hybrids which showed high heterosis were involved parents with high *per se* performance for pollen

fertility (%). The hybrid ICPA 2092 x ICP 3514 recorded significant and positive heterosis for plant height, number of primary and secondary branches plant^{-1}, number of pods plant^{-1}, pod weight, and grain yield plant^{-1}. Likewise the hybrid ICPA 2043 x ICP 10934 showed significant and positive heterosis for days to maturity, number of secondary branches plant^{-1}, number of pods plant^{-1}, pod weight, 100-seed weight and grain yield plant^{-1}. It was observed that the hybrids which showed high heterosis for pollen fertility were also exhibited significant and positive SCA effects.

5.3 Combining ability analysis

Genetic enhancement in the crops is a continuous process. In order to have breakthrough for yield, quality and other important characters like disease resistance, the breeders look for the variability or create the variability. The progress of genetic improvement depends on the type of parental lines selected, the inheritance of characters and the approach of handling the breeding materials.

In a systematic breeding program, the choice of suitable parents for hybridization depends upon the general combining ability (GCA) of the parents. General combining ability is the average performance of parents in several cross combination and is important for the varietal developmental program; whereas, specific combining ability (SCA) gives an idea for the performance of a specific hybrid exhibiting the dominance and epistasis. The specific combining ability is the deviation from the performance predicted on the basis of GCA (Allard, 1960). According to Sprague and Tatum (1942) the specific combining ability is controlled by non-additive gene action. The SCA effect is an important criterion for the evaluation of hybrids. In the present investigation the analysis of variance for combining ability in the F_1 generation over four environments and over pooled environment is presented in Tables 4.16 - 4.20 and estimates of general and specific combining ability effects in Tables 4.21 - 4.30.

5.3.1 Analysis of variance

The analysis of variance (ANOVA) for line × tester mating scheme indicated significant differences among the parents and hybrids for all the characters under study. The significant variances for parents versus hybrids

indicated occurrence of substantial heterotic response in almost all the characters over all.

5.3.2 Nature of gene action

The phenomenon of heterosis has been extensively exploited in a number of cross-pollinated crops, and it evolved around its exploitation in developing open-pollinated synthetics, composites or hybrid varieties. Basically, the manifestation and expression of hybrid vigour is a complex phenomenon and various theories have been proposed to understand it at genetic, molecular, biochemical, physiological, developmental and gene regulation levels, but still the issue remains unresolved. Since dominant genes in the population have evolutionary advantage, the heterosis was initially considered a discernible phenomenon of the hybrid-pollinated crops but later the commercial exploitation of hybrid vigour in cereal and vegetable crops established its utility in the self-pollinating crops also. Sharma and Dwivedi (1995) argued that since over-dominance and dominance gene actions are not very common for yield in both self as well as cross-pollinated crops, the additive gene action and the additive × additive interallelic and intergenomic interactions play an important role in the expression of hybrid vigour. The pollination system of a crop therefore, possesses no restriction in the manifestation of heterosis. From practical viewpoint, however, it is necessary to identify correct cross combinations. The likelihood of obtaining such elite combinations is relatively high in the cross-pollinated crops and low in the self-pollinated crops because the former can carry a considerable hidden genetic load of undesirable recessive genes, while in the self-pollinated groups such traits stabilize rapidly. In conclusion, the dispersion of completely or incompletely dominant genes and over-dominance along with some contribution of non-allelic interactions has been considered to be the prime factors responsible for the expression of heterosis. In pigeonpea, Saxena and Sharma (1990) observed the predominance of additive and non-additive gene actions for yield and yield components.

5.3.2.1 Yield and yield components

The variances due to SCA were higher than GCA variances for all the characters in all the environments indicating the predominance of dominant and non-additive gene action. This was supported by the ratio of 6^2GCA to 6^2SCA. Predominance of non-additive gene action for days to 50% flower was also reported by Jaymala and Rathanaswamy (2000), Pandey and Singh (2002) and Jahagirdar (2003); for days to maturity by Reddy *et al.* (1979), Singh *et al.* (1983), Patel *et al* .(1987), Jaymala and Rathanaswamy (2000), and Pandey and Singh (2002); for plant height, Pandey (1972), Reddy *et al.* (1979), Pandey (1999), and Pandey and Singh (2002). Pandey (1999) and Singh and Srivastava (2001) for number of primary branches; Marekar (1982), Pandey (1999) and Dalvi (2007) for number of secondary branches, Jadhav (1983), Pandey (1999), Singh and Srivastastava (2001), and Jahagirdar (2003) for number of pods per plant; Reddy *et al* .(1979), Kutwal (1980), Sidhu *et al* .(1996), Jaymala and Rathnaswamy (2000) and Jahagirdar (2003) for grain yield per plant. Non-additive gene action was reported by Kapur (1977), Dahiya and Brar (1977), Dahiya and Satija (1978), Rao and Nagur (1979), Reddy *et al* .(1979), Kutwal (1980), Sidhu and Sandhu (1981), Sidhu *et al* .(1981), Marekar (1982), Singh *et al*. (1983), Malik *et al.* (1985), Patel (1985), Patel *et al* .(1987), Patel *et al* .(1992), Patel and Patel (1992), Khapre *et al.* (1993), Aghav *et al.* (1998), Srinivas *et al.* (1998), Pandey (1999), Vanniarajan *et al.* (1999), Jahagirdar (2003) and Phad *et al.* (2007), Dalvi (2007), Gupta *et al.* (2008) and Yadav *et al.* (2008) for grain yield.

5.3.3 Estimates of general combining ability effects over the environments

The general combining ability (GCA) effects give an idea about the breeding behavior of the parental lines and helps in screening of the lines for varietal improvement programme. The utility of this technique in pigeonpea has been widely demonstrated by several workers. The results are discussed as below.

5.3.3.1 Grain yield plant^{-1} (g)

Grain yield plant^{-1} is the effect of the component characters related to it. The potentiality of line to be used as a parent in hybridization, or in a cross to be used as a commercial hybrid may be judged by comparing the *per se* performance of

the parents, the F_1 value and the combining ability effects. In the present study, the parental lines ICPA 2092 among females and ICP 3374, ICPL 20106 and ICP 10934 among males had significant and high positive GCA effects for seed yield plant^{-1}. These parents were found to be good general combiners on pooled mean basis. Hence these parents appear to hold great promise for breeding work. The parents having better general combining ability for yield also showed better general combining ability for one or the other related characters like days to maturity, number of secondary branches, number of pods plant^{-1}, pod weight (g) and pollen fertility (%) on pooled data basis. In general, the parental lines having early in days to maturity, higher number of secondary branches, high number of pods plant^{-1}, greater pod weight (g) and more pollen fertility (%) showed desirable general combining ability and high *per se* performance for grain yield plant^{-1} as compared to the control. Similar findings have been reported by Venkateswarlu and Singh (1982), Patel *et al.* (1992), Narladkar and Khapre (1995), Aghav *et al.* (1998), Jahagirdar (2003), Dalvi (2007), Yadav *et al* .(2008), Phad *et al. (2009)* and Sameer Kumar *et al.* (2009) in pigeonpea.

5.3.3.2 Days to 50 % flowering

Early and prolonged flowering is desirable to have a wide span of pod development and harvesting. The GCA effects calculated over pooled data revealed that, 10 parents had significant and negative GCA effects. ICP 3475 (-3.877), BSMR 736 (-3.502), and AKT 8811 (-3.211) registered significant and negative GCA effects indicating their good general combining ability for days to flower. Breeding of early genotypes has been emphasized in pigeonpea by Singh (1972), Hazarika *et al*. (1988), Srinivas *et al*. (1998), Singh and Srivastava (2001), Pandey and Singh (2002), Phad (2003), Baskaran and Muthiah (2007) and Yadav *et al*. (2008). Jahagirdar (2001) reported the good general combining ability of the parents ICPL 87 and TV 1 for days to flower. Phad *et al*. (2007) observed the highest significant and negative GCA effects in parent BSMR 198 for days to flower in pigeonpea. Yadav *et al*. (2008) observed parents GT 10 and GT 101 as good general combiner for days to 50% flowering. Sameer Kumar *et al*. (2009) observed good general combining ability of parental lines ICPL 85034, LRG 38

and ICP 8863 for days to flower in pigeonpea. Parents ICPL-87 and BSMR 736 were good general combiners for earliness was reported by Vaghela *et al*. (2009).

5.3.3.3 Days to maturity

The parents ICPA 2043, HPL 24-63 and PHULE T-00-4-11-6-2 were good general combiners for earliness on pooled data analysis. It was observed that parents who showed high *per se* performance also had high negative GCA effects. The GCA effects of parents were correlated with their heterosis and SCA effects of the hybrids. Similar results in pigeonpea earlier reported by Aghav *et al*, (1988), Phad (2003), Dalvi (2007), and Sameer Kumar *et al.,* (2009). Hazarika *et al.* (1988) observed that early and determinate type were best combiners for maturity but are poor yielder in pigeonpea. Phad *et al.,* (2007) observed the parental line BSMR 198 for highest significant and negative GCA effects for days to maturity in pigeonpea. Yadav *et al.* (2008) observed the parents GT 10 and GT 101 as good general combiner for days to maturity in pigeonpea. Sameer Kumar *et al.,* (2009) observed the parental lines ICPL 85034, LRG 38 and ICP 8863 exhibited good general combining ability for days to maturity in pigeonpea.

5.3.3.4 Plant height (cm)

The parents ICPA 2047, AKT 9913, PHULE T-00-1-25-1, and TV 1 showed desirable significant and positive GCA effects over pooled data. Positive GCA effects were found desirable as the crop habit is indeterminate and the grain yields were related to the growth habit. Similar results in pigeonpea were reported by Sharma *et al*. (1973a), Singh and Srivastava (2001). Phad (2003), Dalvi (2007), Yadav *et al*. (2008), Mishra *et al*. (2009) and Sameer Kumar (2009). Baskaran and Muthiah (2007) observed that the parents APK 1, CORG 9904 and ICPL 83024 exhibited negative GCA effect for plant height in pigeonpea.

5.3.3.5 Number of primary branches plant^{-1}

The canopy development depends on the number of primary and secondary branches plant^{-1} in turn it determines the yield. The parents TV 1, BDN 2001-6, BSMR 2, and ICP 3525 were good general combiners and possessed favorable genetic architecture for number of primary branches plant^{-1}. Similar results were

reported by Patel *et al.* (1992), Ghodke *et al.* (1995), Jahagirdar (2003), Phad (2003), Dalvi (2007), Yadav *et al.* (2008), Mishra *et al.* (2009) and Sameer Kumar *et al*. (2009). The GCA effects of parents TV 1, BDN 2001-6, BSMR 2, and ICP 3525 were co-related with the *per se* performance. Reddy (1976) and Chaudhari (1979) reported the similar results in pigeonpea. Mehetre *et al.* (1988), Narladkar and Khapre (1997) and Phad *et al*. (2007) found that the high GCA effects of parents were associated with high *per se* performance. Yadav *et al*. (2008) reported that the parents GT 100 and GT 101 exhibited significant desirable GCA effects for number of primary branches plant^{-1}.

5.3.3.6 Number of secondary branches plant^{-1}

The pooled data showed that ICP 3374 had highest significant and positive GCA effect (4.556), followed by ICP 3514 (2.935) and ICPL 20106 (2.756). It was observed that the parents having high *per se* performance also showed high GCA effects. Patel *et al.* (1992), Ghodke *et al.* (1995), Pandey *et al.* (1998), Pandey and Singh (2002), Jahagirdar (2003), Yadav *et al.* (2008) and Mishra *et al.* (2009) also reported similar results for good general combining ability for secondary branches plant^{-1} in their studies.

5.3.3.7 Number of pods plant^{-1}

This character is important in determining grain yield and productivity per unit area. The parental lines ICPL 20106, ICP 10934 and ICP 3374 recorded desirable significant and positive GCA effect on pooled basis for number of pods plant^{-1}. It was observed that the parents which showed high GCA effects were associated with medium to high *per se* performance. Venkateswarlu and Singh (1982), Patel *et al.* (1992), Omanga *et al.* (1992) Ghodke *et al.* (1995), Narladkar and Khapre (1995), Pandey *et al.* (1998), Dalvi (2007) and Yadav *et al*. (2008) reported consistency of parental lines for GCA effects. Sinha *et al.* (1994) found that parents AS 3 and Sel 7 had good general combining ability for more pod number as well as more grain yield. These parents appeared promising for use in breeding programme for high seed yield. Jahagirdar (2003) reported that parental line BSMR 175, AKT 8811 and BSMR 736 as good general combiner for number of pods plant^{-1}.

5.3.3.8 Pod weight (g)

The pooled GCA effects showed that 17 parents had significant and positive GCA effects. ICP 3374 recorded the highest GCA effects (69.420), followed by ICP 3374 (64.672) and ICP 10934 (57.252). It was found that the parents showing significant and positive GCA effects were also having medium to high *per se* performance values for the respective traits in most of the cases. Dalvi (2007) observed parents ICPL 87119, ICP 12320, HPL 24-63 and ICPA 2039 were the parents showing significant and positive GCA effects for pod weight in pigeonpea.

5.3.3.9 Seeds pod^{-1}

The estimates of GCA effects over pooled data analysis revealed that 11 parents exhibited significant and positive GCA effects. The parents ICP 3374 recorded high GCA effect (0.264), followed by BDN 2001-6 (0.239), and ICP 3475 (0.228). Omanga *et al*. (1992) observed that MS Prabhat (DT) among female parent and C 11 among male parents had good general combining ability for seeds pod^{-1}. Sinha *et al*. (1994) found good general combining ability of female parent P 1176-53 for seeds pod^{-1}. Phad (2003) reported ICPL 87119 as better parent with desirable general combining ability for seeds pod^{-1}. ICP 12320 and ICP 11376 were two parents showing positive GCA effects as compared with other parents Dalvi (2007). The good general combining ability of parents ICPL 87 and ICPL 871119 for seeds pod^{-1} were reported by Vaghela *et al*. (2009).

5.3.3.10 100-seed weight (g)

The pooled GCA effects showed that the male parents BSMR 175 (0.929) recorded highest, significant and positive GCA effect, followed by ICPL 12749 (0.798) and AKT 9913 (0.639). Singh and Srivastava (2001) and Dalvi (2007) reported that good general combiners for 100-seed weight were the parents of the high heterotic hybrids. Sameer Kumar *et al*. (2009) reported good general combining ability of parents ICP 8863 and ICPL 87119 for 100-seed weight. The good general combining ability of parents ICPL 87, ICPL 87119, GT-1 for 100-seed weight in pigeonpea was reported by Vaghela *et al*. (2009).

5.3.3.11 Pollen fertility (%)

At Patancheru, the highest significant and positive GCA effects for pollen fertility were recorded by parents TV 1 followed by AKT 8811, and ICPL 20106. Similarly at Parbhani, BSMR 2, at Latur ICP 10650, and at Badnapur BWR 154 showed significant and positive GCA effects. The analysis of pooled data showed that parents TV1 recorded the high, significant and positive GCA effect followed by AKT 8811, and BSMR 846.

5.3.4 Specific combining ability (SCA) effects

In hybrid breeding program specific combining ability is important for specific cross combinations for commercial exploitation or varietal development. The results on specific combining ability effects of the present investigation are discussed below.

5.3.4.1 Grain yield plant^{-1} (g)

Most of the hybrids showing significant and positive SCA effects combined with one good and one poor and such hybrids could produce desirable transgressive segregants if the additive genetic system present in the good combiner and the complementary epistatic effects in the F_1's act in the same direction to maximize the desirable plant attributes. Higher estimates of SCA effects were usually recorded in those hybrids which involved high and significant *per se* performance and heterosis. In the present study, the hybrids ICPA 2047 x HPL 24-63, ICPA 2092 x BSMR 164, and ICPA 2043 x ICP 3374 showed the highest significant and positive specific combining ability (SCA) effects on pooled data basis. The high SCA effects in hybrids were due to low x high, high x low and low x high general combiners which gave significant SCA effects thereby indicating the involvement of non-allelic interactions. Vanniarajan *et al.* (1999) reported that some of the cross combinations having parents with high x low and low x high general combining ability (GCA) effects also produced significant SCA effects. Jahgirdar (2003) reported high x low and low x low general combiners were involved in specific cross combinations. Phad *et al.* (2007) observed high specific combining ability of hybrids due to high x low, low x high, low x low general

combining ability of parents. Baskaran and Muthiah (2007) observed that the hybrid CORG 94 x ICPL 83027 had high SCA effect with high x low combinations indicating the operation of additive x dominance gene effects and hence could be used in heterosis breeding. Yadav *et al*. (2008) observed that hybrids expressed high SCA irrespective of the GCA effects of the parents, indicating involvement of dominance and epistatic gene effects in the inheritance of traits. Sameer Kumar *et al*. (2009) revealed that high SCA resulted due to high x high GCA effects of parents in majority of the hybrids.

5.3.4.2 Days to 50 % flowering

At Patancheru, 21 out 102 hybrids registered significant and negative specific combining ability (SCA) effects. Likewise, eight hybrids at Parbhani; 37 at Latur; and 32 at Badnapur registered significant and negative SCA effects. At Patancheru, ICPA 2092 x ICP 11376, ICPA 2092 x BDN 2001-6 and ICPA 2047 x ICP 3514 showed negative specific combining ability for days to flower. Similarly, at Parbhani, ICPA 2043 x BDN 2001-6 registered high, significant and negative SCA effects followed by ICPA 2092 x BDN 2001-6 and ICPA 2043 x BSMR 203. At Latur, the hybrid ICPA 2047 x ICP 3963; at Badnapur ICPA 2043 x PHULE T-00-4-11-6-2 showed high, significant and negative SCA effects. The estimates of specific combining ability over pooled data showed that out of 102 cross combinations evaluated, 22 exhibited SCA effects in desirable direction. Hybrids ICPA 2047 x PHULE T-00-4-11-6-2 (-9.194), ICPA 2043 x PHULE T-00-4-11-6-2 (-5.815), and ICPA 2092 x BDN 2001-6 (-5.241) showed negative specific combining ability effects.

There was no definite trend of GCA of the parental lines for involvement in the cross combinations. It was observed that the combinations of low × low, high × low, and low × low general combiners gave significant SCA effects on pooled analysis thereby indicating the involvement of non-allelic interactions. Patel *et al*. (1993), Singh and Srivastava (2001), Jahagirdar (2001), Phad (2003), Dalvi (2007), and Sameer Kumar *et al*. (2009) also reported the similar results for days to 50% flower. Vaniarajan *et al*. (1999) and Baskaran and Muthiah (2007) revealed that some of the cross combinations having parents with high x low and low x high GCA effects also produced significant SCA effects.

5.3.4.3 Days to maturity

The SCA effects revealed that out of 102 hybrids, 19 showed significant and positive SCA effects for maturity, while 23 exhibited significant and negative SCA effects. At Patancheru, hybrid ICPA 2047 x PHULE T-00-1-25-1 showed the highest significant and negative SCA effect. Similarly at Parbhani, ICPA 2092 x BDN 2001-6; at Latur ICPA 2047 x BSMR 846; and at Badnapur ICPA 2043 x AKT 00-12-6-4 recorded the highest significant and negative SCA effects. The estimated SCA effects on pooled data analysis revealed that 30 hybrids had significant and negative SCA effect for maturity. The hybrids ICPA 2043 x BSMR 175, ICPA 2092 x ICP 13991, and ICPA 2092 x ICP 10650 exhibited significant and negative SCA effects. Most of these hybrids also had superior *per se* performance. The cross combinations of high × low, low × high and low × low general combiners gave significant SCA effects indicating thereby the involvement of additive x dominance gene effects, and hence such lines could be used in heterosis breeding program. This was revealed that there was no definite trend of GCA of the parental lines for involvement in the cross combinations. Phad (2003), Dalvi (2007), Sameer Kumar *et al.,* (2009) also observed similar results for days to maturity. Yadav *et al.* (2008) reported that high x low and low x low GCA effects of parents gave superior SCA effects in hybrids. Vaghela *et al.* (2009) observed that the hybrids which showed negative SCA effects for early maturity also exhibited good SCA effects for grain yield plant^{-1}.

5.3.4.4 Plant height (cm)

Totally 24 hybrids recorded significant and positive SCA effects over pooled data analysis. The highly significant and positive SCA effects in hybrids were recorded by ICPA 2047 x HPL 24-63, ICPA 2092 x BSMR 2, and ICPA 2047 x ICP 13991. It was observed that the high SCA effects in above cross combination were from high x poor, low x poor and high x poor GCA effects of parents respectively. The *per se* performance of high x low, low x low and high x low combinations involved in above hybrids. Baskaran and Muthiah (2007) revealed that the high SCA effects of high x low combinations indicating the operation of additive x dominance gene effects and hence could be used in heterosis breeding in

pigeonpea. The high SCA effects were produced by high x low combination of GCA effects in all the above hybrids. Similar results were reported by Yadav *et al* (2008).

5.3.4.5 Number of primary branches plant^{-1}

On pooled data basis 31 hybrids showed significant and positive SCA effects for number of primary branches plant^{-1}. The highest significant and positive SCA effects for number of primary branches plant^{-1} registered by ICPA 2047 x ICPL 20106, ICPA 2047 x AKT 00-12-6-4, and ICPA 2092 x PHULE T-00-5-7-4-1. The high SCA effects were produced due to low x high, low x low and high x low GCA effects of the parents. It was concluded that the cross combination ICPA 2047 x ICPL 20106 was identified as the best based on the basis of *per se* performance, standard heterosis and significant SCA effects for plant height, secondary branches, pods plant^{-1}, pod weight, 100-seed weight and grain yield plant^{-1}. Vanniarajan *et al*. (1999) reported that some of the cross combinations having parents with high x low and low x high GCA effects also produced significant SCA effects. Vanirajan *et al*. (2007) reported that some of the hybrids having high SCA effects included both the parents with poor general combiners. Sameer Kumar *et al*. (2009) observed significant and positive SCA effects for primary branches plant^{-1} in pigeonpea.

5.3.4.6 Number of secondary branches plant^{-1}

The highly significant and positive SCA effects was present in ICPA 2043 x BSMR 175 (4.799), ICPA 2092 x BSMR 571 (4.723), and ICPA 2092 x PHULE T-04-1-3-1 (4.536). The high SCA effects among above all the hybrids were involved parents with high x low general combining ability. The high SCA effects of high x low combinations indicated the operation of additive x dominance gene effects and hence could be used in heterosis breeding. Baskaran and Muthiah (2007) revealed the operation of non-additive gene effects in hybrids of pigeonpea in their study. Sameer Kumar *et al*. (2009) reported significant and positive heterosis for secondary branches plant^{-1} in pigeonpea.

5.3.4.7 Number of pods plant^{-1}

Totally 39 out of 102 hybrids exhibited significant and positive SCA effects on pooled mean basis. Hybrids, ICPA 2047 x HPL 24-63, ICPA 2092 x BSMR 164 and ICPA 2043 x ICP 3475 showed the highest significant and positive SCA effects on pooled basis for number of pods plant^{-1}. The low x high, high x low, low x high general combiners were present in above cross combinations respectively. Also high SCA effects showing hybrids for number of pods plant^{-1} had medium x high, high x low and high x average performing parents. The hybrid ICPA 2047 x HPL 24-63 had good SCA effects for plant height, seeds pod^{-1}, pod weight and grain yield plant^{-1}. The hybrid ICPA 2092 x BSMR 164 had good SCA effects for pod weight, 100-seed weight and grain yield^{-1}. Likewise, the hybrid ICPA 2043 x ICP 3475 had good SCA effects for number of primary branches plant^{-1}, pod weight and grain yield plant^{-1}. Similar results earlier reported by Singh *et al*. (1983). They reported that the hybrids which involved one parent with significant GCA effect and other with poor GCA effect could throw up transgressive segregates and giving rise to new population, if additive genetic system present in good combiners and epistatic present in hybrids act in complementary fashion to maximize desirable plant attributes which could be exploited for further breeding purposes. Heterosis observed in above hybrids might tend to be unfixable. Sinha *et al* (1994) reported significant and positive SCA effects for pods plant^{-1}. Vanarajan *et al*. (2007), Dalvi (2007) and Sameer Kumar *et al*. (2009) reported that the high SCA effects in hybrids obtained from low x high GCA effects of parents.

5.3.4.8 Pod weight (g)

The estimates of SCA effects over pooled data analysis revealed that the highest significant and positive SCA effect was recorded by hybrid ICPA 2047 x HPL 24-63 (97.042). It was followed by ICPA 2092 x BSMR 164 (48.674), and ICPA 2043 x ICP 3475 (40.568). The best specific combining ability and high *per se* performance was noticed in above all the hybrids. The SCA effects of above all the hybrids were from poor x medium, medium x poor and poor x medium GCA effects of parents. Similar results earlier reported by Singh *et al*. (1983) and Dalvi (2007).

5.3.4.9 Seeds pod^{-1}

The highest significant and positive SCA effects for seeds pod^{-1} was observed with hybrids ICPA 2043 x ICPL 12749 (0.429), ICPA 2092 x BSMR 846 (0.416), and ICPA 2043 x AKT 222521 (0.412) on pooled data. The high SCA effects of hybrids were due to low x high, high x low and low x low GCA effects of parents. It was observed that the hybrids expressed high SCA irrespective of the GCA effects of parents, indicating involvement of dominance and epistatic gene effects in inheritance of traits. Similar results reported by Patel *et al*. (1992) and Vanirajan *et al*. (2007) in pigeonpea.

5.3.4.10 100-seed weight (g)

The SCA effect calculated over pooled basis showed that, 41 hybrids showed significant and positive SCA effects, whereas 41 exhibited significant and negative SCA effects. The highly significant and positive SCA effects registered by ICPA 2047 x BSMR 846 (1.721) followed by ICPA 2047 x AKT 9913 (1.721) and ICPA 2047 x BSMR 2 (1.553). Baskaran and Muthiah (2007) reported that the high SCA effects for 100-seed weight were due to high x low GCA effects of parents indicating the operation of additive x dominance gene effects and hence could be used in heterosis breeding. Dalvi (2007) reported that the hybrids which showed high SCA effects involved high × low, high × high and low × high positive general combiners. Vaghela *et al*. (2009) reported that hybrids which showed high SCA effects for 100-seed weight had direct effect for increasing seed yield.

5.3.4.11 Pollen fertility (%)

The highest significant and positive SCA effect was present among the hybrids ICPA 2043 x BSMR 175, ICPA 2092 x BSMR 203, and ICPA 2047 x ICP 13991. The parents of these hybrids exhibited low x low, high x low and low x low general combiners. It was observed that hybrid ICPA 2043 x BSMR 175 also had high heterosis for 100-seed weight and number of secondary branches plant^{-1}.

5.4 Phenotypic stability of parents and hybrids

The analysis of stability of parents and hybrids revealed that the linear component of genotype-environment interaction (bi) as well as non-linear component (S^2di) for the characters studied was non-significant for most of the genotypes. Information on genotype × environment interaction helps in the breeding of stable genotypes. Eberhart and Russell (1966) emphasized the need of considering both the linear (bi) and non-linear (S^2di) components of interaction in judging the stability of a genotype.

5.4.1 Grain yield plant^{-1} (g)

More number of stabile hybrids observed on ICPA 2092 based cross combinations (16) followed by ICPA 2047 (9) then ICPA 2043 (6). The linear regression (bi) was significant for 17 hybrids, while the deviation from regression (S^2di) was significant for 23 hybrids. Overall 29 out of 102 hybrids showed above average mean yield, a regression coefficient of unity (bi =1) and non-significant mean square deviations from regression (S^2di). While, four hybrids manifested above average mean yield, greater values of regression coefficient (bi >0) and deviation from regression line (S^2di >0). This follows that these hybrid were very highly sensitive to environments, i.e. they responded 3-4 times for a unit change in the environmental milieu. Under intensive agriculture when inputs are no limitations, such varieties can yield maximum. But under the poor environments they miserably failed.

All the parents and hybrids assessed for their stability performance based on regression coefficient (bi) and deviation from regression line (S^2di) for each character are presented in Table 5.2-3. It was observed that 12 out of 37 parents evaluated, showed high mean yield, non-significant value of regression coefficient (bi) of around unity and deviation from regression (S^2di) near to zero for grain yield plant^{-1}. These parents were classified as stable for grain yield plant^{-1}. The parent PHULE T-00-1-25-1 was stable for most of the characters like plant height, secondary branches plant^{-1}, pods plant^{-1}, pod weight and pollen fertility. Whereas, HPL 24-63 was stable for number of primary branches plant^{-1}, pods plant^{-1} and pod weight. It was observed that parents ICP 3963, PHULE T-00-4-11-6-2, ICP 10934 and ICP 3514 showed stability for grain yield plant^{-1} and also exhibited stability for secondary branches plant^{-1}, pods plant^{-1} and pod weight. For stability

of 12 parents, the linear as well as non-linear regression was responsible for yield and yield contributing characters. It was observed that the parents which showed wider stability for grain yield also exhibited non-significant values of regression coefficient (bi =1) for all the characters except for number of secondary branches plant^{-1}, pod weight and pollen fertility. For number of secondary branches plant^{-1} ICPB 2043 and BDN 2001-6 showed significant value of linear regression (bi>1) and non-significant value of deviation from regression line (S^2di =0), which indicated specific adaptability. For pod weight the parents BSMR 571 and for pollen fertility ICP 3514 showed high mean yield but significant value of both bi>1 and S^2di>0 indicated instability under different environments. Out of 12 wider stable parents for grain yield plant^{-1} 11 parents showed stability for pods plant^{-1} followed by nine for pod weight, seven for secondary branches plant^{-1}, five for plant height, three for pollen fertility and one for number of primary branches plant^{-1} and days to maturity. The parents which showed wider stability for grain yield plant^{-1} did not show wider stability for days to flower.

Among the 102 hybrids evaluated, 29 were stable for grain yield plant^{-1}, of which 25 showed stability for pods plant^{-1} and 22 for pod weight, six showed stability each for days to flower and primary branches plant^{-1}, five each for days to maturity and plant height, four for pollen fertility and one for secondary branches plant^{-1} exhibited phenotypic stability. The hybrid ICPA 2043 x PHULE T-00-4-11-6-2 showed stability for grain yield plant^{-1} and other characters including primary branches plant^{-1}, secondary branches plant^{-1}, pods plant^{-1} and pod weight. Whereas ICPA 2043 x ICPL 20106 exhibited stability for days to flower, days to maturity, pods plant^{-1} and pod weight. In general it was observed that the hybrids which showed stability for grain yield plant^{-1} showed with stability for pods plant^{-1}, pod weight, days to maturity and number of primary branches plant^{-1}. The stable hybrids for grain yield plant^{-1} showed significant value of both regression coefficient (bi >1) and deviation from regression line (S^2di>0) for number of primary branches plant^{-1} (3), number of secondary branches plant^{-1} (3), for days to maturity (2), for pollen fertility (2) and days to flower (1). This indicated instability under favorable as well as poor environments.

It was observed that the hybrids with wider adaptability involved both stable parents. A stable male parent when crossed with stable male sterile line produced

stable hybrids. ICPA 2043 based stable hybrids were ICPA 2043 x ICP 3514, ICPA 2043 x ICP 10934, ICPA 2043 x PHULE T-00-4-11-6-2 and ICPA 2043 x BSMR 2, Similarly, ICPA 2092 based stable hybrids were ICPA 2092 x PHULE T-00-4-11-6-2, ICPA 2092 x ICP 3963, and ICPA 2092 x BDN 2001-6. The hybrids on ICPA 2047 based male sterile lines involved stable and unstable parent. The ICPA 2047 based stable hybrids were ICPA 2047 x ICPL 20106, ICPA 2047 x ICP 12749 and ICPA 2047 x VIPULA. The hybrids showing specific adaptability and general adaptability had parents with high x high and high x low *per se* performance. This is in support with results of Ghodke *et al. (*1992), Khapre *et al.* (1996) and Manivel *et al.* (1998), who also reported the stable genotype with high mean, regression coefficient not deviating from unity and non-significant minimum deviation from regression. Phad *et al.* (2005) and Muthiah and Kalaimagal (2005) reported stability of experimental hybrids under stress environments and also found that few hybrids performing better only under favorable environments. Vanniarajan (2007) found that entries which showed unstable performance for one character also, showed the same for yield. This was present in the characters days to flower, days to maturity, plant height, branches plant^{-1}, and pods plant^{-1} with seed yield per plant. Patel *et al.* (2009) indicated differential response of the genotypes to the environmental changes. Pillai *et al*. (2010) also reported the instability of some blackgram genotypes under different environmental condition. While only few genotypes exhibited stability for unfavorable environments and were having more yield than most of the genotypes. Sreelakshmi *et al*. (2010) found stable genotypes ICPL 20036 and ICPL 20058 for seed yield and were found to be suitable for low input cultivation. Therefore it would be better to evaluate the experimental hybrids at all possible environmental conditions to judge the stability.

5.4.2 Days to 50 % flowering

The mean performance for days to flower of parents ranged from 116 days (ICPA 2043) to 129 days (BDN 2001-6). The linear regression was significant for all the 37 parents, while the deviation from regression (S^2di) was significant for 35 parents depicting preponderance of unpredictable components of environment x genotype interaction. Parents ICPA 2047 (mean = 119, bi = 0.85, S^2di = 2.1) and

BSMR 198 (mean = 122, bi = 0.763, S^2di = -0.579) were stable and early in days to flower. These parents showed low mean days to flower with non-significant value of regression coefficient (bi =1) and deviation from regression line (S^2di=0), thereby indicating stability under different environment. ICPA 2043, TV-1, PHULE T-00-1-25-1 were showed low mean days to flower with non-significant value of bi =1 and significant value of S^2di =0 which indicated suitability of parents under favorable environmental condition.

Similarly, the linear regression was significant for only one hybrid while the deviation from regression line was significant for 79 hybrids. The significant value of stability parameters suggests that the performance of different varieties fluctuated significantly from their respective linear path of response to environments. The stable hybrids for days to flower derived from ICPA 2043 were ICPA 2043 x ICP 3475 (mean = 115, bi = 1.704, S^2di= 0.792), ICPA 2043 x ICP 10934 (mean = 119, bi = 1.405, S^2di = 0.044), ICPA 2043 x ICP 12749 (mean = 121, bi = 0.953, S^2di= 0.346) and ICPA 2043 x BSMR 164 (mean = 123, bi = 0.941, S^2di= -0.375). Likewise, ICPA 2047 based stable hybrids were ICPA 2047 x BSMR736 (mean = 123, bi = 0.941, S^2di= -0.375) and ICPA 2047 x PHULE-T-00-1-25-1 (mean = 123, bi = 1.067, S^2di= 0.883) and ICPA 2092 based stable hybrids were ICPA 2092 x ICP 10934 (mean = 134, bi = 2.342, S^2di= 0.072) and ICPA 2092 x AKT 9915 (mean = 123, bi = 1.392, S^2di= 853). All these stable hybrids showed regression coefficient less than unity and mean square deviation less than zero indicating stability of hybrids across the environmental conditions. Shoran *et al*. (1981), Shoran (1985), Phad *et al*. (2005), Muthiah and Kalaimagal (2005), Dalvi (2007), Vanniarajan *et al*. (2007) and Kachanur *et al*. (2008), reported stability of hybrids across the environments for days to flower. Based on stability parameters the genotype ICP 7035 was found to be stable and desirable for days to flower as indicated by non-significant deviation from regression and bi >1 (Sreelakshmi *et al*., 2010).

5.4.3 Days to maturity

In pigeonpea low mean performance and below average linear response are desirable for days to maturity. Parent ICPA 2043 was earliest in maturity (166 days) with non-significant values of regression coefficient (bi = 0.54) and

deviation from regression line (S^2di = -0.633), which showed above average stability of this line. In hybrids, nine out of 102 recorded above average mean value for days to maturity with non-significant value of bi =1 and S^2di =0, which indicated stable performance of hybrids under different environmental conditions. The stable hybrids identified on ICPA 2043 based male sterile lines were ICPA 2043 x BSMR 571, ICPA 2043 x PHULET-04-1-3-1, ICPA 2043 x ICP 3963, ICPA 2043 x ICP 3514, ICPA 2043 x AKT 9913 and ICPA 2043 x ICP 13991. Likewise, ICPA 2047 based stable hybrids were ICPA 2047 x BSMR 198 ICPA 2047 x BSMR 846 and ICPA 2047 x VIPULA 27. Phad *et al.* (2005), Dalvi (2007) and Patel *et al.* (2009) reported stability of hybrids across the environments in pigeonpea. The pigeonpea genotypes ICPL 98008, ICPHAL 4979-2 and ICP 77303 with low mean, bi>1 and less deviation from regression were identified as desirable and stable for days to maturity (Sreelakshmi *et al*., 2010).

5.4.4 Plant height (cm)

Out of 37 parents analyzed for stability analysis the linear regression (bi) was significant for three parents while the deviation from regression (S^2di) was significant for 27 parents. Five out of 37 parents recorded the above average mean with non-significant value of bi=1 and S^2di=0, which indicated the above average stability of parents under different environmental conditions. The stable parents were BSMR 175, BDN 2001-6, BSMR 2, BSMR 164 and ICPL 20106. Out of 102 cross combinations, in six the linear regression (bi =1) was significant while 83 showed significant deviation from regression line. It was observed that 12 hybrids showed greater plant height with non-significant values of bi and S^2di =0 which showed the stability of these hybrids under different environmental conditions. The stable hybrids identified using ICPA 2043 male sterile line were ICPA 2043 x BWR 154, ICPA 2043 x AKT 22252. Likewise ICPA 2047 based stable hybrids were ICPA 2047 x PHULE T-00-5-7-4-1, ICPA 2047 x HPL 24-63, ICPA 2047 x PHULE-T-00-1-25-1, ICPA 2047 x BSMR 203, ICPA 2047 x AKT 8811, ICPA 2047 x BWR 154 and ICPA 2047 x ICPL 12749. In the same way stable hybrids identified on ICPA 2092 male sterile lines were ICPA 2092 x AKT 9913, ICPA 2092 x BSMR 203 and ICPA 2092 x PHULE T-04-1-3-1. Garton *et al*. (1989) and Khapre *et al*. (1996) also reported similar results for stability of

genotype BDN 681 for plant height. Phad (2003) reported that BSMR 175 and BDN 2010 were the most stable parents for plant height. Dalvi (2007) observed that the hybrids ICPA 2039 × ICP 13991, ICPA 2067 × ICP 12320, ICPA 2052 × ICP 13991 and ICPA 2052 × ICP 11376 were stable combinations for plant height in pigeonpea across the environments.

5.4.5 Number of primary branches plant^{-1}

None of the parents registered significant linear regression (bi), while the deviation from regression was significant for 27 parents for number of primary branches plant^{-1}. The stable parents identified for number of primary branches plant^{-1} were AKT 9915, ICP 10650, ICP 11376, HPL 24-63, TV 1 and ICP 3374. Out of 102 cross combinations studied, only two showed significant linear regression coefficient (bi >1) while 86 showed significant values for deviation from regression (S^2di >0). The stable hybrids for number of primary branches plant^{-1} identified on ICPA 2043 based male sterile line were ICPA 2043 x BSMR 2, ICPA 2043 x ICP 3475, ICPA 2043 x PHULE-T-04-1-3-1, ICPA 2043 x ICP 3963 and ICP A2043 x PHULE T-00-4-11-6-2. Likewise ICPA 2047 based stable hybrids for number of primary branches plant^{-1} were ICPA 2047 x BDN 2001-6 and ICPA 2047 x PHULE T-00-4-11-6-2. Similarly, ICPA 2092 based stable hybrids for number of primary branches plant^{-1} were ICPA 2092 x BSMR 198, ICPA 2092 x BSMR 203, ICPA 2092 x AKT 9915 and ICPA 2092 x TV 1. Shoran (1981), Balkrishnan and Natrajaratnam (1989) studied stability of parents SA 1 and PLS 361/1 under different environmental conditions for number of primary branches plant^{-1}. Ghodke *et al*. (1992) observed stability for primary branches of pigeonpea genotypes. The phenotypic stability of primary branches plant^{-1} reflecting into yield stability was also reported by Vanniarajan *et al*. (2000), Muthiah and Kalaimagal (2003), and Patel *et al*. (2005). Phad *et al*. (2005) reported specific adaptability of hybrids BDN 2 x BWR 23, and BSMR 736 x BWR 376 for primary branches plant^{-1} in pigeonpea. Phad (2003), Vanniarajan *et al.* (2007), and Patel *et al.* (2009) reported stability of parents and hybrids for number of primary branches plant^{-1} under different environments. The genotypes ICPHAL 4978-8, ICPHAL 4989-11 and ICPX 77303 showed high mean for number of primary branches plant^{-1}, bi >1 and non-significant S2di indicating

predictable performance and stable over favorable environments (Sreelakshmi *et al*., 2010).

5.4.6 Number of secondary branches plant^{-1}

The stable parents BSMR 175, VIPULA and PHULE T-00-5-7-4-1 performed well under good as well as poor environments. Ten hybrids registered above average mean with non-significant value of regression coefficient and deviation from regression line (S^2di), which indicated stability of hybrids under favorable as well as unfavorable environments. The stable hybrids identified on ICPA 2043 based male sterile lines were ICPA 2043 x ICPL 20106, ICPA 2043 x VIPULA, ICPA 2043 x PHULE T-00-4-11-6-2 and ICP A2043 x BWR 154. Similarly, ICPA 2047 based stable hybrids were ICPA 2047 x ICP 13991, ICPA 2047 x BSMR 203, ICPA 2047 x AKT 9913 and ICPA 2047 x AKT 222521 and ICPA 2092 based stable hybrids were ICPA 2092 x ICP 3475 and ICPA 2092 x ICP 11376. Similarly, Balkrishnan and Natrajaratnam (1989), Khapre *et al.* (1996), Phad (2003), Vanniarajan *et al.* (2007) and Patel *et al.* (2009) reported wider adaptability of pigeonpea hybrid for number of secondary branches plant^{-1}. The genotypes ICPL 20042, ICPL 20062, ICPL 87089 and ICPX 77303 recorded higher number of pods plant^{-1} with stable performance over average environmental conditions (Sreelakshmi *et al*., 2010).

5.4.7 Pods plant^{-1}

Parents, 10 out of 37 showed regression coefficient less than unity. The stable parents identified for number of pods plant^{-1} were HPL 24-63, ICP 10934, ICP 3963, PHULE T-00-4-11-6-2, AKT 8811, PHULE T-00-1-25-1, ICPA 2043, AKT 00-12-6-4, AKT 9915, AKT 222521, VIPULA, ICP 3475, BSMR 571, ICPA 2092 and BWR 154. Most of the parents had good general combining ability. Hybrids, 24 out of 102 showed regression coefficient less than unity. More number of stable hybrids were identified on ICPA 2092 (18) based male sterile lines followed by ICPA 2047 (8) and ICPA 2043 (5) for number of pods plant^{-1}. The first three stable hybrids identified for number of pods plant^{-1} on ICPA 2043 based male sterile lines were ICPA 2043 x ICP 3514, ICPA 2043 x PHULE T-00-4-11-6-2, and ICPA 2043 x ICP 10934. The stable hybrids involved medium, high

and low SCA effects for number of pods plant^{-1}. Likewise, first three ICPA 2047 based stable hybrids were ICPA 2047 x ICPL 20106, ICPA 2047 x ICP 10650 and ICPA 2047 x BSMR 198. These hybrids had respectively low, low and medium SCA effects for pods plant^{-1}. Similarly, ICPA 2092 based stable first three hybrids were ICPA 2092 x BSMR 164, ICPA 2092 x ICP 3963 and ICPA 2092 x ICP 3514. These stable hybrids had high, high and poor SCA effects for pods plant^{-1}. Khapre *et al.* (1996), Phad (2005), Patel *et al*. (2005) and Vaniarajan *et al*. (2007) reported similar results for parental stability in pigeonpea. Patel *et al.* (2009) reported the wider stability of genotype SKNP-9260-2 for pods plant^{-1}.

5.4.8 Pod weight

The highest pod weight was obtained from the parent ICP 3525 (232.675) while the lowest pod weight was realized from the parent ICP 11376 (67.675). The linear regression (bi) was significant for five parents while the deviation from regression (S^2di) was significant for 10 parents. The stable parents identified for pod weight were ICP 3525, HPL 24-63, TV 1, ICPA 2043, ICP 13991, ICP 3963, PHULE T-00-1-25-1, PHULE T-00-4-11-6-2, ICP 10934, AKT 00-12-6-4 and ICPA 2092. These can be grown under different environments. Only two out of 102 hybrids showed the significant regression coefficient (bi) while deviation from regression line (S^2di) was significant for 38 hybrids. The first three stable hybrids derived from ICPA 2043 male-sterile line were ICPA 2043 x ICPL 20106, ICPA 2043 x BDN 2001-6 and ICPA 2043 x ICP 3475. Likewise, ICPA 2047 based stable hybrids were ICPA 2047 x ICP 3514, ICPA 2047 x BDN 2001-6 and ICPA 2047 x ICP 10934. Similarly, ICPA 2092 based stable hybrids were ICPA 2092 x ICP 10934, ICPA 2092 x ICPL 20106 and ICPA 2092 x ICP 3374.

5.4.9 Seeds pod^{-1}

There was no genotype x environment interaction present between the parents and cross combinations hence stability analysis was not carried out. The non-significant effects of genotype x environments interaction (linear) for seeds pod^{-1} were reported by Singh *et al*. (1987), and Venkateshwaralu (1998) and Patel *et al*. (2009). They calculated stability parameters of individual genotypes for unpredictable traits.

5.4.10 100-Seed weight

As there was no genotype x environment interaction present between parents and cross combinations over pooled data basis. Hence stability analysis was not carried out for 100-seed weight. The non-significant effects of genotype x environments interaction (linear) for 100-seed weight were reported by Singh *et al*. (1987), Venkateshwaralu (1998) and Patel *et al*. (2009). They calculated stability parameters of individual genotypes for unpredictable traits.

5.4.11 Pollen fertility (%)

The linear regression (bi) was significant for two parents, while the deviation from regression (S^2di) was significant for 26 parents. Eight parents BSMR 846, BSMR 164, HPL 24-63, PHULE T-00-1-25-1, ICP 3525, ICPL 20106, AKT 00-12-6-4 and ICP 11376 showed high pollen fertility (%) with non-significant value of regression coefficient (bi=1) and deviation from regression line ($S^2di>0$). This showed that parents were stable under favorable as well as unfavorable environmental condition. The stable hybrids derived from ICPA 2043 male-sterile lines were ICPA 2043 x ICP 3525, ICPA 2043 x BSMR 175, ICPA 2043 x BSMR 2, ICPA 2043 x ICP 10934, ICPA 2043 x ICP 3407, ICPA 2043 x TV 1, ICPA 2043 x HPL 24-63, ICPA 2043 x AKT 8811and ICPA 2043 x VIPULA. Likewise, ICPA 2047 stable hybrids were ICPA 2047 x ICP 10650, ICPA 2047 x BSMR 846 and ICPA 2047 x AKT-00-12-6-4. Similarly, ICPA 2092 stable hybrids were ICPA 2092 x ICP 3514 and ICPA 2092 x PHULE T-04-1-3-1.

5.5 Genetics of fertility restoration

In the present study, the mechanism by which the restorer act to suppress the expression of CGMS was characterized by studying F_1, F_2 and BC_1F_1 generations obtained by crossing CGMS lines and known fertility restorers. The practical importance of the CGMS system in breeding is highly dependent on the presence of a restorer of fertility (*Rf* or *Fr*) genes and their stability in different environments. The data collected on segregation in F_2 and BC_1F_1 populations for fertility restoration are given in Table 4.71**.** The χ^2 test was applied to know the goodness of fit for different genetic ratios. Out of four hybrids, two exhibited a

monogenic dominance of fertility restoring gene, while in the other two hybrids exhibited two duplicate dominant genes for fertility restoration in pigeonpea.

The genetics of fertility restoration is important for the transfer of restorer gene from one genotype to another. Similarly, it is controlled by few genes, identification of restorer parents is also easy. In the present study, it was observed that the restorer ICP 2766 when crossed with male-sterile line ICPA 2092 showed monogenic inheritance (3:1), while its cross with another male-sterile line ICPA 2043 revealed digenic inheritance of fertility restoration. Both the A lines contain the same cytoplasm (*Cajanus cajanifolius*) but it can play an important role in the fertility restoration of different A-R lines. The interaction of dominant genes of ICP 2766 with male sterile line ICPA 2092 produces F_1 100% fertile and showed complete dominance for fertility restoration. In the cross between restorer ICP 2766 and male-sterile line ICPA 2043, the dominant gene of fertility restoration at either of two loci masked the expression of male-sterile recessive alleles at the two loci. These nuclear and cytoplasm gene interactions produced male-fertile and male-sterile progenies in F_2 generation in such a way that it modified normal di-hybrid ratio in to 15:1 ratio and produced duplicate gene interaction. Such a phenomenon was also observed in pigeonpea by Mehetre *et al*. (1989). They showed that fertility restoration was governed by duplicate gene (15 fertile: 1 sterile) in pigeonpea. Monogenic inheritance for fertility restoration was observed in common bean (*Phaseolus vulgaris*) by Abad *et al*. (1995) and in petunia by Bentolila and Hanson (2001). Such variable restoration among cytoplasmic sources with the same set of male parents had been reported by earlier workers (Saxena, 2003 and Saxena *et al*. 2005b). Bai and Gai (2005) observed that in soybean fertility restoration was controlled by monogenic (3 fertile: 1 sterile) to digenic (15 fertile: 1 sterile) gene in CMS lines of NJCMS2A. The mono-factorial inheritance associated with fertility restoration in red pepper (*Capsicum annum* L.) reported by Gulyas *et al*. (2006). Dalvi *et al*. (2008) reported monogenic inheritance (F_2 ratio = 3 fertile: 1 sterile and backhybrid ratio = 1 fertile: 1 sterile) and digenic inheritance (F_2 ratio = 15 fertile: 1 sterile and backhybrid ratio = 3 fertile: 1 sterile) for fertility restoration studies in male sterile lines derived from three different cytoplasm of pigeonpea. Nadarajan (2008) and Nithya (2008) observed variable restoration among a

common set of male parents within a single cytoplasmic source. Saxena *et al*. (2010) showed the presence of two dominant genes, with one basic and one inhibitory gene action for the determination of fertility restoration in ICPA 2067.

5.6 Stability of CMS lines

Environment is a major factor in inducing male sterility in environmental sensitive male sterile lines (ESMS) of pigeonpea. The temperature and daylength decreases under short days which result in increased of pollen sterility (%) and vice versa. These two factors are interdependent in respect to expression of photo-thermo sensitive male sterility hybrid seed production (Basha *et al*. 2008). In present experiment three male sterile lines ICPA 2043, ICPA 2047 and ICPA 2092 were planted during rainy season 2009 at Department of Agricultural Botany, Marathwada Agricultural University, Parbhani under insect-proof selfing net. Among the male sterile line ICPA 2043, 27 out of 32 plants showed the 100 % male sterility at initial stage of observation (Table 4.61). At later stage of flowering when temperature decreased from 33.2^{0C} to 5.8^{0C}, the three plants were converted from male sterile into male fertile. Thus it showed that these plants were not stable. Such lines, however, can easily be purified by selfing and single-plant selection for 2–3 generations as has been demonstrated in the hybrid breeding program at ICRISAT. In case of another male sterile line ICPA 2047, 30 out of 32 plants, were recorded 100 per cent male sterility while two plants showed fertility at initial stage of observation (Table 4.62). At later stage of observation one sterile plant converted into fertile at 15 December 2009. The minimum temperature of 5.8^{0C} has been recorded during this conversion of male sterility to fertility period. In case of another male sterile line ICPA 2092 it was observed that 28 out of 32 plants, showed 100 per cent male sterility and four plants recorded fertility of which two plants showed fertility at 25 October (temperature range 11.0 to 33.2^{0C}) and another two plants showed sterility to fertility at 15 December (temperature range 5.8 to 29.2^{0C}) (Table 4.63). The temperature range of 5.8^{0C} to 36.5^{0C} was recorded during the respective days of flowering. In general it was observed that out of three male sterile lines, ICPA

2047 showed high per cent of sterility (90.63%) followed by ICPA 2092 (98.7%) and ICPA 2043 (97.2%) (Fig. 2). Similar results in pigeonpea earlier reported by Dalvi (2007).

5.7 Quality parameters

Pigeonpea plays a significant role in Indian dietary as a primary supplier of protein in contrast to predominantly starchy diet of cereals. The *dal* or decorticated split is used in the preparation of a variety of dishes. Two important types of pigeonpea viz. annual and perennial types are commonly grown in India. The present results on quality parameters have been discussed as below.

The analysis of variance for four quality traits studied was highly significant, indicating the existence of sufficient variation in the materials studied. The analysis of variance revealed significant differences among the parents as well as hybrids for all the traits under consideration.

5.7.1 Cooking time (min)

The housewives prefer a dal which cooks in least time and shows the maximum increase after cooking. This type of dhal fetches higher price. The cooking time of the different parents and hybrids of dals are given in table 4.53-4.54. Kurien *et al*. (1972) stated that cooking time of various grain legumes varied from 30 minutes to one hour. The cooking time among parents ranged from 18.5 to 55.0 min. In this study the minimum cooking time of pigeonpea dal was recorded by the parents ICP 3525, AKT 8811, TV 1 and PHULE T-00-5-7-4-1 than the control ICPH 2671. The parents ICP 3525 and AKT 8811, which showed less cooking time had high protein (%), whereas parent TV 1 and PHULE T-00-5-7-4-1 which showed less time to cook had low protein content. This indicated that the cooking time is not correlated with protein content of the genotypes. The parents which showed early cooking absorbed less water and had low dal recovery (%). The cooking time among hybrids ranged from 13.5 to 61.0 min. Hybrids ICPA 2047 x PHULE T-00-1-25-1, ICPA 2092 x PHULE T-00-1-25-1, ICPA 2043 x BSMR 736, and ICPA 2047 x ICP 3514 recorded the least cooking time as compared to the control. The cooking time among these hybrids showed negative correlation with protein (%), water absorption (%) and dal recovery (%). The hybrid made of

all the three male-sterile lines with four male parents ICP 3525, ICP 3963, ICP 3374 and ICPL 20106 took less time to cook than the control. Again it was observed that the hybrids between ICPA 2043, ICPA 2047 and ICPA 2092 male-sterile lines with ICP 3525, and ICP 3963 male parents were earlier to cook than the control.

Kurien *et al*. (1972) stated that cooking time of various grain legumes varied from 30 minutes to one hour. In this study the cooking time of cultivar CO1 was 40 minutes; whereas, for other varieties it was 50 to 60 minutes. Tripathi and Singh (1979) found significant differences in varieties and locations for protein contents, dal recovery (%) and cooking time (min). Jambunathan and Singh (1982) found negative and highly significant correlation coefficients between cooking time and water absorption characteristics of dal. Raghuvanshi *et al*. (1994) observed the correlation of cooking time with protein and revealed that cooking time was negatively correlated with protein content (r = 0.19). Gupta *et al*. (2000) studied the pigeonpea genotypes for cooking quality and found that less cooking time for pigeonpea genotypes from 37 to 53 minutes.

5.7.2 Protein (%)

The protein content among the parents ranged from 17.4 to 23 %. Parent ICPL 20106, ICP 3525, and ICP 3514 recorded significantly high protein (%) than the control ICPH 2671. The parent ICPL 20106 showed high protein content (%) and took more time to cook, with more water absorption (%) and greater dal recovery (%) than the control. This indicated that the presence of negative correlation between protein content (%) and cooking time (min); and positive correlation between protein content (%) and water absorption (gg^{-1}) and dal recovery (%). Whereas, ICP 3525 and ICP 3514 had high protein content (%) with less cooking time and water absorption (gg^{-1}) and low dal recovery (%). This indicated negative correlation between protein (%) and cooking time, water absorption (gg^{-1}) and dal recovery (%). The protein (%) among the hybrids ranged from 17.2 to 23.0 %. The hybrids ICPA 2043 x BSMR 198, ICPA 2043 x BSMR 175 and ICPA 2043 x ICP 3407 recorded significantly more protein (%) than the control. It was observed that the hybrid ICPA 2043 x BSMR 198 and ICPA 2043 x ICP 3407, which showed high protein (%) were earlier to cook, and had more water

absorption capacity but low dal recovery (%). This indicated that there was positive correlation between protein (%) and cooking time (min) and water absorption (gg^{-1}). Tripathi and Singh (1979) found the significant differences in varieties and locations for protein (%), dal recovery (%) and cooking time (min). Raghuvanshi *et al*. (1994) observed the correlation of cooking time (min) with protein (%) and revealed that cooking time was negatively correlated with protein content (r = 0.193). Panigrahi *et al*. (2002) revealed that protein content of *C. cajanifolius* (30.8%) was much higher than the two pigeonpea cultivars, AKT 9013 (22.8%) and AKPH 1156 (21.6%). The F_1 hybrids from both the crosses had much higher protein (%) than the mid-parental values, and were very close to the wild species *Cajanus cajanifolius* evidencing for positive heterosis (Rangasamy *et al*. 1991). Murali *et al*. (2009) observed that when dal cooked in distilled water took less time (32.80 min) to cook than in bore well water, which required greater time (77.33 min) for cooking.

5.7.3 Water absorption (gg^{-1})

The water absorption (gg^{-1}) recorded by the parents BWR 154, BDN 2001-6, AKT-00-12-6-4, and ICPL 20106 was more than the control BSMR 736. Among these parent BDN 2001-6 recorded less cooking time, high protein (%) and low dal recovery (%). It was observed that all the parents which showed more water absorption showed low dal recovery (%). The hybrids ICPA 2043 x ICP 11376, ICPA 2043 x ICP 3514, and ICPA 2047 x PHULE T-005-7-4-1 registered significantly more water absorption than the control. Among these, hybrid ICPA 2047 x PHULE T-00-5-7-4-1 recorded less time to cook, high protein (%) and greater dal recovery (%) than the control. It was observed that parents ICP 11376, ICP 3514, PHULE T-00-5-7-4-1 and BSMR 2 when crossed with male-sterile lines ICPA 2043, ICPA 2047 and ICPA 2092 produced hybrids with mfore water absorption ability. Jambunathan and Singh (1982) found negative and highly significant correlation coefficients between cooking time and water absorption among cultivars of pigeonpea dal. Singh *et al*. (1984) revealed that water absorption was significantly correlated with the cooking time.

5.7.4 Dal recovery (%)

Out of 37 parents used for making dal only PHULE T-00-11-6-2 recorded significantly higher (83.3 %) dal recovery (%) as compared to the control ICPH 2671 (71.0 %). The parent PHULE T-00-11-6-2 recorded less cooking time, high protein (%) and less water absorption. This indicated that dal recovery (%) had positive correlation with cooking time (min), protein (%) and water absorption (gg^{-1}). Similarly, out of 102 hybrids evaluated, only ICPA 2047 x ICP 3374 and ICPA 2092 x ICP 3374 (77.9 %) recorded significantly greater dal recovery (%) as compared to the control. These hybrids contain common parent ICP 3374 which was responsible for greater dal recovery (%). Both the hybrids recorded less cooking time (min), high protein (%) and low water absorption (gg^{-1}). Tripathi *et al*. (1975) found that late varieties had significantly higher dal recovery (%) and protein (%) than the early varieties. Tripathi and Singh (1979) found significant differences in varieties and locations for protein contents, dal recovery (%) and cooking time. They reported hight dal recovery of 84.5% among varieties of pigeonpea. Ehiwe and Reichert (1987) reported relatively less variation (79-83%) in dal yield of pigeonpea cultivars compared to other legumes. Gupta *et al*. (2000) studied pigeonpea genotypes for cooking quality and found less cooking time for pigeonpea genotypes UPAS 120 and Bahar.

5.8 Implications in hybrid breeding strategies

Information on heterosis, combining ability, stability, genetics of fertility restoration and quality parameters is helpful in planning of future breeding programmes. The breeding repercussions of the present study are given below.

1) As the crosses made on male-sterile line ICPA 2043 were earlier to flower and mature. So the segregating population may be screened for early maturing plant selections.
2) Seven crosses ICPA 2043 x ICP 3525, ICPA 2043 x BSMR 175, ICPA 2043 x BSMR 203, ICPA 2043 x ICP 10934, ICPA 2043 x ICP 3407, ICPA 2043 x TV 1, and ICPA 2092 x ICP 3514 showed 100% pollen-fertility across the four locations. So parents of these crosses should be given priority in a hybridization programme aimed at yield improvement in pigeonpea.

3) For grain yield plant^{-1} higher heterotic estimates were recorded in the hybrids involving female parent ICPA 2092. These high heterotic crosses may also be considered for varietal improvement programme.
4) Parents ICP 3475, and BSMR 736 for days to flower; ICPA 2043, and HPL 24-63 for maturity; ICPA 2047 and AKT 9913 for plant height; TV 1, and ICP 3525 for number of primary branches plant^{-1} registered desirable GCA effects indicating their good general combining ability. When these parents used for crossing, their cross combination likely to give desirable transgressive segregants in advance generations and may be utilized for selecting better and high yielding genotypes.
5) Hybrid ICPA 2047 x ICPL 20106 showed high SCA effects for grain yield plant^{-1} and was identified as promising for plant height, number of primary and secondary branches plant^{-1}, number of pods plant^{-1}, pod weight, 100-seed weight on the basis of *per se* performance, standard heterosis and GCA effects. Such crosses could be utilized in the production of high yielding recombinant homozygous lines following recurrent selection.
6) For days to maturity parents ICPA 2043 identified as stable. For number of pods plant^{-1}, pod weight and grain yield plant^{-1} HPL 24-63, ICP 10934, ICP 3963, PHULE T-00-4-11-6-2, PHULE T-00-1-25-1, ICPA 2043, VIPULA, and ICPA 2092 showed stability. A stable male sterile line when crossed with stable male parent produced stable hybrids and vice versa. So more importance need to be given these stable parents in pigeonpea hybrid breeding programme to develop stable hybrids under low input cultivation.
7) Hybrids ICPA 2043 x ICP 3514, ICPA 2043 x PHULE T-00-4-11-6-2, and ICPA 2043 x ICP 10934 were found to be stable for number of pods plant^{-1}, pod weight and grain yield plant^{-1}. The crosses showing stability for yield need to be tested for yield across more diverse environments over seasons.
8) The information generated on genetics of fertility restoration will help in knowing the selection of breeding methods and further transfer of fertility restorer genes in to elite backgrounds. The number of genes identified will help to transfer in to other genotype by backcross methods.

9) For genetics of fertility restoration the cytoplasmic influence was found to be highly cross-specific and depended on the nuclear background of CMS line and fertility restorer. The data on fertility restoration of CMS lines may be used for diversification of CMS lines and for development of heterotic cross combinations.

CHAPTER VI

SUMMARY AND CONCLUSIONS

The present investigations were carried out to derive information on heterosis, combining ability, stability and some quality parameters in a series of CGMS-based pigeonpea hybrids. Also, it was aimed to study the genetics of fertility restoration and stability of the male-sterile lines of pigeonpea. A line x tester mating design was used to develop F_1 hybrids using three CGMS lines ICPA 2043, ICPA 2047 and ICPA 2092 developed at International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru (Andhra Pradesh). All three A-lines were derived from *Cajanus cajanifolius* (A_4) cytoplasm. The testers comprised of 13 inbred lines obtained from ICRISAT; 10 lines from Agricultural Research Station, Badnapur, M.A.U., Parbhani, five lines from MPKV Rahuri; and six lines from Pulses Research Unit, PDKV, Akola. All the materials were evaluated at Patancheru, Parbhani, Latur and Badnapur. All the cross combinations were made during *kharif* 2008 in a line × tester mating design. The hybrids and parents were evaluated in α-lattice design with two replications. Observations were recorded on five competitive plants on days to 50% flowering, days to maturity, plant height (cm), number of primary branches plant^{-1}, number of secondary branches plant^{-1}, total number of pods plant^{-1}, seeds pod^{-1}, pod weight (g), 100-seed weight (g), pollen fertility (%) and grain yield plant^{-1} (g). Standard heterosis was estimated over popular variety BSMR 736 and hybrid ICPH 2671. The quality parameters included cooking time (min), protein (%), water absorption (gg^{-1}), and dal recovery (%). The highlights of the results are summarized below.

A) *Per se* performance

1. The crosses made on male-sterile line ICPA 2043 were earlier to flower and mature.

2. Parents BSMR 175, ICP 3525 and ICP 3374 were taller than the control ICPH 2671. Among crosses ICPA 2047 x TV 1, ICPA 2047 x AKT 9913, and ICPA 2047 x PHULE T-00-5-7-4-1 recorded more plant height over the control.

3. Three parents ICP 10934, AKT 9915 and ICP 10650 and five crosses ICPA 2043 x TV 1, ICPA 2047 x ICPL 20106, ICPA 2092 x ICP 3525, ICPA 2092 x BSMR 2 and ICPA 2092 x ICP 3514 had more number of primary branches plant^{-1} over the control ICPH 2671. Parent ICP 3525 and cross ICPA 2092 x ICP 3407 had more number of secondary branches plant^{-1} as compared to control ICPH 2671.
4. Parents ICP 3525, TV 1 and HPL 24-63 and crosses ICPA 2092 x ICPL 20106, ICPA 2092 x ICP 10934 and ICPA 2047 x HPL 24-63 had higher number of pods plant^{-1}, pod weight, and grain yield plant^{-1} as compared to the control.
5. Parents PHULE T-04-3-1, ICP 10934, and ICP 3374 had large seed size than the control ICPH 2671; whereas hybrids ICPA 2092 x BSMR 736, ICPA 2043 x ICP 11376 and ICPA 2043 x BSMR 2 recorded significant superiority over the control.
6. Seven crosses ICPA 2043 x ICP 3525, ICPA 2043 x BSMR 175, ICPA 2043 x BSMR 203, ICPA 2043 x ICP 10934, ICPA 2043 x ICP 3407, ICPA 2043 x TV 1, and ICPA 2092 x ICP 3514 showed 100% pollen-fertility across the four locations.

B) Heterosis

1. Heterosis for early flowering was observed only at Latur and Patancheru.
2. Cross ICPA 2047 x ICPL 20106 showed positive heterosis for plant height, number of primary and secondary branches plant^{-1}, number of pods plant^{-1}, pod weight, 100-seed weight and grain yield plant^{-1}.
3. For grain yield plant^{-1} high heterotic estimates were recorded in the hybrids involving female parent ICPA 2092. It was also observed that hybrids ICPA 2043 x ICP 3374, ICPA 2047 x HPL 24-63 and ICPA 2092 x ICPL 20106 showed positive heterosis over the control ICPH 2671. The parents with high *per se* performance showed higher heterosis for grain yield plant^{-1}.

C) Combining ability

I) General combining ability (CGA) effects

1. Parents ICP 3475, BSMR 736, and AKT 8811 for days to flowering and ICPA 2043, HPL 24-63 and PHULE T-00-4-11-6-2 for maturity registered negative GCA effects indicating their good general combining ability. It was also observed that parents showing high *per se* performance also expressed negative GCA effects for days to flower and maturity.
2. Parents ICPA 2047, AKT 9913, PHULE T-00-1-25-1, and TV 1 showed high positive GCA effects for plant height; whereas for number of primary branches plant^{-1} TV 1, BDN 2001-6, BSMR 2, and ICP 3525 registered high positive GCA effect.
3. For number of secondary branches plant^{-1} and number of pods plant^{-1} ICP 3374 recorded the highest, significant positive GCA effect; whereas BSMR 175 recorded the highest, significant positive GCA effect for 100-seed weight.
4. ICPA 2092, ICP 3374, ICPL 20106 and ICP 10934 were found to be good general combiners for grain yield. These parents also showed good general combining ability for days to maturity, number of secondary branches plant^{-1}, number of pods plant^{-1}, pod weight (g) and pollen fertility on pooled data basis.

II) Specific combining ability (SCA) effects

1. Hybrids ICPA 2047 x PHULE T-00-4-11-6-2, ICPA 2043 x PHULE T-00-4-11-6-2, and ICPA 2092 x BDN 2001-6 exhibited negative SCA effects for days to flower; whereas ICPA 2043 x BSMR 175, ICPA 2092 x ICP 13991, and ICPA 2092 x ICP 10650 exhibited significant and negative SCA effects for maturity.
2. For plant height the high positive SCA effects recorded by ICPA 2047 x HPL 24-63, ICPA 2092 x BSMR 2, and ICPA 2047 x ICP 13991.
3. Hybrid ICPA 2047 x ICPL 20106 showed high SCA effects for primary branches plant^{-1} and was identified as promising for plant height, secondary branches plant^{-1}, number of pods plant^{-1}, pod weight, 100-seed weight and grain yield plant^{-1} on the basis of *per se* performance, standard heterosis and SCA effects.

4. High positive SCA effect for number of secondary branches plant^{-1} was present in crosses ICPA 2043 x BSMR 175, ICPA 2092 x BSMR 571, and ICPA 2092 x PHULE T-04-1-3-1.
5. Cross ICPA 2047 x HPL 24-63 showed high positive SCA effect for number of pods plant^{-1} which also showed high SCA effects for plant height, seeds pod^{-1}, pod weight and grain yield plant^{-1}. Cross ICPA 2092 x BSMR 164 had good SCA effects for number of pods plant^{-1}, pod weight, 100-seed weight and grain yield^{-1}. Likewise the cross ICPA 2043 x ICP 3475 had good SCA effects for number of primary branches plant^{-1}, pods plant^{-1}, pod weight and grain yield plant^{-1}.

D) Stability

1. For days to flower ICPA 2047 and BSMR 198 showed low mean for days to flower with non-significant regression coefficient (bi =1) and deviation from regression line (S^2di=0), which indicated stability under different environmental condition. The stable hybrids for days to flower were ICPA 2047 x BSMR736 and ICPA 2047 x PHULE-T-00-1-25-1.
2. For days to maturity parents ICPA 2043 identified as stable. The stable hybrids were ICPA 2043 x BSMR 571, ICPA 2043 x PHULE-T-04-1-3-1, ICPA 2043 x ICP 3963, ICPA 2043 x ICP 3514, ICPA 2043 x AKT 9913 and ICPA 2043 x ICP 13991.
3. The stable parents for plant height were BSMR 175, BDN 2001-6, BSMR2, BSMR 164 and ICPL 20106. The stable hybrids were ICPA 2043 x BWR 154, ICPA 2043 x AKT 22252, ICPA 2047 x PHULE T-00-5-7-4-1, ICPA 2047 x HPL 24-63, ICPA 2047 x PHULE T-00-1-25-1, ICPA 2047 x BSMR 203, ICPA 2047 x AKT 8811, ICPA 2047 x BWR 154 and ICPA 2047 x ICPL 12749, ICPA 2092 x AKT 9913, ICPA 2092 x BSMR 203, and ICPA 2092 x PHULE T-04-1-3-1.
4. The stable parents identified for number of primary branches plant^{-1} were AKT 9915 and TV 1, which when crossed with ICPA 2092 produced stable hybrids ICPA 2092 x AKT 9915 and ICPA 2092 x TV 1.

5. The stable parents HPL 24-63, ICP 10934, ICP 3963, PHULE T-00-4-11-6-2, PHULE T-00-1-25-1, ICPA 2043, VIPULA, and ICPA 2092 were identified for number of pods plant^{-1}, pod weight and grain yield plant^{-1}.
6. Hybrids ICPA 2043 x ICP 3514, ICPA 2043 x PHULE T-00-4-11-6-2, and ICPA 2043 x ICP 10934 were found to be stable for number of pods plant^{-1}, pod weight and grain yield plant^{-1}.
7. The stability of CGMS-based pigeonpea hybrids was due to irrespective of stability of hybrid parents and *per se* performance.
8. The results of the present study indicated that none of the genotypes studied was found superior for all the characters in all the environments. The stable genotypes identified could be used as parents in future breeding programme for developing suitable genotypes with wider adaptability.

E) Quality parameters

1. Hybrids ICPA 2047 x PHULE T-00-1-25-1, ICPA 2092 x PHULE T-00-1-25-1, ICPA 2043 x BSMR 736 and ICPA 2047 x ICP 3514 were earlier to cook as compared to the control ICPH 2671.
2. Parents, ICPL 20106, ICP 3525, and ICP 3514 and hybrids ICPA 2043 x BSMR 198, ICPA 2043 x BSMR 175 and ICPA 2043 x ICP 3407 recorded significantly more protein (%) than the control ICPH 2671.
3. For water absorption, parents BWR 154, BDN 2001-6, AKT-00-12-6-4, and ICPL 20106 recorded significantly more water absorption than the control BSMR 736. ICPA 2043 x ICP 11376, ICPA 2043 x ICP 3514, and ICPA 2047 x PHULE T-005-7-4-1 registered significantly more water absorption than the control.
4. The high dal recovery (%) was recorded by parent PHULE T-00-11-6-2 and hybrids ICPA 2047 x ICP 3374 and ICPA 2092 x ICP 3374 as compared to the control ICPH 2671.

F) Fertility restoration

1. The study of genetics of fertility restoration indicated that monogenic as well as digenic control of fertility restoring gene. For genetics of fertility

restoration the cytoplasmic influence was found to be highly cross-specific and depended on the nuclear background of CMS line and fertility restorer.

G) Stability of CGMS lines

1. All the three male-sterile lines viz., ICPA 2043, ICPA 2047 and ICPA 2092 were stable in different month temperature.

CHAPTER VII

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