STUDIES ON HYBRID VIGOUR AND INBREEDING DEPRESSION IN CMS-BASED PIGEONPEA [*Cajanus cajan* (L.) Millspaugh] HYBRIDS

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(B.Agr.Sc)

MASTER OF SCIENCE IN AGRICULTURE
(GENETICS AND PLANT BREEDING)

2011

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BY

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(B.Agr.Sc)

THESIS SUBMITTED TO THE
ACHARYA N.G. RANGA AGRICULTURAL UNIVERSITY
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF

MASTER OF SCIENCE IN AGRICULTURE
(GENETICS AND PLANT BREEDING)

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2011

DECLARATION

I**, KHIN LAY KYU** hereby declare that the thesis entitled **"STUDIES ON HYBRID VIGOUR AND INBREEDING DEPRESSION IN CMS-BASED PIGEONPEA [*Cajanus cajan* (L.) Millspaugh]"** submitted to the **Acharya N.G. Ranga Agricultural University** for the degree of **MASTER OF SCIENCE IN AGRICULTURE** is the result of original research work done by me. I also declare that any material contained in the thesis has not been published earlier in any manner.

Place: Hyderabad **(KHIN LAY KYU)**

Date: 11.08.2011 RAM/09-50

CERTIFICATE

Ms. KHIN LAY KYU has satisfactorily prosecuted the course of research and that the thesis entitled **"STUDIES ON HYBRID VIGOUR AND INBREEDING DEPRESSION IN CMS-BASED PIGEONPEA [*Cajanus cajan* (L.) Millspaugh] HYBRIDS"** submitted is the result of original research work and is of sufficiently high standard to warrant its presentation to the examination. I also certify that neither the thesis nor its part thereof has been previously submitted by her for a degree of any university.

Date: 11.08.2011

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Chairperson

CERTIFICATE

This is to certify that the thesis entitled **"STUDIES ON HYBRID VIGOUR AND INBREEDING DEPRESSION IN CMS-BASED PIGEONPEA [*Cajanus cajan* (L.) Millspaugh] HYBRIDS"** submitted in partial fulfilment of the requirements for the degree of **'MASTER OF SCIENCE IN AGRICULTURE'** of the Acharya N.G. Ranga Agricultural University, Hyderabad is a record of the bonafide research work carried out by **Ms. KHIN LAY KYU** under our guidance and supervision.

No part of the thesis has been submitted by the student for any other degree or diploma or has been published. The published part and all assistance received during the course of the investigation have been duly acknowledged by the author of the thesis.

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ACKNOWNLEDGEMENT

It is a great pleasure for me to express gratitude to several personalities who guided and extended all help required directly or indirectly during my study.

First I would like to express my deep sense of gratitude and sincere regards to my chairperson of advisory committee ***Dr. K.B. Saxena****, Principal Scientist, Pigeonpea Breeding, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Hyderabad for his guidance, encouragement, affectionate treatment, and systematic planning of my research program during the entire course of investigation, and giving me various learning opportunities at ICRISAT. Indeed my indebtness to him is unquantifiable.*

I am also thankful to ***Dr. M. Ganesh****, Dean of Student Affairs, Acharya N.G. Ranga Agricultural University (ANGRAU), College of Agriculture, Rajendranagar, Hyderabad as a co-chairman of my advisory committee for his munificent acquiescence and meticulous reasoning to refine the dissertation most explicitly to reckon with set standards. Ineffable is my gratitude and sincere thanks to him for his transcendent suggestion to embellish the study.*

I offer my profuse thanks to ***Sri. M.H.V. Bhave****, Assistant Professor, Department of Statistics and Mathematics, College of Agriculture, Rajendranagar, Hyderabad as a member of my advisory committee for his good counsel and help during my course of investigation.*

At the outset, I intend to place on record my deep sense of gratitude and respect to ***Dr. C.L.L Gowda****, Director, Grain Legumes Program, ICRISAT and* ***Dr. G.V. Ranga Rao****, Special Project Scientist, IPM, Grain Legumes Program, ICRISAT, Patancheru, Hyderabad, for his guidance and advice during the course of this investigation.*

My deepest admiration and heartful thanks to ***Dr. M. V. Brahmeshwara, Rao,*** *Head of Department of Genetics and Plant Breeding, ANGRAU, Rajendranagar, Hyderabad for his generous help and encouragement during my research work.*

I cordially offer my profound gratitude to my teachers in Department of Genetics and Plant Breeding ***Dr. T. Dayakar Reddy, Dr. N. A. Ansari, Dr. S. Sudheer Kumar, Dr. M. V. Radha Krishana, Dr. M. Bharathi, Dr. Farzana Jabeen, Dr. Sheshagiri Rao, Dr.J.Suresh, Dr.Sujatha, Dr. Radhika, and Dr.Ch. Anuradha and***

Dr.Ch.V.Durga rani, Dr.Balram, Dr.Manorama from institute of Biotechnology *for their excellent teaching and guidance which enabled me complete my course work.*

My sincere thanks to ***Mr. R Vijaya Kumar*** *(Lead Scientific Officer, Pigeonpea Breeding, ICRISAT) for his continuous help during the course of my research.*

I feel immense pleasure to express my sincere thanks to ***Dr. Vales Isabel***, ***Dr. Myer Mula***, ***Dr. R Sultana***, ***Ms. Badar***, ***Mr. Satyanarayana***, ***Mr. R. Rama Rao***, ***Mr. M. Pentaiah***, ***Mr. G. Ramulu***, ***Mr. G. Anji Reddy***, *and all the research technicians from Pigeonpea Breeding, ICRISAT for their help in conducting the research trails at Patancheru.*

I am profoundly thankful to ***Dr. Abhishek Rathore***, *Principal Scientist, Statistics Unit, ICRISAT and* ***Mr. Anil Kumar***, *and* ***Ms. Roma Das*** *(Scientific Officers, Statistics Unit, ICRISAT),* ***Dr. Shrikant L. Sawargaonkar***, *Research Associate, Agricultural Genomic Lab, ICRISAT for their help in statistical analysis.*

My deepest admiration and heartful thanks to ***Dr. Rosana P Mula***, *Coordinator, Learning system unit (LSU) for her generous help and encouragement during my course work and research work. I am also thankful to* ***Dr. Balaji, Mr. S.V. Prasad Rao and all other staff of LSU, Library, Housing and Food Services, ICRISAT, Patancheru.***

I cherish with appreciation the joyful and cheerful company of my colleagues ***Sravani***, ***Niveditha, Prasanna***, ***Romi, Rajendar, Sadaiah, Kotilingam, Gonya nayak, Sudharsan, Tou thong, Bharati, Dipali*** *who always shared the burden of my work, Cheered me in the moments of despair and made the things much smoother.*

The words are not worthy to mention the love and affectionate core of my beloved parents ***U SAN OO*** *and* ***DAW TIN OWN,*** *all of my Lovely sisters and brothers they remain pillars of source and constant inspiration for me in stepping up educational career and molding my life.*

I am thankful to ***Acharya N.G.Ranga Agricultural University, Hyderabad*** *for providing opportunities to study master degree and* ***International Crops Research Institute (ICRISAT)*** *for financial assistance in the form of research scholar during course of M.Sc (Ag).*

(KHIN LAY KYU)

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LIST OF ABBREVIATIONS

Millimetre	mm
Centimetre	cm
Gram	g
Kilogram	kg
Litre	L
Acre	ac
Hectare	ha
Kilogram per hectare	kg ha^{-1}
Per cent	%
Degree Celsius	°C
And others people	et al.
As such mean	per se
Namely	viz.,
Standard Deviation	SD
Analysis of Variance	ANOVA
Randomized Block Design	RBD
Critical Difference at 5 per cent level	CD (P=0.05%)

Name of the student	**: KHIN LAY KYU**
Title of the thesis	**: STUDIES ON HYBRID VIGOUR AND INBREEDING DEPRESSION IN CMS-BASED PIGEONPEA [*Cajanus cajan* (L.) Millspaugh] HYBRIDS**
Degree to which it is submitted	**: MASTER OF SCIENCE IN AGRICULTURE**
Faculty	**: AGRICULTURE**
Department	**: GENETICS AND PLANT BREEDING**
Major Advisor	**: DR. KB SAXENA**
University	**: ACHARYA N.G. RANGA AGRICULTURAL UNIVERSITY**
Year of submission	**: 2011**

ABSTRACT

An investigation was carried out during *kharif* (monsoon) season of 2010-11 at ICRISAT, Patancheru, Hyderabad, to study (i) relative mid-parent heterosis, heterobeltirosis, and standard heterosis in medium duration disease resistant pigeonpea hybrids, (ii) inbreeding depression from F_1 to F_2 generations for important economic traits, and (iii) genetics of fertility restoration. A total of 22 hybrids were synthesized by hand pollinating five CMS-lines with 14 restorers during 2009 *kharif* season. The F_1 plants of each hybrid were selfed to obtain F_2 seeds. Genetics of fertility restoration was studied by using F_1, F_2, and BC_1F_1 data in four crosses.

Hybrid ICPH 2671 showed higher negative heterosis indicating exploitable hybrid vigour for earliness. For maturity, six hybrids ICPH 2671, ICPH 3461, ICPH 3762, ICPH 3763, ICPH 4022, and ICPH 4024 exhibited significant negative heterosis. For plant height ICPH 2671 (11.35%), ICPH 3933 (23.94%), and ICPH 3759 (8.28%) showed significant positive heterosis over mid parent. Hybrids ICPH 2671, ICPH 2751, and ICPH 3759 expressed positive heterosis for number of primary branches. Hybrids ICPH 2671 and ICPH 3933 showed significant positive heterosis over mid and better parents for pod clusters. A considerable amount of heterosis for number of pods plant^{-1} ranged from -38.40 to 113.46%, -21.88 to 120.47% and -24.44 to 149.19% over better, mid and standard parent, respectively. Five hybrids ICPH 2671, ICPH 2740, ICPH 3359, ICPH 3477, and ICPH 4017 exhibited higher positive heterosis at all the three

bases of estimation. Hybrids ICPH 3477 and ICPH 3758 had significant positive heterosis over better and mid parents for seed size. Wide range of positive and negative heterosis was observed for seed yield, hybrid ICPH 2671 (148.94-208.44%) exhibited the high heterosis in seed yield followed by ICPH 2740 (49.89-121.45%), ICPH 3477 (48.54-119.45%), ICPH 3491 (50.99-134.17%), ICPH 4017 (55.82-184.90%), and ICPH 4022 (127.23-155.64%) at different levels of heterosis, respectively.

There was no significant inbreeding depression for days to flower and maturity and plant height. In case of number of pod cluster plant^{-1}, inbreeding depression ranged from -64.50% (ICPH 3494) to 68.44% (ICPH 4012). For number of pods plant^{-1} ICPH 2671, ICPH 2740, ICPH 3359, ICPH 3461, ICPH 3758, ICPH 3933, ICPH 4012, and ICPH 4017 exhibited high heterosis and inbreeding depression. Seventeen out of 22 hybrids, demonstrated significant inbreeding depression for seeds pod^{-1}. For 100-seed weight, significant inbreeding depression was found in ICPH 3359 (19.61%). For seed yield plant^{-1}, 14 hybrids showed 44.69 to 73.28% inbreeding depression. These results indicated the predominance of non-additive gene action. For plot yield, 12 hybrids exhibited positive heterosis and inbreeding depression ranging from 7.64 to 52.33%. The results on inbreeding depression suggested that the genes affecting yield showed both additive and non-additive gene action.

The fertility restoration in pigoenpea hybrids appeared to be governed by two genes with epistatic interaction. ICPH 2671 and ICPH 2740 which have the same restorers but different male sterile lines segregated in the ratio of 12:3:1 in F_2 and 2:1:1 in BC_1 generation showing digenic dominant epistatic interaction, respectively. ICPH 3359 showed a segregation ratio of 9:6:1 and 1:2:1 in F_2 and BC_1 generation indicating two major genes governing fertility restoration showing epistasis with incomplete dominance while ICPH 4012 segregated in the ratio of 9:3:4 and 1:1:2 in F_2 and BC_1 generations for pollen fertility/sterility.

Chapter I

INTRODUCTION

Pigeonpea [*Cajanus cajan* (L.) Millspaugh], is a short-lived perennial member of family Fabaceae and it is invariably cultivated as annual crop. Pigeonpea is an often cross-pollinated (20 - 70%) crop with 2n = 2x = 22 diploid chromosome number. It is the fourth important pulse crop in the world and predominantly cultivated in the developing countries (FAO, 2008) of tropics and sub-tropics. India is considered as the native of pigeonpea (van der Maesen, 1980) because of its natural genetic variability available in the local germplasm and the presence of its wild relatives in the country. Pigeonpea is a hardy, widely adapted, and drought tolerant crop. It has a range of maturity which helps in its adaption in a wide range of environments and cropping systems. Recently, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) developed a super early genotype maturing in 70-75 days. The super early and short-duration (100-140 days) cultivars are grown as sole crop, while the medium (160-180 days) and long-duration (> 200 days) landraces and cultivars are grown as intercrop or mixed crop with other short-duration cereals such as sorghum (*Sorchum bicolor*), pearl millet (*Pennisetium glaucum*), maize (*Zea mays*), and legumes such as soybean (*Glycine max*), greengram (*Vigna radiata*), cowpea (*Vigna unguiculata*) and peanuts (*Arachis hypogaea*). Being a pulse, pigeonpea enriches soil through symbiotic nitrogen fixation, releases soil-bound phosphorous, recycles the soil nutrients, and adds organic matter and other nutrients that make pigeonpea an ideal crop for sustainable agriculture (Saxena, 2008). It is chiefly grown for its seeds which are consumed either as dry splits (dal) or as a green vegetable. It is also used on a limited scale as a fodder crop while its stems provide a good source of fuel wood.

Pigeonpea is grown world wide on 5.2 M ha land in about 50 countries and 77% of its area is in India (FAO, 2008). It is followed by Myanmar (0.62 M ha) and China (0.15 M ha). In sub-Sahara Africa (Kenya, Malawi, Tanzania, Uganda, and Mozambique) long duration pigeonpea constitute an important component of rainfed agriculture. In India, pigeonpea is a important crop in the states of Maharashtra (1.1 M ha), Karnataka (0.58 M

ha), Andhra Pradesh (0.51 M ha), Uttar Pradesh (0.41 M ha), Madhya Pradesh (0.32 M ha), and Gujarat (0.35 M ha). These six states account for over 70% of the total pigeonpea area and production in India.

Since 1976, pigeonpea has globally recorded a 56% increase in its area and production but the productivity of the crop has remained low at about 700 kg ha^{-1} (http://faostat.fao.org/site/ 339/default.aspx). This is a matter of concern since the majority of the Indian population is vegetarian and their protein source directly depends on pulses. In order to meet this requirement, the Indian Government annually imports about 0.5 to 0.6 m. tons of pigeonpea mainly from Myanmar and southern and eastern Africa (Saxena and Nadarajan, 2010).

To promote the pigeonea production, genetic improvement of pigeonpea was emphasized by researchers for more than five decades and a number of cultivars were developed from hybridization programmes and selection of landraces (Singh *et al*., 2005). However, the progress in the genetic improvement of yield potential has been limited and the improved cultivars failed enhance the productivity of the crop.

Therefore, an alternative breeding approach such as hybrid technology, which has been profitably used in a number of cereals, fruits, and vegetable crops was attempted in pigeonpea to enhance the yield. The development of commercial hybrid pigeonpea programme was innovated at ICRISAT in collaboration with ICAR (Indian Council of Agricultural Research). In 1974, a source of genetic male-sterility (GMS) was identified. As a consequence, a genetic male-sterility based pigeonpea hybrid ICPH 8 was released in 1991 in India (Saxena *et al*., 1992). It is considered a milestone in the history of crop breeding as ICPH 8 is the first ever commercial hybrid released in any food legume in the world. This hybrid, however, could not be commercialized due to its high seed cost and difficulties in maintaining the genetic purity. This development provided the most important information on the role of partial natural out-crossing in large-scale hybrid seed production. This component is essential for commercial exploitation of hybrid vigour in pigeonpea (Saxena and Nadarajan, 2010). Natural out-crossing in pigeonpea was first reported by Howard *et al*. (1919). The out-crossing in this crop is mediated by a variety of insects (Onim, 1981) and wind does not play any role in this event (Kumar and Saxena, 2001). Bhatia *et al*. (1981) reported 24% natural out-crossing in pigeonpea at Patancheru. The estimates of natural out-crossing vary greatly between 2 to 70% in different

environmental conditions (Saxena *et al.*, 1990). This level of out-crossing was found sufficient to maintain male-sterile lines and also to produce F_1 hybrid seeds.

Due to the limitation of large-scale hybrid seed production in GMS-based hybrids, the development of cytoplasmic-nuclear male-sterility (CMS) became imperative. To develop a CMS system, pigeonpea genome was inserted in the cytoplasm of wild species through hybridization and backcrossing. It is believed that the interaction between wild cytoplasm and cultivated nuclear genome would produce male sterility effect. So far, seven such CMS systems have been bred (Table 1) in pigeonpea with varying degrees of success (Saxena *et al.*, 2010). Of these, A_2 and A_4 systems derived from crosses involving wild relatives of pigeonpea and cultivated types have shown promise because of their stability under various agro-climatic conditions and availability of good maintainers and fertility restorers (Saxena and Nadarajan, 2010). By using A_2 cytoplasm, a hybrid GTH-1 was released by ICAR for commercial cultivation in Gujarat state. It demonstrated 57.40% yield superiority over the best GMS hybrid AKPH 4101 (1183 kg ha^{-1}) and 32% superiority over the best local variety GT 101 (1330 kg ha^{-1}). This hybrid is early (140 days) in maturity.

Meanwhile, ICRISAT developed a number of experimental hybrids and tested in multi-location trials. They also developed genetically diverse male-sterile lines and their fertility restorers for developing widely adaptability hybrids to different agro-ecological areas and cropping systems. Among the short duration hybrids ICPH 2433, which is based on A_4 cytoplasm, recorded highest yield of 2419 kg ha^{-1} and it exhibited high levels of hybrid vigour over all the local controls. The other promising hybrids were ICPH 2438 (2377 kg ha^{-1}) and ICPH 2429 (2164 kg ha^{-1}). Hybrid ICPH 2438 produced highest yield in Aurangabad (4533 kg ha^{-1}) and Nizambad (3472 kg ha^{-1}).

Among the medium duration hybrids with A_4 cytoplasm, ICPH 2671 and ICPH 2740 are very promising. In multi-location trials conducted for four years hybrid ICPH 2740 recorded 35.8% superiority over the control. During 2009, the best performing hybrid ICPH 2671 was evaluated in 1248 on-farm trials in four Indian states (Saxena *et al.*, 2010). In these trials ICPH 2671, on average, recorded 28.4% yield advantage over local control, and therefore, ICPH 2671 was released for commercial cultivation in Madhya Pradesh in 2010.

It is obvious that pigeopea has sufficient level of exploitable hybrid vigour. In the hybrids the level of heterozygosity of the parents is highest, thereby masking various deleterious recessives gene. Also simultaneously, it increases the number of loci expressing heterosis in their first filial generation. The frequency of such deleterious alleles, which varies from population to population, is popularly called as genetic load (Vencovsky and Barriga, 1992). In comparison to other pulses, pigeonpea has more inherent capacity to carry hidden genetic load of recessive genes due to its partial natural out-crossing nature and with little efforts breeders can make use of it in enhancing yield (Saxena *et al*., 2006a). Consequently, heterosis and inbreeding depression are complementary to each other. Inbreeding reduces the level of heterozygosity and thereby, exposed deleterious recessives to selection and simultaneously reducing the number of loci expressing heterosis. The present study was undertaken to estimate the magnitude and direction of hybrid vigour in F_1 generation, inbreeding depression in F_2 generation, besides fertility restoration of cytoplasmic nuclear male sterility (CMS) based hybrids. This study was designed to study the relationship between heterosis and inbreeding depression. In summary, the major objectives of this study were to:

- provide information on relative mid-parent heterosis, heterobeltirosis and standard heterosis in medium duration disease resistant pigeonpea hybrids,
- estimate the inbreeding depression from F_1 to F_2 generations for important economic traits, and
- study the genetics of fertility restoration in four crosses using F_1, F_2 and BC_1F_1 generations.

Table 1.1. List of CMS sources derived from different wild relatives of pigeonpea.

Sr. No.	Wild relative	Designation
1	*Cajanus sericeous*	A_1
2	*Cajanus. scarabaeoides*	A_2
3	*Cajanus volubilis*	A_3
4	*Cajanus cajanifolius*	A_4
5	*Cajanus cajan*	A_5
6	*Cajanus lineata*	A_6
7	*Cajanus platycarpus*	A_7

Source: Saxena *et al*., 2010

Chapter II

REVIEW OF LITERATURE

Recently, ICRISAT developed a hybrid pigeonpea breeding technology that was based on cytoplasmic-nuclear male-sterility (CMS) and insect-aided natural out-crossing systems (Saxena *et al*., 2006b). So far, over 1500 experimental hybrids have been tested and promising hybrids with yield advantages of 25 to 156% over the best inbred variety (Kandalkar 2007, Saxena and Nadarajan 2010). In 2010, a promising hybrid ICPH 2671 was released in Madhya Pradesh for commercial production. Therefore, it is important to obtain information on heterosis, heterobeltirosis, and standard heterosis in pigeonpea hybrids, and study the genetics of fertility restoration using F_1 and F_2 and BC_1F_1 generations, and to estimate the relative inbreeding depression from F_1 to F_2 generation for important economic traits. The review on related subjects of the study is presented below under suitable headings.

2.1 Heterosis

"Heterosis" is defined quantitatively as an upward deviation of the mid-parent, based on the mean values of the two parents (Johnson and Hutchinson, 1993). Heterosis is manifested as improved performance for F_1 hybrids generated by crossing two inbred parents. Heterosis may be positive or negative. Depending upon the breeding objectives, both positive and negative heterosis are useful for crop improvement. In general, positive heterosis is desired for yield and negative heterosis for matu rity. Heterosis is expressed in three ways, depending on the criteria used to compare the performance of a hybrid. The three ways are: mid-parent, standard variety and better parent heterosis. However, from the plant breeders' viewpoint, better parent (heterobeltiosis, Fanseco and Peterson, 1968) and/or standard variety (standard heterosis) are more effective. Exploitation of heterosis in agriculture provides enhancing food security and represents a single greatest applied achievement in the discipline of genetics. Pigeonpea is a partially cross pollinated crop and the plants express strong heterosis in their F_1 hybrids. These led to the conclusion of the presence of significant heterosis in pigeonpea, which could be exploited commercially by

developing F_1 hybrids. Solomon *et al*. (1957) were the first to report hybrid vigour in pigeonpea in 10 inter-varietal crosses. Subsequently, a number of reports have been published on hybrid vigour for yield and yield components. Chauhan *et al*. (2008) reported 19.9 to 26.1 % heterosis for yield in pigeonpea, and it was related to an increase in the number of pods plant^{-1}, pod length, and seed size. Recently, 25 to 156 % of seed yield over the best inbred variety have been reported by Kandalkar (2007) and Saxena and Nadarajan (2010).

The research carried out by earlier workers in pigeonpea on heterosis is briefly reviews hereunder.

Solomon *et al*. (1957) were the first to report a study of heterosis in pigeonpea. Hybrid vigour up to a maximum of 24.51 % in grain yield, 13.04% for plant height, 9.6% for pod length were obtained in some of the crosses under his study. However, the fact that the best yielding hybrid had not been able to outyield the yielding type involved in one or more of the crosses.

Shrivastava *et al*. (1976) reported the heterosis in pigeonpea. They studied the heterosis in 17 F_1 hybrid combinations involving 14 genotypes of pigeonpea. Heterotic effects were analysed for yield, its components and some growth factors. Mean heterosis of 67% was obtained for yield, 96% for secondary branches and 80% for number of pods per plant. In general, medium x medium, low x medium crosses resulted in high heterotic performance and indicated that genetic diversity was the key to obtaining hybrid vigour.

Patel *et al*. (1991) reported high degree of standard heterosis for various morpho-physiological traits in short and medium duration genetic male-sterility based pigeonpea hybrids. Short duration hybrid, MS Prabhat x DL 78-1 showed 71.9% standard heterosis and it was due to significant and positive heterosis for morpho-physiological traits such as plant height, harvest index, per day productivity and reproductive period. Hybrid MS 3A x ICPL 8504 in medium group had highest heterosis (74.90%) over standard variety S 5 and BDN 2, respectively. In medium duration group, delayed flowering, taller plant height and high per day productivity was observed to be the causes of high heterotic response for seed yield plant^{-1}.

Patel and Patel (1992) reported heterosis in 30 hybrids derived from six lines and five testers in pigeonpea for yield and important yield contributing traits. Maximum heterosis response over better parent was obtained for number of pods plant^{-1} (169.31%) and it was followed by seed yield plant^{-1} (136.49%). None of the hybrids exhibited significant heterobeltiosis in any direction for pod length and seeds pod^{-1}.

Gumber and Singh (1996) studied the phenomenon of heterosis in pigeonpea crosses involving genotypes of three different growth habits (DT: determinate; SDT: semi-determinate, and IDT: indeterminate). They observed heterosis over better parent was from -16.3 to 19.3% for seed yield plant^{-1}, 36.0 to 78.0% for plant height and -4.0 to 20.30% for pods plant^{-1}. They also indicated that, the cross combinations involving parents of different growth habits expressed greater heterosis while the cross combinations involving parents of similar growth habit (DTxDT or IDTxIDT) exhibited low heterosis over better parent.

Kumar and Srivastava (1998) studied heterosis in relation to combining ability in a line x tester mating design involving three male sterile lines and 12 male fertile lines of long duration pigeonpea for yield and its components. Heterosis over better parent for seed yield ranged from -77.91 to 110.07 %. Pods plant^{-1} and primary branches plant^{-1} contributed substantially towards the expression of heterosis for seed yield. The observed gene action was predominantly non-additive for the characters studied.

Hooda *et al*. (1999) provided the information on heterosis of pigeonpea in seven yield-related traits in the parents and 40 hybrids from a 4 line × 10 tester crosses. Maximum heterosis over the best standard check (Manak) was obtained for the pods plant^{-1} in crosses Qms1 × TAT10 (38.1%), Qms1 × H88-22 (32.9%) and MS Prabhat (DT) × H88-43 (28.9%). For seed yield plant^{-1}, a good magnitude of heterosis ranging from 21.1 to 28.9% was observed.

Khorgade *et al*. (2000) reported the heterosis over the mid-parent and control cultivar (BDN 2) in 24 pigeon pea hybrids. Significant heterosis was observed for seven quantitative characters studied. Significant heterosis over the mid-parent and control cultivar was recorded for seed yield plant^{-1} in the hybrids AKMS 11 × AKT 9221, AKMS 11 × C11, and AKMS 21 × C11.

Chandirakala and Raveendran (2002) reported the heterosis for yield and yield components in 30 pigeonpea hybrids. Crosses with MS Prabhat DT showed marked heterosis for number of pods plant^{-1}, number of clusters plant^{-1}, 100-grain weight, and grain yield plant^{-1}. Significant negative heterosis over mid, better, and standard parents were observed in MS Prabhat DT × ICPL 88009 and MS CO 5 × ICPL 88009 for days to 50% flowering, and in MS Prabhat DT × ICPL 87104, MS Prabhat DT × ICPL 89020, MS Prabhat DT × ICPL 90012, and MS CO 5 × ICPL 87104 for plant height.

Lohithaswa and Dharmaraj (2003) studied heterosis for yield and yield attributes. Observations were recorded for 12 quantitative characters. Non-additive gene effects were predominant for all characters, except for days to 50% flowering, 100-seed weight and protein content, for which additive gene action was predominant. The heterosis values when considered alone were misleading as there was no correspondence with *per se* performance.

Sekhar *et al*. (2004) studied the heterosis in 36 early maturing pigeopea hybrids involving 3 male sterile lines and 12 pollinator lines. Three crosses [QMS-1 x Sel 90307, QMS-1 x Sel 90311 and MS Prabhat (NDT) x Sel 90214] exhibited 51.3 to 171.6% heterosis for seed yield plant^{-1} over the standard check and better parent, respectively. Among the tested materials, the best five hybrids exceeded 40% standard heterosis for seed yield and its components.

Yadav and Singh (2004) reported the heterosis of pigeonpea in yield and its related traits. In their research finding, 20 to 49.8 % of standard heterosis for primary branches plant^{-1} was expressed in all the hybrids except msUPAS 120 x Pant A 134. For seed pod^{-1}, significant positive heterosis was observed in seven hybrids. Number of pods plant^{-1} expressed up to 203.9 % of standard heterosis. The highest standard heterosis for 100-seed weight was 12.1 % in UPAS 120 x Pant A 169. The range of standard heterosis for grain yield over standard variety was -46.03 to 180 %.

Wankhade *et al*. (2005) investigated the amount of heterosis for seed yield and its components by using three genetic male sterile lines (females) and eight testers (males) in a line x tester mating design. The heterosis study was observed for most of the traits, except plant height. The cross AKMS 11 × AKT 9221 showed highest seed yield plant^{-1} and exhibited high heterosis (63.19%) and useful heterosis over BDN 2 (83.34%). The mean squares due to parents and crosses were highly significant for all the characters.

Aher *et al*. (2006) reported the range of heterosis for MP and BP was from 3.25 to 2.25% and 2.50 to 10.50% for days to maturity, -1.10 to 3.15% and 2.9 to 2.4% for number of primary branches plant^{-1}, and -0.95 to 3.35% and -3.0 to 2.5% for secondary branches plant^{-1}. For number of pods plant^{-1}, significant and positive heterosis over mid-parent and better parent was observed in BDN-2 × BDN-201. Heterosis over mid-parent and better parent ranged from -1.65 to 3.60% and -3.30 to 3.20%, respectively, for number of seeds per pod. Heterosis for 100-seed weight was from -0.51 to 0.22% and -1.97 to 0.03% for mid-parent and better parent, respectively. For grain yield plant^{-1}, the range of heterosis over better was -20.66 to 23.79%.

Baskaran and Muthiah (2006) reported the magnitude of relative heterosis, heterobeltiosis and standard heterosis of 18 hybrids derived for seed yield and yield attributing characters. Significant positive heterotic effect over mid-parent, better parent and standard control (CO 5) was recorded for seed yield plant^{-1} in hybrid VBN 1 × ICPL 83027 (81.74%, 66.57% and 68.36%) followed by CO 5 × ICPL 83027 (24.46%, 23.80% and 25.13%) and CORG 9904 × ICPL 83027 (56.47%, 17.77% and 19.03%).

Banu *et al*. (2007) investigated the relative heterosis and heterobeltiosis in 45 pigeonpea hybrids on days to 50% flowering, maturity, plant height, number of branches plant^{-1}, number of clusters plant^{-1}, number of pods plant^{-1}, number of seeds pod^{-1}, pod length and 100-seed weight and single plant yield. ICP 13201 × CO 5 was the best with the maximum heterosis for most of the yield attributing characters, followed by ICP 11961 × ICP 7118 and ICP 11961 × CO 5, which showed higher heretobeltiosis and relative heterosis for most of the yield-attributing characters.

Wanjari *et al*. (2007) evaluated the heterosis in a set of 136 CMS-based pigeonpea hybrids in the background of A_2 cytoplasm along with AKT 8811 as the control. Heterosis over male parent and the control was investigated. Among the 136 hybrids, 11 expressed high pollen fertility (>80%) in all the plants. The hybrids characterized by high pollen fertility varied in terms of heterosis. Six hybrids showed positive heterosis.

Dheva *et al*. (2008a) reported the heterosis in CMS based pigeonpea hybrids. The highest heterosis is observed for the character such as number of pods plant^{-1} (79.43%) followed by grain yield plant^{-1} (68.06%) and plant height (37.89%) over the better parent in desirable positive direction. The highest heterosis over the better parent observed for the character days to 50% flowering (-23.84%) followed by days to maturity (-16.94%) in desirable negative directions.

Dheva *et al.* (2008b) evaluated the heterosis in CMS based hybrid pigeonpea. They studied on 31 hybrids showing fertility more than 80% which are evaluated for the heterosis over the male parent, better parent and standard check. Among these, three hybrids showed heterosis more than 40 % for number of pods and grain yield plant^{-1}. The range of heterosis over check for number of pods per plant is 0.84 to 87.68 % and 0.72 to 57.35 % for grain yield.

Kumar and Krishna (2008) reported the heterosis in pigeonpea over superior and economic parent (T-7) for 13 quantitative characters in pigeonpea. Eight hybrids KA-1 × KA32-1, K35 × Banda Palera, KA-1 × Banda Palera, KA26-8 × Banda Palera, KA26-8 × KA32-1, T_7 × Banda Palera, K9125(B) × Banda Palera, and KA108 × KA32-1 were judged to be promising for grain yield plant^{-1} on the basis of their high heterosic response, *per se* performance.

Patel and Tikka (2008) reported the heterosis for yield and yield components in 45 hybrids and 18 parental genotypes of pigeonpea. For number of pods plant^{-1}, 10 and 20 hybrids recorded significant positive heterosis over the better parent and control, respectively. Eight hybrids were superior over the better parent with respect to number of seeds pod^{-1}. Only two hybrids over the better parent and one hybrid over the control showed significant positive heterosis over the better parent for protein content. For seed yield, 2 hybrids exhibited positive heterosis over the better parent. Hybrid MS 3783 × BSMR 853 (97.54%) recorded the highest positive heterobeltiosis.

Bhavani and Bhalla (2009) analyzed the heterotic effects in 20 hybrid pigeonpea combinations involving five diverse parents belonging to different maturity groups (early, medium and late) for yield and its components. The average heterosis was maximum for yield plant^{-1}, followed by pods plant^{-1} and number of fruit bearing branches. Comparatively, the other yield components showed low average heterosis values. In general, early × late and medium × late combinations resulted in high heterosis for yield.

Dheva *et al*. (2009) reported the heterosis in 31 hybrids for the heterosis over the male parent, better parent and standard check. The three hybrids showed heterosis more than 40% for the number of pods and grain yield plant^{-1}, respectively. The highest standard heterosis is observed for the number of pods plant^{-1} followed by grain yield plant^{-1}. The range of heterosis over check for the number of pods plant^{-1} is 0.84 to 87.68 % and the heterosis over check for the character grain yield plant^{-1} ranged from 0.72 to 57.35 % in desirable direction.

Kumar *et al*. (2009) reported the heterosis of pigeonpea for yield and its component traits. Significant and positive heterosis over better parent and standard check for seed yield plant^{-1} in four crosses was accompanied by significant and high positive heterosis for number of primary branches plant^{-1}, number of pods plant^{-1}, number of pod clusters plant^{-1} and 100 seed weight. This study suggested that heterosis for yield should be through component trait heterosis. Hybrid vigour of individual yield components may have additive or synergistic effect on the yield.

Phad *et al*. (2009) reported the heterosis in pigeonpea by using 60 crosses in four different environments. The top 10 cross combinations recorded significant positive standard heterosis for number of secondary branches plant^{-1}, whereas nine cross combinations recorded standard heterotic effect for plant spread, number of primary branches plant^{-1} and number of pods plant^{-1}. Significant positive standard heterosis was recorded in seven cross combinations for harvest index, two cross combinations for plant height and only one cross combination for 100-seed weight. On the basis of pooled mean, the top 10 cross combinations showed superiority in different environments.

Sarode *et al.* (2009) estimated the heterosis in long duration pigeonpea for yield and yield traits using five lines and three testers. The maximum standard heterosis was recorded in the cross Pusa 9 × Bahar (52.11%), followed by Pusa 9 × ICPL 84023 (44.17%) and DA 11 × Bahar (42.03%) for number of pods plant^{-1}. Hybrid Pusa 9 × Bahar exhibited maximum economic heterosis (55.32%) for 100-seed weight, number of seeds pod^{-1}, pods plant^{-1} and number of primary and secondary branches.

Chandirakal *et al*. (2010) studied the heterosis, heterobeltiosis and standard heterosis in 30 GMS based pigeonpea hybrids. Among these, 13 hybrids exhibited significant and positive heterosis over all the three bases of estimation. The two hybrids showed highly significant and positive heterosis over MP, BP and standard check. The proportion of hybrids exhibiting significant heterotic effect for grain yield with genic male sterile line MS Prabhat DT was greater as compared to lines, MS Prabhat NDT and MS CO5.

Shoba and Balan (2010) studied the magnitude of heterosis in 27 early maturing hybrids. They observed standard heterosis for single plant yield varied from -25.0 (CORG 990047 A x ICPL 87) to 325% (MS CO 5 x PA 128). The promising hybrids, CORG 990047 A x APK 1 manifested heterosis for days to 50% flowering (56.3%), days to maturity (92.47%), plant height (113.0%), number of pods plant^{-1}(106.0%), seed protein content (22.71%) and single plant yield (40.0%). MS CO5 x ICPL 83027 had significant standard heterosis for plant height (98.38%), number of branches plant^{-1}(128.2%), number of pods plant^{-1}(110.0%), number of seeds pod^{-1} (4.50%) and single plant yield (70.0%).

Lay *et al*. (2011) reported the heterosis in CMS-based pigeonpea hybrids. They evaluated fifteen ICRISAT's pigeonpea hybrids in Myanmar at three locations. Hybrids ICPH 2671, ICPH 2673, ICPH 2740 and ICPH 3497 were found stable over the three environments and produced 30.4 to 41.7% standard heterosis. Hybrid ICPH 3461 was found suitable for one environment with 42.0% standard heterosis. In 36 on-farm trials, hybrid ICPH 2671 was 11.9 to 53.1% superior in yield over the control. The other promising hybrid ICPH 2740 also exhibited 70.0% standard heterosis in an on-farm trial.

2.2 Inbreeding Depression

Inbreeding (genetic assortive mating), a converse phenomenum of heterosis, is usually defined as the lowered fitness or vigour of inbred individuals compared with their non-inbred counterparts. It is the most powerful of all mating systems in all self pollinated crops to lower the percentage of heterozygosity in the population leading to fixation of alleles and thus the phenotype to the extent that is under genetic control (Allard, 1960). Precisely assortive mating or inbreeding reduces the proportion of heterozygous loci by half in each generation and homozygous types are correspondingly increased. In quantitative genetic theory, inbreeding depression and heterosis are due to non-additive gene action, and are considered to be two aspects of the same phenomenon (Mather and Jinks, 1982). Thus, the most striking observed consequence of inbreeding is the reducing of mean phenotypic value and the phenomenum known as inbreeding depression. The literature on inbreeding depression in pigeonpea is briefly reviewed here under.

Govil *et al*. (1986) reported various gene effects for eight agronomic characters in pigeonpea in five crosses, (F_1, F_2 and F_3 derivatives of the cross C11 x UPAS-120, UPAS-120 x Pant A3, NP (WR) 15x UPAS-120, Mukta x Prabhat and No.148 x UPAS-120) based on the relationship between mean, heterotic response and inbreeding depression. They observed both additive and dominance gene effects have been found to be predominant for grain yield and its components. Additive effect and the dominance x dominance have reinforced each other considerably in cross UPAS-120 x Pant A3.

Gumber and Singh (1996) studied the inbreeding depression in pigeonpea from data on four yield components in six parents and their F_1 and F_2 hybrids. Cross combinations involving parents of different growth habit expressed high heterosis and low inbreeding depression, whilst cross combinations involving parents of similar growth habit exhibited low heterosis and high inbreeding depression for most of the traits. Of the nine crosses, AF98 × AL201 was identified as having high heterosis for plant height(103.3%), seed yield(19.3%), pod plant^{-1} (12.0%) and low inbreeding depression (36.0%, 5.72% and -3.0%), respectively.

Gupta *et al*. (1996) reported the inbreeding depression in four pigeonpea crosses by using F_1, F_2 and BC_1F_1 population. Relative estimates of gene effects showed the importance of additive and non-additive gene effects in the expression of flowering and maturity. All the four crosses showed inbreeding depression for maturity which reduces the possibility of selecting early types in advanced generations.

Valarmathi *et al*. (1998) studied the inbreeding depression in pigeonpea in the crosses of Pusa 33 X MS Prabhat DT and High Branch X ICPL 4. F_1s of these crosses were selfed and F_2s were evaluated. Heterosis of certain yield components followed by inbreeding depression in the crosses indicated the predominance on non-additive gene action. It is concluded that heterosis for grain yield can be used in breeding programme.

Hooda *et al*. (1999) provided the information on inbreeding depression of pigeonpea derived from data on seven yield-related traits in the parent and 40 hybrids from a 4 line × 10 tester cross. Inbreeding depression in the F_2 over the F_1 generation was generally low for most of the crosses. MS Prabhat (DT) × H88-45 was identified as the best cross in terms of high heterosis and low inbreeding depression.

Aher *et al*. (2006) studied the heterosis and inbreeding depression for seed yield and its components in three crosses of pigeonpea. Positive inbreeding depression was observed for days to maturity, primary branches plant^{-1}, number of pods plant^{-1} and grain yield plant^{-1} due to recessive genes in F_2.

Kumar and Krishna (2008) studied the inbreeding depression in F_2 progenies for 13 quantitative characters in pigeonpea. Eight hybrids showed high heterosis for grain yield per plant and low inbreeding depression.

Anantharaju and Muthiah (2008) studied inbreeding depression for yield *per se* in pigeonpea. The results revealed that inbreeding depression does not seem to be significant in pigeonpeas and dominance played a major role compared to additive genes for yield per se in this crop. They observed that the cross combination LRG 41 and ICPL 87119 exhibited high inbreeding in all character, there was 64.28% for days to 50% flower, 78.57% for maturity, 57.14% for plant height and primary branches, 21.42% for pod cluster, 28.57% for pods plant^{-1}, 21.42 % pod length, 28.57% for 100-seed weight and 35.71% seed yield, respectively.

Since the availability of limited publication in pigeonpea, the literature on inbreeding depression in other crops was briefly reviewed here under suitable crop wise headings.

Soybean (*Glycine max*)

Yin and Yi (2009) studied the inbreeding depression in F_1-F_3 generations of 14 yield and quality traits among parental materials of soybean. The results revealed that the traits with high F_1 heterosis performed high inbreeding depression in F_2 and F_3.

Burton and Brownie (2006) discovered the inbreeding depression in two soybean single crosses by using F_1, F_2, F_3, F_4, and F_5 generations. Cross 1 showed significant heterosis in F_1 than cross 2 F_1 and inbreeding depression when regressed on percentage inbreeding which is clear evidence of dominance for yield.

Darwish (2007) reported the inbreeding depression of some quantitative characters in three crosses of soybean with six populations (P_1, P_2, F_1, F_2, BC_1 and BC_2). Significant positive inbreeding depression were detected for plant height, number of branches plant^{-1}, number of pods plant^{-1}, 100-seed weight and seed yield plant^{-1} in the three crosses, and number of seeds plant^{-1} in the first and second crosses. However, a significant negative value was found for flowering date in the three crosses. In the remaining traits, the values of inbreeding depression were not significant.

El-Sayad *et al*. (2005) reported the inbreeding depression in F_1 and F_2 diallel crosses among six soybean genotypes differing in maturity groups. Some crosses expressed significant inbreeding depression in F_2, ranging from -5.7 to -8.5% for days to maturity, 10.6 to 74.7% for number of pods plant^{-1}, 8.1 to 47.8% for number of seeds plant^{-1}, 5.0 to 21.9% for seed index and from 1.4.5 to 48.7% for seed yield plant^{-1}.

Lentil (*Lens culinaris*)

Sharma (1991) studied the inbreeding depression in lentil together with heterosis. He reported the inbreeding depression in F2 under short days was variable for different crosses and traits. There was heterosis in F1 but no inbreeding depression in F2 generation for morphological triats such as plant height, days to flowering, and harvest index. However, yield related characters such as number of primary and secondary branches, pods plant^{-1}, pod clusters plant^{-1}, and seed yield^{-1} had high heterosis and also high inbreeding depression.

2.3 Genetics of Fertility Restoration

Of the various approaches contemplated to break the existing yield barriers in pigeonpea to feed the increasing population, hybrid technology is considered as one of the promising, sustainable and eco-friendly technologies. Impressive progress and success made by ICRISAT in this regard has encouraged the global pigeonpea production and productivity by adopting the CMS-based hybrid technology. Presence of exploitable hybrid vigour, availability of cytoplasmic nuclear male sterility and fertility restoration system and sound seed production techniques are the pre-requisites for the success of any hybrid breeding programme. In the exploitation of heterosis from potential crosses, the level of fertility restoration would likely be the key for added yield advantages. Therefore, a precise understanding of the genetics of fertility restoration is necessary for improving the efficiency and quality of restorers used in hybrid pigeonpea breeding. The literature on genetics of fertility restoration in pigeonpea is briefly reviewed here under:

Saxena *et al*. (1983) reported the inheritance of the B15B male sterile/fertile character. For the study of male sterile/fertile, male sterile plants of B15B were crossed with cultivars 3D8 103, QPL- 1, and Royes. The F_1 and F_2 generations and test cross progenies of fertile F_1 plants crossed to male sterile B15B were classified for male fertility. The results fitted a 3 fertile: 1 sterile ratio in all cases (all P>001, most P>0.05). The test cross progenies were of limited size but each fitted a 1: 1 ratio. These results suggested that B15B male sterility/fertility was conditioned by a single recessive/dominant gene.

Saxena and Kumar (2003) studied the fertility restoration system in A_2 cytoplasm in pigeonpea. They developed the crosses between 3 CMS lines on the basic of A_2 cytoplasm with 14 diverse pigeonpea lines. Among these, five crosses had 94 to 100% fertility restoration and these parents need to be preserved to use directly in breeding high yielding restorer lines. Six crosses were male-sterile and from this group one or two crosses can be selected to develop maintainer by backcrossing to diversify the genetic base of the CMS system. The remaining three crosses segregated for partial fertility and such pollinators need to improve their genetic purity for fertility restoration ability.

Chauhan *et al*. (2004) studied fertility restoration in cytoplasmic genic male-sterile (CGMS) of pigeonpea derived from *C. scarabaeoides*. To identify perfect pollen fertility restoers, 543 derivative lines of *C. scarabaeoides* x *C. cajan* and 1365 germplasm accessions were used as pollen parent on stable cytoplasmic genic male sterile line GT-288A during *kharif* 1997 to 2003. The F_1 progenies of all the crosses were evaluated during kharif 1998 to 2003 for their pollen fertility. The promising pollen fertility restoring parents were advanced and purified through selfing. Finally, eighteen fertility restoeres were identified and characterized.

Dalvi *et al*. (2008a) reported the fertility restoration in cytoplasmic-nuclear male-sterile lines derived from 3 wild relatives of pigeonpea. To study the fertility restoration of the CMS lines, three cytoplasmic-nuclear male-sterile (CMS) lines derived from *C. sericeus* (A_1 cytoplasm), *C. scarabaeoides* (A_2 cytoplasm), and *C. cajanifolius* (A_4 cytoplasm), were crossed to seven pigeonpea cultivars in a line x tester mating scheme. Twenty-one F_1 hybrid combinations were planted in three environments. 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 2 (A_2 and A_4) cytoplasms. Among crosses involving CMS line (of A_4 cytoplasm) ICPA 2039 one hybrid combination was male-sterile and another male fertile. The remaining five combinations segregated for male-fertility (66–84% fertility restoration). Such testers can easily be purified for use in hybrid breeding programmes by selfing and single-plant selection for 2–3 generations.

Dalvi *et al*. (2008b) studied the genetics of fertility restoration in a CMS line ICPA 2039 and its five fertility restoers in pigeonpea. All the F_1 plants in 5 crosses were fully fertile indicating the dominance of fertility restoring genes. Among the 5 crosses studied, 3 (ICPA 2039 x ICPL 12320, ICPA 2039 x ICPL 11376, and ICPA 2039 x HPL 24-63) segregated in a ratio of 3 fertile : 1 sterile in F_2 generation and 1 fertile : 1 sterile in BC1F1 generation indicating the monogenic dominant nature of a single fertility restoring gene. The crosses ICPA 2039 x ICP 10650 segregated two dominant duplicated gene action with a ratio of 15 fertile : 1 fertile in F_2 and 3 fertile : 1 sterile in BC_1F_1, respectively. The rest cross ICPA 2039 x ICP 13991 had two complementary gene action of 9 fertile : 7 sterile in F_2 and 1 fertile : 3 sterile in BC_1F_1, respectively.

Nadrajan *et al*. (2008) studied the extent of fertility restoration for various cytoplasmic sources across germplasm lines, advanced breeding lines and cultivars. One hundred and sixty eight CGMS based hybrids were synthesized by adopting L x T mating design with 12 CGMS lines and 14 testers. The hybrids were tested for fertility restoration by observing the pollen fertility status. The results indicated that 19 hybrids were restored out of 168 crosses evaluated accounting to 11.3 %. The extent of restoration varied from 9.5 to 14.3 % across the three cytoplasmic sources *viz.*, A_1, A_2 and A_4. Among the three sources of male parents selected, restoration was maximum in the germplasm inbreds as compared to advanced breeding lines and cultivars indicating need for intensive exploration across genetically and geographically diverse genetic resources.

Saxena *et al*. (2010) reported the development of cytoplasmic–nuclear male sterility, its inheritance, and fertility restoration for potential use in hybrid pigeonpea breeding. They searched wide diversity of fertility restores and male-sterility maintainers to produce heterotic hybrids for diverse environments. Among 251 F_1s evaluated, 30 (12.0%) maintained male sterility, 23 (9.2%) restored fertility, and 198 (78.9 %) segregated for male-fertility and sterility traits due to heterozygosity within germplasm accessions. In genetic of fertility restoration studies, all 35 F_1 plants of hybrid ICPA 2067 x ICP 12320 were male fertile indicating the dominance of fertility restoring genes. Out of 359 F_2 plants grown, 303 were fertile where as only 56 exhibited male sterility. This segregation fit well to a ratio of 13 fertile :3 sterile ($P = 0.01$). In BC_1F_1 generation out of 175 plants, 121 were male fertile and 54 had male-sterile anthers, which showed a good fit for a 3 fertile:1 sterile ($P = 0.01$) ratio. These results suggested the presence of 2 dominant genes, with one basic and one inhibitory gene action for the determination of fertility restoration in ICPA 2067.

Saxena *et al*. (2011) reported the genetics of fertility restoration in A_4-based cytoplasm based on diverse maturing hybrids of pigeonpea. They observed that the fertility restoration of extra-early-maturing hybrid (ICPA 2089 x PHR 31) was governed by mono gene with the segregation ratio of 3 fertile: 1 sterile in F_2 and 1 fertile : 1 sterile in BC_1F_1 while early-maturing hybrids ICPA 2039 x ICPR 2438 and ICPA 2039 x ICPR 2447 were governed by digenic duplicate dominant ratio of 15 fertile: 1 sterile in F_2 and 3 fertile : 1 sterile in BC_1F_1. Similarly, late-maturing hybrid ICPA 2043 x ICPR 2671 and ICPA 2043 x ICPR 3497 were also governed by two duplicate dominant genes. It was also observed that hybrids with two dominant genes produced a greater pollen load and expressed greater stability as compared with those carrying a single dominant gene.

Saxena *et al*. (2011) studied the inheritance of the abcordate leaf trait and its fertility restoration ability of the obcordate leaf line ICP 5529. The crosses were made between four CMS-lines (ICPA 2089, ICPA 2047, ICPA 2048 and ICPA 2049) and ICP 5529. All the F_1 plants of the obcordate donor were fully male-fertile and had normal leaves, suggesting that the abcordate leaf trait was recessive and that fertility restoration was due to the effect of dominant gene(s).

Since hybrid pigeonpea breeding technology was the first and new among the legumes, there was limited literature to review. Hence, the available literature on genetics of fertility restoration in other CMS based hybrid crops such as rice, sorghum, peral milliet, sunlower, and sorghum were briefly reviewed hereunder.

Hybrid rice

Ramalingam *et al*. (1992) reported the genetic analysis of fertility restoration in hybrid rice (*Oryza sativa* L.) involving four male sterile lines and five pollen parents. The F_2 segregation classified based on both pollen as well as spikelet fertility in 6 combinations was governed by digenes (9:3:4, 9:6:1, and 12:3:1) and concluded that change in fertility restoration by same pollen parent with different male sterile lines could be due to the influence of female parent genotype.

Anandakumar and Subramaniam (1992) also reported the genetics of fertility restoration in hybrid rice. The cross involving 14 male sterile lines with different maintainers, showed fertility restoration in certain combinations. When F_2 segregating populations were classified based on spikelet fertility, fertility restoration was shown to be governed by 3:1, 9:3:3:1, and 12:3:1 due to allelic differences. This indicated that the cyto-sterility of the same group showed monogenic fertility restoration, whereas crossing plants belonging to different cyto-sterile groups showed a digenic pattern of segregation.

Pradhan and Jachuck (1999) studied the genetics of fertility restoration of elite lines for different cytoplasmic male sterile sources in rice involving sixteen hybrids involving seven CMS lines and seven restorers. The fertility restoration ability of the restorers was controlled by two independent dominant genes which varied from crosses to crosses studied. Such variation could be due to the presence of different restoring genes in the restorers or to the differential penetrance and expression of the restoring genes depending on the nuclear genotype of the female parent.

Shridhara *et al*. (1999) studied the genetics of fertility restoration of WA CMS lines in rice by using five crosses derived from three CMS lines. Pollen and spikelet fertility was 100% in the F_1 generation while in the F_2 the fertility to sterile ratio was 15:1, both for pollen and spikelet fertility. These results indicated the fertility restoration of male sterile lines in rice was controlled by two genes which were independent and dominant in action.

Sharma *et al*. (2001) studied the inheritance pattern of spikelet of fertility restoration in two crosses of hybrid rice. They observed the segregation pattern for spikelet of fertility restoration corresponded with digenic mode of inheritance in both the crosses. The two independently segregating fertility restoring genes present in these restorers exhibited fertile, semi-fertile, semi-sterile and sterile plants to an epistatisis with recessive gene action (9:3:4).

Sarkar *et al*. (2002) studied on five diverse restorers and a 'WA' type CMS in basmati background, revealed the fertility restoration to be governed by two major genes with epistatic interactions that differed from cross to cross. Two restorers segregated in the ratio of 9:3:4 and 1:1:2 in F_2 and BC_1 generations, respectively for pollen and spikelet fertility indicating two major genes with recessive epistasis. Other two crosses showed a segregation ratio of 9:6:1 and 1:2:1 in F_2 and BC_1 generations indicating two major genes governing fertility restoration showing epistasis with incomplete dominance. The rest one gave segregation ratio of 12:3:1 in F_2 and 2:1:1 in BC_1 generation showing digenic dominant epistatic interaction.

Sharma and Singh (2003) studied the inheritance of fertility restoration in four crosses of WA-cms system in rice in Tamil Nadu, India. Genetic analysis was carried out in F_2 and BC_1 populations. The segregation pattern in 2 crosses corresponded to digenic mode of inheritance of fertility restoration with dominant (12:3:1) and recessive (9:3:4) epistasis, respectively. The segregation pattern in the remaining 2 crosses fitted in the trigenic epistatic ratio of 27:30:7, revealing the involvement of a dominant gene, in addition to the 2 major fertility restorer genes, which enabled or enhanced the expression of one of the 2 restorer genes.

Sawant *et al*. (2006) analyzed the inheritance of fertility restoration in five sources of CMS-line in rice. The F_2 segregation classification based on pollen and spikelet fertility in the 28 cross combinations, indicated the presence of 2 independent dominant fertility-restoring genes. The mode of action of the 2 genes varied in different crosses revealing 3 types of interaction, namely epistasis with dominance, epistasis with incomplete dominance and epistasis with recessive.

Ahmadikhah *et al*. (2007) studied the inheritance of fertility restoration of hybrid rice on Neda-A line with seven restore lines. Results from fertility test in F_2 populations indicated that pollen fertility is controlled by two major genes in one line in a ratio of 15 fertile : 1 sterile and one major gene in the remaining lines with ratio of 3 fertile : 1 sterile.

Tan *et al*. (2008) investigated genetic mode and allelism of fertility restorer (*Rf*) genes and the relationship between *Rf* and CMS. Genetic analysis of *Rf* genes indicates that HL- or BT-CMS are controlled by single dominant *Rf* gene and WA-CMS is controlled by one or two pairs of dominant Rf genes, which reflects the characters of the gametophytic and sporophytic restoration CMS type.

Yuan *et al*. (2008) identified the inheritance of restorer gene based on new male sterile cytoplasm (CMS-FA) from wild rice by using six populations, namely, P_1, P_2, P_3, F_1, F_2, B_1F_1, and B_2F_2. The F_1 generation showed a normal condition in fertility, and the F_2 generation had a segregation ratio of 3 (fertile): 1 (sterile) according to Chi-square test. The two test-cross populations both had a segregation ratio of 1 (fertile): 1 (sterile). The results indicated there was only one dominant gene controlling the fertility in the restorer line.

Kunkerkar *et al*. (2009) studied the fertility restoration of four sources of cytoplasmic male sterility in rice. The F_2 and BC_1 populations classified based on pollen and spikelet fertility in the 20 cross combinations, indicated the presence of two independent dominant fertility-restoring genes. The mode of action of the two genes varied in different crosses revealing 3 types of interaction, i.e. epistasis with dominance, epistasis with incomplete dominance and epistasis with recessive. Change in fertility restoration by the same restorer with a CMS line of the same source and of different sources were due to the influence of the female parent genotype or fertility restoring genes having different penetrance or modifier effect.

Hossain *et al*. (2010) studied the genetcis of fertility restoration in hybrid rice using three *indica/japonica* restorers and three 'WA'-type cytoplasmic male sterile lines. Crosses Pusa 6A/P1277-100 and Pusa 3A/P1266-89 showed a segregation ratio of 12:3:1 and 2:1:1 in F_2 and BC_1 generations, respectively, for pollen fertility, indicating two major genes with dominant epistasis involved in fertility restoration. The restorer P1266-89, when crossed with Pusa 5A, segregated in different digenic ratios of 9:3:4 and 1:1:2 in F_2 and BC_1 generations indicating two major genes with recessive epistasis. The same restorer P1266-89 when crossed with Pusa 6A, segregated in ratios of 27:30:7 and 1:2:1 in F_2 and BC_1 generations, respectively, indicating three major genes governing fertility restoration. Restorer P1266-8 when crossed with Pusa 5A and Pusa 6A, gave the same segregation ratios of 27:30:7 in F_2 and 1:2:1 in BC_1 generation, indicating that fertility restoration is also governed by three major genes. The results revealed that two or three major genes govern the fertility restoration, with epistatic interactions that differed from cross to cross.

Sorghum

Tripathi *et al*. (1985) studied the genetics of fertility restoration of sorghum in A x B, A x R, and B x B, and B x R crosses. Based on the results, they observed different segregating patterns and concluded that fertility restoration was governed by three fertility restorer genes; one of them shows major effect. Action of the genes changed with the cytoplasmic-genetic background of male sterile line.

Murty (1986) studied the genetics of fertility restoration in sorghum based on F_2 progenies of A_2 cytoplasm. From these results, at least 3 genes control fertility restoration on A_2 cytoplasm with a ratio of 45 fertile: 19 sterile.

Murty and Gangadhar (1990) studied the genetics of fertility restoration in milo (A_1) and non-milo (A_2) cytoplasms. Among 19 F_2 progenies from crosses between 3 CMS and 8 fertile lines, those based on A_1 cytoplasm segregated in a 3 : 1 ratio and those based on A_2 in a 9 : 7 ratio. Alternative ratios based on digenic control in the former and trigenic in the latter also fitted well. In the present investigation concluded that a single major gene, Msc_1 or Msc_2, governs fertility restoration in A_1 cytoplasm. Both Msc_1 and Msc_2 are necessary for fertility restoration in A_2.

Lonkar (1994) studied the inheritance of cytoplasmic male sterility in sorghum in the F_1, F_2 and backcrossed (F_1 x male sterile parent) generations of A_1 and A_2 male sterile lines. In the F_1 hybrids there was more than 80% seed set, demonstrating satisfactory fertility restoration. In 9 F_2 populations in A_1, 4 had digenic interactions, 3 had trigenic interactions and 2 were monogenic. These results indicate the role of 1-3 genes in fertility restoration of A_1 cytoplasm. In the 9 F_2 populations with A_2, 5 had trigenic interaction, 3 had digenic and 1 had tetragenic interaction. These results indicate the role of 2-4 genes in fertility restoration of A_2 cytoplasm. In the backcross generation, trigenic control of male sterility appeared to be the more appropriate for A_2 cytoplasm.

Arunkumar *et al*. (2004) studied the inheritance of fertility restoration on two hybrids each of milo and maldandi sources of male sterility in rabi sorghum [Sorghum bicolor (L.) Moench]. In milo, fertile and sterile plants in the F_2 involving two hybrids segregated in the ratio of 3 (fertile):1 (sterile), indicating that a single dominant gene controlled fertility restoration. In maldandi, segregated into 15 (fertile) :1 (sterile) in both hybrids, indicating that fertility restoration was controlled by two dominant genes with duplicate epistasis.

Nematzadeh and Kiani (2010) studied the inheritance of fertility restoration in F_2 population at flowering and grain filling stages. Pollen staining test with 1% I_2KI solution showed segregation ratio of 15:1 (fertile:sterile), representing two nuclear independent dominant genes. Segregation for spikelet fertility in F_2 confirmed the results of pollen fertility test.

Sanjana *et al*. (2010) reported the inheritance of male-fertility restoration in A_1, A_2, A_3 and A_4 (M) cytoplasmic male-sterility systems of sorghum (*Sorghum bicolor* L. Monech). The fertility restoration of A_1 CMS system was governed by one basic gene and two duplicate complimentary genes (45F:19S in F_2) all action in dominant fashion while A_2 and A_3 CMS systems was governed by three genes where all of the three complimentary genes in dominant condition restore fertility (27F:37S in F_2). The fertility restoration in A_4(M) CMS system was governed by three genes where any two of the three dominant duplicate-complimentary genes restored fertility (54F:10S in F_2) in post-rainy season while two complementary genes in dominant state restored fertility (9F:7S in F_2) in rainy season in the absence of expression of the third gene.

Pearl Millet

Du *et al*. (1996) studied the inheritance of fertility restoration in pearl millet in a cross between 81 A_4 and 864B. Six F_1 plants were selfed to produce F_2 progenies and backcrossed on 81A_4 to produce BC_1 progenies. The aggregate segregation ratio showed 3 fertile:1 sterile in the F_2 generation and 1:1 in BC_1 generation and indicated that 834B carries a single dominant gene for male fertility restoration of the A_4 CMS system.

Maize

Pour *et al.* (1981) studied the genetics of fertility restoration in the C-group of cytoplasmic male sterility in maize using crosses involving stable maintainer lines and lines that restored full pollen fertility. The data indicated that a single, dominant Rf gene is involved in the restoration of several C-group cytoplasms. This is the first single-gene, sporophytic restorer system described in maize.

Sunflower

Jan and Vick (2007) reported the inheritance and allelic relationships of fertility restoration genes for seven new sources of male-sterile cytoplasm in sunflower. They observed that single dominant gene in a ratio of 3 fertile: 1 sterile controlled the fertility restoration in F_2's segregation ratio in all male sterile lines.

Soybean

Bai and Gai (2005) studied the inheritance of male fertility restoration on 25 restorers for the cytoplasmic-nuclear male-sterile line NJCMS1A of soybean [*Glycine max* (L) Merr.]. The results showed that two pairs of duplicate dominant genes controlled the male fertility restoration in two crosses. Meanwhile, F_2 of other 23 crosses between NJCMS1A and its 23 restorers showed a fertility segregation ratio of 3:1 or 15:1. The five testcrosses selected from the above 23 crosses showed that fertility segregation ratio of 3:1 in BC_1F_1s. Allelism tests showed that restore genes of all restorers in the experiment were allelic to two pairs of dominant genes. All results showed that some restorers bore one pair of dominant restore gene and the others bore two pairs of duplicate dominant gene.

Chapter III

MATERIALS AND METHODS

3.1 Materials

The present investigation was carried out to obtain information on different types of heterosis such as heterobeltiosis (superiority of hybrid over better parent), relative heterosis (superiority of hybrid over mid-parent value) and standard heterosis (superiority of hybrid over standard variety) in first filial generation, inbreeding depression in crosses in the F_2 generation, and genetics of fertility restoration. Twenty-two medium duration disease resistance pigeonea hybrids were selected on the basis of their performance in the multi-locational trials conducted by ICRISAT. The present experiment comprised of 22 F_1 hybrids made by crossing 5 cytoplasmic-nuclear male sterile (CMS) lines and 14 restorers, their F_2 populations, parental lines, and standard check, Asha. Five CMS-lines were ICPA 2043, ICPA 2047, ICPA 2048, ICPA 2078, and ICPA 2092 with A_4 cytoplasm derived from *Cajanus cajanifolius* (Saxena *et al*., 2005) and 14 restorers lines were ICPL 20093, ICPL 20096, ICPL 20098, ICPL 20107, ICPL 20108, ICPL 20111, ICPL 20116, ICPL 20120, ICPL 20123, ICPL 20125, ICPL 20129, ICPL 20136, ICPL 20186, and ICPL 87119 developed by ICRISAT (Table 3.1). The present study was conducted during the *kharif* (monsoon) season of 2010-2011 at ICRISAT, Patancheru, Andhra Pradesh.

3.1.1 Hybridization and selfing

A total of 22 hybrids were synthesized by hand pollinating five females with 14 male lines. Sufficient numbers of hand pollinated seeds were produced during 2009-10 rainy season at ICRISAT. The F_1 plants of each hybrid were selfed to raise quality F_2 seeds.

3.2 Methods

The experimental materials comprised of 22 F_1 hybrids along with their F_2 populations, the parental lines, and a standard check variety. These were evaluated in a randomized complete block design with three replications. A popular variety, Asha was used as standard check variety. The experiment was sown in 27th of May, 2010. The plot size for each female parent (P_1), male parent (P_2), standard check, hybrid (F_1) was three rows while nine rows were sown for each F_2 population. The row length was four meters and these were spaced at 75 cm. The plant to plant spacing was 30 cm. To control sterility mosaic one spray each of Rogor, Thiovit, and Acephate @ 1 l ha^{-1} were used in the early stage of vegetative growth. During reproductive period there was serious damage due to pod borers (*Maruca vitrata* Fab. and *Helicoverpa armigera* Hub.) and sucking insect such as Aphids (*Aphidoidea*). Therefore, one spray each of Thiodan, Indoxacarb, and spinosad @ 1 l ha^{-1} was applied to control the pod borers, whereas Pogor, Thiovit, and Acephate @ 1 l ha^{-1} were used for sucking insects. To reduce competition between the crop and weeds for nutrient uptake, water absorption, and photosynthesis, two weedings were done at the early vegetative growth. Two irrigations were provided at the time of early vegetative growth and pod filling period of plant at reproductive stages, respectively.

Table 3.1 Descriptions of the female parental lines used in hybridization

Sr. No.	Entry	Pedigree	Days to		Plant height (cm)	Seeds pod^{-1}	100-seed weight (g)	Seed colour	% Disease reaction in nursery	
			flower	mature					Wilt	SM
	CMS Lines									
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	114	162	198	4.1	10.0	Brown	19	-
2.	ICPA 2047	ICPA 2047 (ICPA 2039 x ICPL 99050) x ICPL 99050 x ICPL 99050 x ICPL 99050 x ICPL 99050 x ICPL 99050	122	165	242	3.9	10.8	Brown	-	-
3.	ICPA 2048	ICPA 2048 (ICPA 2039 x ICPL 99052) x ICPL 99052 x ICPL 99052 x ICPL 99052 x ICPL 99052 x ICPL 99052	123	168	235	4.2	12.9	Brown	-	-
4.	ICPA 2078	ICPA 2078 (ICPA 2039 x ICPL 118) x ICPL 118 x ICPL 118 x ICPL 118 x ICPL 118 x ICPL 118	103	146	132	4.4	13.7	Brown	-	-
5.	ICPA 2092	ICPA 2092 (ICPA 2039 x ICPL 96058) x ICPL 96058 x ICPL 96058 x ICPL 96058 x ICPL 96058 x ICPL 96058	120	167	220	4.2	9.7	Light Brown	11	-

Where, SM = sterility mosaic disease

Table 3.2 Descriptions of the male parental lines used in hybridization

Sr. No.	Genotype	Pedigree	Days to		Plant height (cm)	Seeds pod^{-1}	100-seed weight (g)	Seed colour	% Disease reaction in nursery	
			flower	mature					Wilt	SM
	Restorer lines									
1.	ICPL 20093	ICPL 87119 x ICP 13831 (Inbred)	124	169	232	3.2	11.3	Brown	8	-
2.	ICPL 20096	ICPL 87119 x ICP 12746 (Inbred)	123	162	228	3.8	10.8	Brown	15	-
3.	ICPL 20098	ICPL 87119 x ICP 12746 (Inbred)	130	174	235	4.2	14.3	Light Brown	-	-
4.	ICPL 20107	MS 3783 x ICPL 87119 (IPH 487 Inbred)	128	168	215	3.7	9.7	Light Brown	86	49
5.	ICPL 20108	MS 3783 x ICPL 87119 (IPH 487 Inbred)	122	165	235	4.3	11.4	Cream	-	-
6.	ICPL 20111	MS 3783 x ICPL 87119 (IPH 487 Inbred)	125	166	245	3.7	9.1	Light Brown	11	4
7.	ICPL 20116	MS 3783 x ICPL 87119 (IPH 487 Inbred)	122	168	180	3.5	9.3	Light Brown	5	-
8.	ICPL 20120	MS 3783 x ICPL 87119 (IPH 487 Inbred)	131	186	288	3.5	12.2	Brown	-	-
9.	ICPL 20123	MS 3783 x ICPL 87119 (IPH 487 Inbred)	122	168	228	3.9	10.8	Brown	-	-
10.	ICPL 20125	MS 3783 x GAUT 85-19 (GUPH 1126 Inbred)	130	182	230	3.7	12.0	Light Brown	7	20
11.	ICPL 20129	MS 3783 x GAUT 85-19 (GUPH 1126 Inbred)	139	184	210	3.7	13.0	Light Brown	-	-
12.	ICPL 20136	MS 3783 x GAUT 85-19 (GUPH 1126 Inbred)	122	165	195	4.0	12.1	White	59	-
13.	ICPL 20186	ICP 10928 selection	145	188	242	3.7	9.4	Light Brown	28	6
14.	ICPL 87119	C11 x ICP 1-6W3B	122	172	228	3.4	10.6	Brown	-	-

Where, SM = sterility mosaic disease

The details of the experimental site, weather conditions, and soil characteristics are presented hereunder:

3.2.1 Experimental site

The experimental site is located at an altitude of 545 m above sea level at a latitude of 17º 32´ N and longitude of 78º 16´ E.

3.2.2 Weather conditions

The mean meterological data recorded during the crop growth period such as rainfall, temperature, sunshine hours, relative humidity, wind speed and numbers of rainy days are presented in Appendix I.

3.2.3 Soil characteristics

The soil of the experimental site is black and classified as Vertisols.

3.3 Collection of Data

Five competitive plants were randomly selected for recording observations on each hybrid, parental line, and standard check. In each F_2 population, 40 plants were sampled in each replication. The details of the observations recorded are as follows:

3.3.1 Days to 50% flower

The difference between date of sowing and the flowering date when about 50% of plants in a plot flowered.

3.3.2 Days to maturity

It was recorded as number of days taken from date of sowing to the date when about 75% of pods in a plot reached maturity.

3.3.3 Plant height

Height of the plant from ground level to the tip of the plant was measured in centimeters at the time of maturity.

3.3.4 Number of primary branches

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

3.3.5 Pod clusters plant^{-1}

The total number of pod clusters which had at least two pods per bunch was recorded.

3.3.6 Pods plant^{-1}

The number of pods born on the sampled plants was counted at maturity.

3.3.7 Pod length (mm)

Ten well developed pods were selected at random from each sample plant and their length was measured in milimeter to estimate average pod length.

3.3.8 Pod width (mm)

It was measured on 10 well developed pods from each sample plant. Their width was recorded in milimeter to estimate average pod width.

3.3.9 100-seed weight (g)

Fully grown 100 seeds of each entry were collected randomly in each plot and their weight was recorded using an electronic balance.

3.3.10 Seeds pod^{-1}

Seeds from randomly selected 10 pods from each sample plant were counted and the average seeds pod^{-1} was calculated.

3.3.11 Seed yield plant^{-1} (g)

From each selected plant dry grains were harvested and threshed separately. Grain weights were recorded after thorough sun drying.

3.3.12 Seed yield plot^{-1} (g)

The plot yield was estimated based on the inner rows of each plot in each replication.

3.3.13 Seed yield (kg ha^{-1})

The grain yield (kg ha^{-1}) was estimated using plot yields.

3.4. Statistical Analysis

The following statistical techniques were used to analyze the data collected from the above mentioned experiment.

3.4.1 Estimation and testing of heterosis

The magnitude of heterosis was worked out on the basis of (i) mid-parent value, (ii) mean value of better parent, and (iii) mean value of standard check. Then estimations are expressed as follows.

3.4.1.1 Heterosis over the mid-parent

Heterosis was expressed as percent increase or decrease in the value of F_1 over the mid-parent using the formula:

$$\text{Per cent heterosis over mid-parent (MP)} = \frac{\overline{F_1} - \overline{MP}}{\overline{MP}} \times 100$$

Where,

$\overline{F_1}$ = mean value of the F_1

$\overline{MP}$ = mean value of the two parents involved in F_1 i.e $(P_1 + P_2)/2$

Significance of relative heterosis was tested by using t-test (Wynne et al., 1970).

$$t = (\overline{F_{1ij}} - \overline{MP_{ij}} / \sqrt{3/8\delta^2 E})$$

Where, $\overline{F_{1ij}}$ = the mean of the ij^{th} F_1 cross

$\overline{MP_{ij}}$ = the mid-parent value for the ij^{th} cross

$\delta^2 E$ = estimate of error variance

3.4.1.2 Heterobeltiosis

Heterobeltiosis was expressed as percent increase or decrease in the value of F_1 over the better parent and it was estimated as per the formula of Liang et al., (1971) and Mather and Jinks (1971).

$$\text{Per cent heterosis over better parent (BP)} = \frac{\overline{F_1} - \overline{BP}}{\overline{BP}} \times 100$$

Where, $\overline{F_1}$ = mean value of the F_1

$\overline{BP}$ = mean value of the better parent

Significance of heterobeltiosis was tested by using t-test (Wynne et al., 1970).

$$t = (\overline{F_{1ij}} - \overline{BP_{ij}} \;/\; \sqrt{3/8\delta^2 E})$$

Where, $\overline{F_{1ij}}$ = the mean of the ijth F_1 cross

$\overline{BP_{ij}}$ = the better parent value for the ijth cross

$\delta^2 E$ = estimate of error variance

3.4.1.3 Standard heterosis

Standard heterosis was expressed as percent increase or decrease in the F_1 value over the standard check.

$$\text{Per cent heterosis over standard check (SC) variety, Asha} = \frac{\overline{F_1} - \overline{SC}}{\overline{SC}} \times 100$$

Where, $\overline{F_1}$ = mean value of the F_1

$\overline{SC}$ = mean value of the standard check variety, Asha

Significance of standard heterosis was tested by using t-test (Wynne et al., 1970).

$$t = (\overline{F_{1ij}} - \overline{SC_{ij}} \;/\; \sqrt{3/8\delta^2 E})$$

Where, $\overline{F_{1ij}}$ = the mean of the ijth F_1 cross

$\overline{SC_{ij}}$ = the standard check value for the ijth cross

$\delta^2 E$ = estimate of error variance

3.4.2 Estimation of inbreeding depression

Inbreeding depression was measured using F_1 and F_2 means values according to the following formula:

$$\text{Per cent of inbreeding depression (ID)} = \frac{\overline{F_1} - \overline{F_2}}{\overline{F_1}} \times 100$$

$$\text{Test of ID} = \frac{\text{Estimated value of ID}}{\text{Standard error of mean}}$$

Where, $\text{Standard error of mean} = \sqrt{V\overline{F}_1 + V\overline{F}_2}$

$V\ \overline{F_1}$ = Variance of F_1 mean

$V\ \overline{F_2}$ = Variance of F_2 mean

3.5. Genetics of Fertility Rstoration

3.5.1 Hybridization and selfing

The genetics of fertility restoration was studied in four hybrids along with their F_2 generation, and their test crosses progenies. These hybrid combinations were selected on the basis of their genetic diversity of parental lines. During 2009 *kharif* (monsoon) season, the parental lines were planted at ICRISAT, Patancheru to undertake crossing programme. The crossing programme involved by crossing three male-sterile lines (ICPA 2043, ICPA 2047, ICPA 2092) with their restorer lines to obtain hybrid crosses and then crossing of these four hybrids with their respective CMS-lines to develop test cross progenies (Table 3.2). Simultaneously, selfing of hybrid plants was done to produce quality F_2 seeds. In the present study, CMS-line ICPA 2047 was crossed with different restorer (ICPL 87119 and ICPL 20107) to obtain information on the influence of restorer line in different genetic backgrounds.

Table 3.3. Crosses selected for studying genetics of fertility restoration

Sr. No.	Hybrid no.	Parentage	Pedigree of male parent
1.	2671	ICPA 2043 x ICPL 87119	C11 x ICP 1-6W3B
2.	2740	ICPA 2047 x ICPL 87119	C11 x ICP 1-6W3B
3.	3359	ICPA 2047 x ICPL 20107	IPH 487 Inbred -2
4.	4012	ICPA 2092 x ICPL 20186	ICP 10928 - Selection
	Test crosses		
1.	2671	ICPA 2043 x ICPH 2671	
2.	2740	ICPA 2047 x ICPH 2740	
3.	3359	ICPA 2047 x ICPH 3359	
4.	4012	ICPA 2092 x ICPH 4012	

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

Materials involving the parents (P_1 and P_2), F_1s, F_2s, and test crosses (A-line x F_1) listed above were planted at Patancheru, Hyderabad during 2010. Three rows of parental lines and hybrids, nine rows of F_2, and six rows of test cross population were grown with four meter row length, spaced at 75 cm between rows and 30 cm between plants.

3.5.3 Recording observations on male-fertility and male-sterility

Pollen fertility/sterility was observed in F_1, F_2, and test cross populations. The hybrids were tested for their pollen fertility status (Alexander, 1969) at the initial flowering stage of each plant for each hybrid, their F_2 and back cross populations. To identify sterility/ fertility of pollen grains, 2 % aceto-carmine solution was used. Ten well developed flower buds were collected randomly from each plant from different parts of the plant at the time of anthesis (9- 10 AM). From each buds the anthers were collected on a micro slide and crushed with a drop of two per cent aceto-carmine stain and examined under a light microscope. Two such microscopic fields were examined for each plant. The round and well stained pollen grains were counted as fertile while shrivelled hyaline pollen grains were scored as sterile. The mean for all the microscopic fields were worked-out and sthe proportion of fertile pollens was expressed in percentage on total for individual plants.

Based on the number of stained and unstained pollen grains, the fertility status was computed as follows:

$$\text{Pollen fertility \%} = \frac{\text{Number of round and stained pollen}}{\text{Total number of pollen grains examined}} \times 100$$

3.5.4 Statistical analysis

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

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

Where,

O = Observed value

E = Expected value

When the calculated value of χ^2 was less than the table value at 2 degree of freedom, the fit was considered to be good or the assumed ratio was correct. Conversely, when the calculated value was more than the table value, the fit was not good and the assumed ratio was not correct. Probability values were recorded for these ratios (Deokar, 1964) for their respective test crosses ratios.

Chapter IV

RESULTS AND DISCUSSION

The present investigation entitled, "**Studies on hybrid vigour and inbreeding depression in CMS-based pigeonpea hybrids"** was conducted using five female parents (A-lines) and 14 male parents (restorers). All the female parents and restorers were obtained from Pigeonpea Breeding Programme, ICRISAT, Patancheru. A set of 22 hybrids was selected on the basis of their performance in ICRISAT's multi-locational trials conducted during the previous two years. These hybrids were evaluated at Patancheru during 2010 *kharif* season to study their hybrid vigour in F_1 generation, and inbreeding depression in F_2 generation. The genetics of fertility restoration was studied in four crosses. Observations were recorded on yield and yield contributing characters such as days to 50% flower, days to mature, plant height (cm), number of primary branches, number of pods plant^{-1}, number of pod clusters plant^{-1}, pod length (mm), pod width (mm), seeds pod^{-1}, 100 seeds weight (g), seed yield plant^{-1} (g), seed yield plot^{-1} (g), and seed yield (kg ha^{-1}). In the present investigation, the *per se* performance of pod setting was low in all the parental lines, standard check variety, F_1s and F_2s. It was attributed to low temperature during the reproductive period that adversely affected pod setting. The low temperature appeared to enhance flower drop in crop plant. The pod setting under low temperature was studied in pigeonpea by Singh and Singh (2010). They reported that at low temperature <6 ºC, all the genotypes stopped their flower opening and cause flower drop. At ICRISAT center, we recorded the low temperature up to 4.5 ºC during the reproductive stage (Appendix II) and consequently there was significant reduction in flower opening and pod setting. A considerable of reduction in yield level was also observed in all the materials as compared to the previous years. The results from the present investigation are described here under:

4.1 Analysis of Variance

The analysis of variance (ANOVA) for parental lines, F_1 hybrids, F_2 generation and standard variety is presented in Table 4.1. The ANOVA showed that the mean sum of squares were significant for all characters except number of pod clusters plant^{-1}. These results indicated highly significant genotypic differences in all the parental lines, standard variety, F_1 hybrids, and F_2 generation for yield and yield components.

Table 4.1. Analysis of variance for yield and related traits

Source	d.f	Mean sum of square											
		Days to 50% flowering	Days to maturity	Plant height (cm)	Primary branches	Pod clusters plant^{-1}	Pods plant^{-1}	Pod length (mm)	Pod width (mm)	Seeds pod^{-1}	100-seed weight (g)	Yield plant^{-1} (g)	Grain yield (kg ha^{-1})
Replications	2	369.47	186.52	3851.2	709.98	3531.4	19884	0.23	1.53	0.14	0.17	1928.60	263187
Treatments	63	177.37**	161.04**	1113.6**	33.49**	858.8^{ns}	8771**	0.15*	0.87**	0.06**	2.96**	1439.70**	107496**
Error	126	13.55	10.24	155.10	16.29	623.30	2378	0.06	0.24	0.04	0.76	466.90	28351

Where, *, ** = significant at 5% and 1% level, respectively

ns = non-significant

4.2 Mean Performance of Hybrids and Parents

The performance of all the tested materials was good for plant growth. However, due to continuous rains and overcast conditions during most vegetative and reproductive period, the flowering was delayed. In addition the problems of flower drop and poor pod set were also observed. Therefore, the yield levels were low as compared to previous years. Since all the A-lines were male sterile, their B-lines were studied. The *per se* performance for all the character studied of parental lines, standard variety, F_1s and F_2s are presented in Table 4.2 - 4.4.

4.2.1 Days to 50% flowering

The female parent ICPB 2078 (118 days) was of short duration, determinate in growth habit and the earliest to flower. Among the medium duration A-lines ICPB 2043 (140 days) was significantly earlier and it was followed by ICPA 2092 (143 days). Among 14 restorer lines, 11 were similar to the check variety, Asha. The rest three restorers ICPL 20093 (161 days), ICPL 20111 (160 days) and ICPL 20129 (163 days) were significantly late in flowering as compared to the check. Nineteen out of 22 hybrids were significantly earlier to flower and the rest three hybrids ICPH 3359, ICPH 4017, and ICPH 4019 were on par with the standard check. The range of 50% flowering was from 129 to 154 days. Among the hybrids ICPH 2671 (129 days) was the earliest to flower followed by ICPH 3763 (137 days) and ICPH 3933 (137 days). Generally, hybrids were earlier in flowering than their respective restorer lines. In F_2 generation, ICPH 3933 (135 days) was the earliest to flower followed by ICPH 2671 (140 days). The range to flowering was from 135 (ICPH 3933) to 156 days (ICPH 3359). All the hybrids in F_2 generation were on par with standard check, Asha (154 days). Most of the hybrids in F_2 generation were earlier to flower than their respective male parents.

In the present investigation, there was continuous rain and cloudy conditions through out crop season. Consequently, there was delayed in flowering in all the tested materials. The line ICPB 2078 (short-duration) started flowering in 118 days. Among the parents, female lines exhibited earliness in days to 50% flower as well as for days to maturity. Hybrids ICPH 2671 was earliest in flowering and maturity on the mean basis followed by ICPH 3933, ICPH 3763, ICPH 3762, and ICPH 4022. In F_2 generation, ICPH 3933, ICPH 2671, and ICPH 4022 were earlier to flower. Pigeopea has been considered as

quantitative short-day flowering plant (Summerfield and Roberts 1985), i.e., onset of flowering is hastened as the day-length shortens. Moreover, both low and high temperature delay flowering in pigeonpea (Whiteman *et al*. 1985).

4.2.2 Days to maturity

ICPB 2078 was a short duration line but it matured in 164 days. Among the medium duration lines, ICPB 2043, ICPB 2048, and ICPA 2092 were earlier than ICPA 2047 (196 days). ICPL 20116 (191 days) and ICPL 20108 (192 days) were the earliest to mature in comparison to other restorers which were at par with the standard check (200 days). All the hybrids were significantly earlier in maturity than standard variety, Asha. ICPH 2671 (174 days) was the earliest to mature followed by ICPH 3933 (183 days), ICPH 3762 (183 days), ICPH 3763 (183 days), ICPH 3461 (185 days), ICPH 4022 (185 days), and ICPH 4024 (186 days). These hybrids were significantly earlier in maturity than standard check. The range of maturity was from 174 (ICPH 2671) to 200 days (Asha). ICPH 3933 (181 days) was earliest to mature followed by ICPH 2671 (185 days). The female parental lines of both the hybrids were also earlier in maturity. The rest of the hybrids took more than 190 days to mature and were on par with standard check. The range of maturity was from 181 (ICPH 3933) to 200 days (Asha).

Based on the present findings, hybrids ICPH 2671, ICPH 3461, ICPH 3762, ICPH 3763, ICPH 3933, ICPH 4022, and ICPH 4024 were earlier in maturity in both F_1 and F_2 generations than starndard variety, Asha. Days to maturity is a difficult character to determine accurately because it is highly influenced by environmental factors such as soil moisture and temperature. All the tested materials showed dealy in maturity. It may be due to interaction between the effect of temperature and photo-period. Bright and dry days are favourable for fertilization, while cloudy, damp weather results in excessive flower drop (Howard *et al.*, 1919; Mahta and Dave, 1931). During the crop season, the extended rainfall and cloudy conditions occurred and there was a serious flower drop resulting in delayed maturity. 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). Days to flower and maturity duration were highly correlated.

4.2.3 Plant height (cm)

ICPB 2078 (145.33 cm) was determinate in growth habit and short in height. Among the female parental lines, ICPB 2092 (282.00 cm) was the tallest followed by ICPB 2047, ICPA 2048. These lines were significantly taller than ICPB 2043 (216.67 cm). Nine hybrids ICPH 2740, ICPH 3477, ICPH 3491, ICPH 3461, ICPH 3359, ICPH 3762, ICPH 2751, ICPH 3494, and ICPH 4019 (262 to 276.33 cm) were significantly taller than the other tested materials. The rest were on par with standard check, Asha (256.67 cm). In F_2 generation, out of 22 hybrids tested, four ICPH 3494 (262.63 cm), ICPH 346 (264.71 cm), ICPH 3762 (262.75 cm), and ICPH 3359 (269.55 cm) were significantly taller than the check.

In the present findings, the range of plant height was from 145 to 283 cm. The female line ICPB 2078 was a determinate type and it had the shortest. Among the medium duration materials, the *per se* performance of the parental lines ICPB 2047, ICPB 2048, ICPB 2092, ICPL 20108, ICPL 20120; hybrids ICPH 2740, ICPH 3461, ICPH 3762, ICPH 3359, ICPH 4012 in F_1 and ICPH 3461 and ICPH 3359 in F_2 generation were significantly superior to the check for plant height. Hybrids ICPH 2671, ICPH 3759, and ICPH 4024 were at par with the check. Plant height is influenced by maturity duration, photoperiod, and environment (Reddy, 1990). It can be substantially increased through prolongation of the vegetative phase by exposure to long-day conditions. Pigeonpea was used in different ways in remote areas such as domestic fuel, to construct huts, and fences. Hence, plant height is an important character to considere for plant selection.

4.2.4 Number of primary branches

Among the five female parental lines, two ICPB 2047 (26.87) and ICPB 2048 (25.40) were significantly higher in this trait than other lines. Out of 14 restorers, five ICPL 20107 (27.87), ICPL 20111 (27.53), ICPL 20120 (25.33), ICPL 20186 (29.07), ICPL 87119 (26.93), and standard variety (25.27) were significantly higher in the number of primary branches than others. Twelve hybrids ICPH 2740, ICPH 3497, ICPH 2751, ICPH 3759, ICPH 2671, ICPH 3759, ICPH 4020, ICPH 3763, ICPH 4017, ICPH 4019, ICPH 3758, and ICPH 4013 were significantly greater in number of primary branches than the others tested materials. The range of these hybrids in this trait was from (26.00 to 30.87). In F_2 generation, ICPH 3491 (26.18), ICPH 4020 (29.15), ICPH 4017 (24.83), ICPH 4019

(24.66) and ICPH 3758 (25.16) were significantly greater than the others. The hybrids ICPH 3933 (19.65) and ICPH 4024 (19.34) showed the lowest value for this trait.

Based on the research findings, the parents ICPB 2047, ICPB 2048, ICPL 20107, ICPL 20111, and ICPL 20186 were higher in *per se* performance for the number of primary branches, whereas, ICPL 20120 and ICPL 87119 were at par with the check. Hybrids ICPH 2740, ICPH 3497, ICPH 2751, ICPH 2671, ICPH 3759, and ICPH 4017 in F_1 and ICPH 4020 in F_2 were significantly higher in number of primary branches than standard variety, Asha. In over 8000 world germplasm accessions the average number of primary branches at harvest time ranged from 2.3 to 66 with a mean of 13.2 (Remanandan *et al*., 1988). In pigeonpea, the plant grows slowly and primary branches start appearing from the 6^{th} to 10^{th} nodes. Varieties differ greatly in the number and angle of their branches when grown at fairly wide plant-to-plant spacings (Reddy, 1990).

4.2.5 Number of pod clusters plant^{-1}

There was no significant difference for this character between parental lines and hybrids and F_2 generation. ICPA 2047 (57.07), ICPA 2048 (48.18) were higher in number of pod clusters followed by ICPA 2092. Among the restorer lines, ICPL 20098 (54.60) and ICPL 20107 (57.33) exhibited the highest *per se* performance in this character followed by ICPL 20111 (43.15), ICPL 20120 (41.33), and ICPL 20129 (45.87). Hybrid ICPH 2740 (74.00) exhibited the highest *per se* performance in pod clusters plant^{-1} followed by ICPH 3359 (71.80), ICPH 3497 (65.26), ICPH 3477 (67.18), ICPH 4012 (62.93), and ICPH 4017 (60.30). Four hybrids ICPH 3762, ICPH 3759, ICPH 3763, and ICPH 4024 showed the lowest *per se* value for this trait varying from 23.07 to 39.20. In F_2 generation, the values of number of pod cluster plant^{-1} in F_2 were lower than that of parental lines and F_1 hybrids. Hybrid ICPH 3491 (36.80) showed the highest value followed by ICPH 3477 (30.80) and ICPH 3762 (30.35). Four hybrids ICPH 3461, ICPH 3763, ICPH 4024, and ICPH 4012 recorded the low value of 11.14 to 17.27 for this trait.

Pod clusters diretly releated to the the number of pods plant^{-1} and determining the performance of yield. The female parents ICPB 2047, ICPB 2048, and male parent ICPL 20107 were significantly higher for pod clusters plant^{-1} whereas hybrids ICPH 2740, ICPH 3477, ICPH 3497, ICPH 3461, and ICPH 3359 had better performance than the check.

4.2.6 Number of pods plant^{-1}

Among the five female parental lines, ICPB 2048 (150.33) manifested the highest value followed by ICPB 2047 (130.80). Among the restorer lines, ICPL 20107 (239.13) and ICPL 20129 (200) and ICPL 20111 (194.67) were significantly higher in pod number than others. Eight hybrids ICPH 2671, ICPH 2740, ICPH 3359, ICPH 3477, ICPH 3497, ICPH 3761, ICPH 4017, and ICPH 4022 expressed significantly higher number of pods plant^{-1} in F_1 than other tested hybrids. Hybrid ICPH 4017 (257.67) showed the highest in *per se* performance followed by ICPH 3359 (248.00), ICPH 3477 (234.20%), and ICPH 2740 (211.07%). Hybrids ICPH 3763 (78.13), ICPH 4019 (84.27), and ICPH 4024 (94.53) manifested low *per se* performance for this character. In F_2 generation, there was no significant difference among F_2 and standard variety. The *per se* performance of number of pods were significantly lower than their F_1 hybrids. ICPH 3762 (128.59) had the highest value followed by ICPH 2671 (114.93).

Based on over all performance, the parents ICPL 20107, ICPL 20111, ICPL 20129; hybrids ICPH 2740, ICPH 3477, ICPH 3497, ICPH 3359, ICPH 2671, ICPH 4017, and ICPH 3761 had significantly higher number of pods plant^{-1} than the check. There was significant reduction in vigour for *per se* performance of primary branches, pod clusters and pods plant^{-1}. The data revealed that hybrids having more number of primary branches, pod clusters and pods plant had superior yield. This indicates that these characters are positively correlated with the seed yield. Sharma *et al*. (1971) also reported seed yield in pigeonpea highly and positively correlated with plant height, number of primary branches, number of secondary branches and number of pods plant^{-1}.

4.2.7 Pod length (mm)

All the female lines showed similar in pod length except ICPA 2048 (4.89 mm). Four male parental lines ICPL 20096 (5.51 mm), ICPL 20098 (5.73 mm), ICPL 20108 (5.61 mm), ICPL 20129 (5.52 mm) had significantly more pod length than others. Out of 22 hybrids tested, seven ICPH 2671 (5.45 mm), ICPH 2740 (5.56 mm), ICPH 3477 (5.42 mm), ICPH 3494 (5.27 mm), ICPH 3758 (5.17 mm), ICPH 3759 (5.49 mm), and ICPH 4019 (5.39 mm) were significantly superior as compared to control and other hybrids. In F_2 generation, three hybrids ICPH 2740 (5.35 mm), ICPH 3477 (5.44 mm), and ICPH 2671 (5.41 mm) had significantly higher in pods than others and standard variety (4.97 mm). ICPH 3491 (4.76 mm) and ICPH 3497 (4.77 mm) had the lowest value for this trait. The

per se performance of the parents ICPL 20108, ICPL 20129, and hybrids ICPH 2740, ICPH 3477, ICPH 3359, ICPH 2671, ICPH 3759 in F_1 and ICPH 3477 in F_2 had significant higher value in pod length than the check.

7.2.8 Pod width (mm)

ICPB 2078 (9.95 mm) showed significantly high value for this character as compare to other female lines. Among the male parental lines, ICPL 20129 (9.62 mm) showed the highest value followed by ICPH ICPL 20098 (8.79 mm) and ICPL 20096 (8.57 mm). The rest of the lines were on par with standard variety. Three hybrids ICPH 3491 (8.62 mm), ICPH 3497 (9.30 mm) and ICPH 4020 (9.27 mm) were significantly superior as compared to control. The rest hybrids were not significantly different for this character. In F_2 generation, eight hybrids ICPH 3491, ICPH 3497, ICPH 3494, ICPH 3933, ICPH 4020, ICPH 4022, ICPH 3763 and ICPH 4024 showed the highest value, varying from 8.52 to 8.97 mm. The rest F_2s were on par with standard variety. The *per se* performance of ICPB 2078, ICPL 20129 and hybrids ICPH 3497 and ICPH 4020 recorded significant higher value in pod width than the check.

4.2.9 Seeds pod^{-1}

For the *per se* performance of seeds pod^{-1} ICPB 2047 (3.58), ICPB 2048 (3.53) and ICPB 2078 (3.39) and ICPB 2092 (3.37) manifested significantly higher value than ICPB 2043 (3.13). Seven restorer lines ICPL 20096 (3.42), ICPL 20098 (3.49), ICPL 20108 (3.41), ICPL 20111 (3.35), ICPL 20123 (3.53), ICPL 20189 (3.40), and ICPL 20136 (3.39) were significantly superior for this character as compared to the control. ICPH 2671 (3.65) and ICPH 3477 (3.59) exhibited the highest *per se* performance followed by ICPH 2740, ICPH 3359, ICPH 3477, ICPH 3497, ICPH 3762, ICPH 3933, ICPH 4012, ICPH 4013, ICPH 4017, ICPH 4024. Other hybrids were not significantly different with standard check in this investigation. There was no significant different in F_2 population in number of seeds per pod. The *per se* performance of this trait was from 3.11 to 3.77. The present investigation indicated that the parents ICPB 2047, ICPB 2048, ICPL 20098 and hybrids ICPH 3477, ICPH 2671, ICPH 3762 in F_1 and ICPH 3477 in F_2 population had more number of seed pod^{-1} than the check.

4.2.10 100-seed weight (g)

ICPA 2078 (12.0 g) was found to have bold seed. It was significantly superior as compared to other female parents. Similarly, ICPL 20129 (11.17 g) was significantly greater than other tested hybrids under study which were not significantly difference from the control. The *per se* performance of 100 seed weight in hybrids ICPH 2671 (10.17 g), ICPH 3933 (10.33 g) and ICPH 4020 (11.50 g) showed bold seed size. The rest of the hybrids under this investigation were not significantly different with the control. Hybrid ICPH 2671 (11.00 g) showed the highest value in F_2 for seed size followed by ICPH 4020 (10.67 g) and ICPH 4022 (10.00 g). Three hybrids ICPH 3497 (7.83 g), ICPH 3359 (7.50 g) and ICPH 4012 (7.67 g) recorded the lowest value for this trait. Seed weight is an important yield component. Cultivars vary widely in this trait. In this study, the parents ICPB 2078, ICPL 20129 and hybrids ICPH 3933, ICPH 2671, ICPH 4020 in F_1 and ICPH 2671, ICPH 4020, and ICPH 4022 in F_2 had bold seed size than the check.

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

ICPA 2048 (67.71 g) showed the highest yield per plant followed by ICPA 2047 (58.46 g). Among the restorer lines ICPL 20107 (103.26 g) manifested significant high yield plan^{-1}. The rest lines were on par with control cultivar. ICPL 20125 (15.54 g), and ICPL 20136 (24.73 g) exhibited the lowest seed yield plant^{-1}. Hybrid ICPH 4017 (98.38 g) recorded the highest seed yield plant^{-1} followed by ICPH 3359 (91.42 g), ICPH 3477 (84.54 g), and ICPH 2740 (78.85 g). These hybrids showed significantly higher yield than standard variety while other tested varieties were at par with control. All the hybrids in F_2 generation showed significantly lower yield than their first filial generation. ICPH 3762 (49.03 g) recorded the highest value in yield plant^{-1} followed by ICPH 3497 (421.15 g), ICPH 3497 (42.15 g), ICPH 4017 (43.76 g), and ICPH 3761 (48.94 g). The lowest value of single plant yield was found in ICPH 4024 (11.39 g).

In our research findings, high grain yield plant^{-1} was recorded by the parental lines ICPB 2048, ICPL 20107, ICPL 20123 and hybrids ICPH 2740, ICPH 3477, ICPH 3497, ICPH 3359, ICPH 2671, ICPH 4017, and ICPH 3761. Among the F_2s, the *per se* performance of individual plant yield of the hybrids ICPH 3477, ICPH 3497, ICPH 3761, ICPH 3762, and ICPH 4017 were more higher than others. These hybrids exhibited high number of pods plant^{-1} and seed pod^{-1}. There was significant yield reduction in F_2 generation. It may be due to low heritability of yield and yield component characters. Due

to dominant gene action in fertility restoration all the F_1s were fertile, however, there was segregation of pollen fertile/sterile plants in F_2s and it may be one of the reasons to reduce yield. Green *et al*. (1981) reported that the plant-to-plant variance in pigeonpea is largely environmental, resulting in ineffective selection for yield on a single-plant basis. The *per se* performance of individual plant yield reflects the effective of the breeding procedure. To develop high yielding hybrids, both the female and male parental lines should have high heritability in single plant yield.

4.2.12 Seed yield (kg ha^{-1})

The female lines ICPB 2078 (602.12 kg ha^{-1}), ICPB 2048 (535.10 kg ha^{-1}) and ICPB 2047 (485.84 kg ha^{-1}) gave significant higher yield than ICPB 2047 and ICPB 2092. Seven out of 14 restorer lines manifested significant higher yield than control and others. These were ICPL 20107 (668.45 kg ha^{-1}), ICPL 20129 (661.98 kg ha^{-1}), ICPL 20111 (601.26 kg ha^{-1}), ICPL 20186 (567.13 kg ha^{-1}), ICPL 20123 (559.30 kg ha^{-1}), ICPL 20096 (513.89 kg ha^{-1}), and ICPL 20108 (472.41 kg ha^{-1}). Hybrid ICPH 2671 (1014.3 kg) showed the highest *per se* performance followed by ICPH 4017 (936.91 kg), ICPH 4022 (840.67 kg). The *per se* performance of eleven hybrids viz. ICPH 2671, ICPH 2740, ICPH 3359, ICPH 3477, ICPH 3491, ICPH 3497, ICPH 3761, ICPH 3933, ICPH 4017, ICPH 4020, and ICPH 4022 were significantly higher in grain yield than control. The rests were at par with standard variety. In F_2 generation, ICPH 3762 (899.09 kg) manifested higher yield followed by ICPH 3761 (809.32 kg) and ICPH 4017 (792.86 kg) than others tested lines. The lowest yield was found in ICPH 4024 (190.79 kg) and ICPH 3763 (186.94 kg).

In the present study, among the parental lines ICPB 2078, ICPL 20107, ICPL 20111, and ICPL 20129 produced the higest *per se* performance of seed yield. Hybrids ICPH 2671 produced the highest yield followed by ICPH 2740, ICPH 4017, ICPH 4022, and ICPH 3491. These hybrids had the high *per se* performance of pod clusters plant^{-1}, pods plant^{-1}, seeds pod^{-1}. In F_2s, hybrids ICPH 3497, ICPH 3761, ICPH 3762, and ICPH 4017 had significant higher yield performance and it was directly correlated with the number of pods plant^{-1}, seeds pod^{-1}, and individual plant yield. Correlation matrix of the important agronomic characters of 10, 670 pigeonpea accessions evaluated from 1975/76 to 1978/88 at ICRISAT Center showed that seed yield had significant correlation in high number of primary and secondary branches plant^{-1}, pod cluster plant^{-1}.

4.2.13 Disease infection

All the tested materials were attacked by sterility mosaic disease in early vegetative growth. However, the infection of wilt (*Fusarium udum* Bulter) and phytophthora blight (*Phytophthora drechsleri* Tucker f. sp. *cajani*) were negligible. The disease infection observed in all the parental lines during cropping season was in table 4.6. There was no infection in ICPB 2043 indicating fully resistant in sterility mosaic. ICPB 2048 had 3.25% of disease reaction. Among the restorer lines, ICPL 20107 (19.31%) had the highest in sterility mosaic infection followed by standard variety, Asha (8.89%). The range of infection among the male-fertility restorers was from 1.62 to 19.31%. Hybrid ICPH 3761 (30.89%) and ICPH 3359 (29.60%) had the highest infection in sterility mosaic disease. It was followed by ICPH 4024 (11.68%). The range of infection was from 0.72 to 30.89%.

Sterility mosaic (SM) is the most important disease of pigeonpea in India and Nepal. In the present study, among the parental lines ICPL 20107 had high per cent of SM disease infection followed by Asha. Hybrids ICPH 3761 was serious in infection of SM in F_1 as well as in F_2. However, the infection was more serious in F_1s than F_2s. Seth (1962) showed that the SM pathogen is transmitted by an eriophyid mite, *Aceria cajani* Channabasavanna. Susceptiblity to SM has been reported to be dominant over resistance and tolerance (Sharma *et al*., 1984) while resistance has been found dominant in certain crosses (Srinivas *et al*., 1997).

Table 4.2. *Per se* performance of yield and yield related traits in female and male parental lines at Patancheru, 2010 *kharif* season

Sr. No.	Genotype	Days to 50% flowering	Days to maturity	Plant height (cm)	Primary branches	Pod clusters plant^{-1}	Pods plant^{-1}	Pod length (mm)	Pod width (mm)	Seeds pod^{-1}	100-seed weigh t (g)	Yield plant^{-1} (g)	Yield plot^{-1} (g)	Seed yield (kg ha^{-1})	Plant stand
	Maintainer lines														
1.	ICPB 2043	140	186	216.67	22.53	17.30	88.67	5.29	8.40	3.13	9.83	21.09	366.70	407.45	41
2.	ICPB 2047	151	196	264.00	26.87	57.07	130.80	5.40	7.45	3.58	8.00	58.46	437.26	485.84	40
3.	ICPB 2048	147	190	262.67	25.40	88.13	150.33	4.89	8.34	3.53	7.83	67.71	481.59	535.10	41
4.	ICPB 2078	118	164	145.33	10.13	17.85	64.92	5.13	9.95	3.39	12.50	18.73	541.91	602.12	40
5.	ICPB 2092	143	187	282.00	20.73	39.33	104.27	5.02	7.65	3.37	8.00	43.47	325.28	361.42	37
	Restorer lines														
1.	ICPL 20093	161	203	241.67	22.87	29.36	105.67	4.84	8.32	3.07	8.50	38.24	311.54	346.15	39
2.	ICPL 20096	153	199	235.33	22.20	26.13	94.73	5.51	8.57	3.42	9.67	33.20	462.50	513.89	41
3.	ICPL 20098	156	200	253.33	23.87	54.60	81.40	5.73	8.79	3.49	8.00	34.77	289.41	321.57	40
4.	ICPL 20107	157	200	242.67	27.87	57.23	239.13	4.85	7.61	3.22	7.50	103.26	601.61	668.45	32
5.	ICPL 20108	154	192	269.00	22.73	37.53	123.13	5.61	8.38	3.41	8.83	47.55	425.17	472.41	41
6.	ICPL 20111	160	205	251.00	27.53	43.15	194.67	5.09	8.22	3.35	7.83	74.64	541.14	601.26	41
7.	ICPL 20116	147	191	231.33	21.13	21.33	71.80	4.96	7.95	3.28	8.33	29.05	285.56	317.29	41
8.	ICPL 20120	158	202	282.67	25.33	41.33	118.93	5.31	8.07	3.29	8.50	45.70	344.65	382.94	41
9.	ICPL 20123	152	196	258.67	23.47	30.27	154.93	5.14	8.09	3.53	8.50	64.92	503.37	559.30	40
10.	ICPL 20125	159	202	246.67	19.60	13.13	36.80	5.13	8.10	3.19	7.67	15.54	110.34	122.60	38
11.	ICPL 20129	163	206	257.67	22.93	45.87	200.00	5.52	9.62	3.27	11.17	58.80	595.78	661.98	39
12.	ICPL 20136	152	198	257.67	23.00	22.73	56.60	5.12	8.18	3.37	7.83	24.73	186.98	207.75	39
13.	ICPL 20186	159	203	253.00	29.07	33.80	111.53	5.28	7.71	3.40	7.67	50.85	510.41	567.13	39
14.	ICPL 87119	152	195	251.00	26.93	52.00	83.87	5.17	7.61	3.34	8.67	33.95	282.86	314.29	38
15.	Asha (check)	154	200	256.67	25.27	25.80	103.40	4.97	8.36	3.32	8.67	38.63	295.97	328.85	40

Table 4.3. *Per se* performance of yield and yield related traits in CMS-based pigeonpea hybrids at Patancheru, 2010 *kharif* season

Sr. No.	ICPH no.	Days to 50% flowering	Days to maturity	Plant height (cm)	Primary branches	Pod cluster plant^{-1}	Pods plant^{-1}	Pod length (mm)	Pod width (mm)	Seeds pod^{-1}	100-seed weight (g)	Yield plant^{-1} (g)	Yield plot^{-1} (g)	Seed yield (kg ha^{-1})	Plant stand
1.	2671	129	174	258.33	29.93	44.20	189.27	5.45	7.62	3.65	10.17	68.06	912.87	1014.3	38
2.	2740	144	188	268.00	28.60	74.00	211.07	5.56	7.70	3.45	9.00	78.85	655.42	728.24	39
3.	2751	146	191	262.33	30.27	44.87	110.08	4.97	7.95	3.32	9.17	39.08	338.31	375.9	37
4.	3359	149	192	279.53	21.80	71.80	248.00	5.31	8.20	3.41	9.33	91.42	567.39	630.43	31
5.	3461	143	185	267.00	23.60	61.60	130.27	5.09	7.56	3.50	8.33	55.39	457.62	508.47	34
6.	3477	146	190	262.00	24.60	67.18	234.20	5.42	7.80	3.59	9.50	84.54	649.51	721.68	36
7.	3491	144	187	262.33	23.33	40.27	184.47	4.87	8.62	3.20	9.33	62.13	693.08	770.09	36
8.	3494	143	190	269.00	26.33	28.93	92.60	5.27	8.17	3.30	8.67	36.33	340.29	378.1	38
9.	3497	146	189	260.33	30.87	62.56	196.13	4.9	9.30	3.55	9.17	76.19	559.17	621.3	36
10.	3758	145	192	253.00	25.47	40.67	134.33	5.17	8.32	3.23	9.83	44.76	433.11	481.23	39
11.	3759	142	187	257.33	28.80	36.33	122.33	5.49	8.40	3.36	8.83	47.91	386.24	429.15	34
12.	3761	147	190	259.00	23.87	54.09	205.53	5.07	7.87	3.35	8.67	76.3	598.35	664.83	32
13.	3762	138	183	276.33	24.13	39.20	150.20	5.22	7.79	3.60	8.67	62.5	521.38	579.31	38
14.	3763	137	183	251.50	26.20	23.07	78.13	4.98	8.05	3.29	8.83	46.48	207.38	230.42	31
15.	3933	137	183	243.33	18.27	54.80	116.60	4.75	8.32	3.43	10.33	39.15	534.14	593.49	37
16.	4012	142	188	264.33	21.07	62.93	144.53	5.07	7.70	3.47	8.50	59.35	468.03	520.03	33
17.	4013	143	188	261.33	24.83	37.67	140.53	5.15	7.79	3.42	8.50	57.34	435.89	484.32	37
18.	4017	151	197	249.67	29.07	60.30	257.67	5.24	7.85	3.41	9.00	98.38	843.22	936.91	35
19.	4019	148	191	276.00	26.00	23.87	84.27	5.39	8.32	3.26	8.33	58.8	301.59	335.09	35
20.	4020	146	192	239.00	24.67	44.20	175.00	5.33	9.27	3.36	11.50	50.44	655.27	728.08	37
21.	4022	139	185	239.33	20.80	41.87	170.93	5.17	8.63	3.27	9.83	56.32	756.6	840.67	35
22.	4024	141	186	256.00	23.67	34.53	94.53	5.35	8.33	3.40	8.83	36.34	292.18	324.65	31
	CV%	2.5	1.7	4.9	16.8	20.4	14.8	4.90	6.10	5.90	9.8	11.8	12.7	12.10	10.10
	$CD_{(0.05\%)}$	5.95	5.16	20.12	6.25	40.34	78.80	0.40	0.80	0.32	1.41	34.91	530.80	272.10	10.29
	SE (±)	3.00	1.84	7.19	2.33	14.41	28.16	0.14	0.28	0.11	0.50	12.47	189.70	97.20	3.67

Table 4.4. *Per se* performance of yield and yield related traits in F_2 generation in CMS-based pigeonpea hybrids at Patancheru, 2010 *kharif* season

Sr. No.	ICPH no.	Days to 50% flowering	Days to maturity	Plant height (cm)	Primary branches	Pod clusters plant^{-1}	Pods plant^{-1}	Pod length (mm)	Pod width (mm)	Seeds pod^{-1}	100-seed weight (g)	Yield plant^{-1} (g)	Yield plot^{-1} (g)s	Seed yield (kg ha^{-1})	Plant stand
1.	2671	140	185	237.42	22.62	22.14	114.93	5.41	7.66	3.48	11	36.32	1612.15	597.09	116
2.	2740	151	196	259.58	23.66	18.43	58.94	5.35	7.76	3.33	9.17	21.07	937.35	347.17	104
3.	2751	151	196	251.38	25.09	21.26	70.04	4.9	8.36	3.35	8.67	27.16	1336.01	494.82	115
4.	3359	156	199	269.55	22.26	28.83	83.62	5.18	7.62	3.23	7.5	36.02	1281.99	474.81	118
5.	3461	148	191	264.71	22.48	17.27	56.32	4.99	7.7	3.49	8.33	23.28	1093.15	404.87	115
6.	3477	154	198	253.13	24.18	30.8	98.74	5.44	8.04	3.77	9.17	41.49	1774.96	657.39	122
7.	3491	147	190	253.5	26.18	36.8	85.16	4.76	8.91	3.23	9	30.58	1824.67	675.8	118
8.	3494	150	196	253.58	22.13	28.87	93.22	5.08	8.87	3.23	9.67	31.06	1517.63	562.09	118
9.	3497	151	194	262.63	24.13	25.02	102.06	4.77	8.97	3.24	7.83	42.15	1917.47	710.17	116
10.	3758	154	197	253.29	25.16	20.25	69.48	4.86	7.89	3.11	9.17	23.23	1092.32	404.56	100
11.	3759	148	194	237.78	22.18	20.69	64.89	5.3	8.27	3.19	9.17	22.69	1280.42	474.23	113
12.	3761	152	195	249.92	23.73	33.62	122.97	5	7.57	3.34	8.17	48.94	2185.17	809.32	104
13.	3762	147	191	262.75	20.09	30.35	128.59	5.2	7.64	3.36	8.83	49.03	2427.56	899.09	110
14.	3763	150	194	246.54	20.62	11.14	31.61	4.89	8.86	3.17	8.17	33.8	504.74	186.94	109
15.	3933	135	181	214.42	19.65	22.32	95.27	5.04	8.88	3.31	9.5	33.96	1712.13	634.12	113
16.	4012	152	198	231.71	22.68	19.86	84.25	4.9	7.46	3.28	7.67	36.22	1737.88	643.66	109
17.	4013	147	191	258.25	23.39	21.9	70.16	5.02	7.64	3.39	8.67	26.7	1465.3	542.7	115
18.	4017	148	191	244.75	24.83	28.52	117.65	4.84	8.09	3.32	9	43.76	2140.71	792.86	109
19.	4019	152	196	261.54	24.66	26.09	73.68	5.1	7.96	3.2	9.33	24.5	1324.17	490.43	121
20.	4020	148	193	241	29.15	29.08	101.93	5.23	8.82	3.24	10.67	35.33	1815.56	672.43	118
21.	4022	141	185	242.33	22.88	25.66	85.34	4.98	8.52	3.08	10	26.07	1608	595.55	109
22.	4024	150	196	245.75	19.34	10.89	34.72	5.21	8.6	3.2	8.17	11.39	515.14	190.79	105
	CV%	2.5	1.7	4.9	16.8	20.4	14.8	4.90	6.10	5.90	9.8	11.8	12.7	12.10	10.10
	$CD_{(0.05\%)}$	5.95	5.16	20.12	6.25	40.34	78.80	0.40	0.80	0.32	1.41	34.91	530.80	272.10	10.29
	SE (±)	3.00	1.84	7.19	2.33	14.41	28.16	0.14	0.28	0.11	0.50	12.47	189.70	97.20	3.67

Table 4.5. The percentage of disease infection in parental lines and standard variety during early vegetative growth at ICRISAT, Patancheru, 2010 *kharif* season

Sr. No.	Genotype	% Disease reaction during crop season		
		Wilt	Sterility mosaic	Phytophthora blight
	Maintainer lines			
1.	ICPB 2043	-	-	-
2.	ICPB 2047	-	0.81	-
3.	ICPB 2048	-	3.25	-
4.	ICPB 2078	-	0.00	-
5.	ICPB 2092	-	1.62	-
	Restorer lines			
1.	ICPL 20093	-	1.75	-
2.	ICPL 20096	-	-	-
3.	ICPL 20098	-	-	-
4.	ICPL 20107	-	19.31	-
5.	ICPL 20108	-	-	-
6.	ICPL 20111	-	1.62	-
7.	ICPL 20116	-	-	-
8.	ICPL 20120	-	-	-
9.	ICPL 20123	-	-	-
10.	ICPL 20125	-	4.57	-
11.	ICPL 20129	-	-	-
12.	ICPL 20136	-	-	-
13.	ICPL 20186	-	4.81	-
14.	ICPL 87119	-	3.73	-
15.	Asha	-	8.89	-

Table 4.6. The percentage of disease infection in F_1 and F_2 generation during early vegetative growth at ICRISAT, Patancheru, 2010 *kharif* season

Sr. No.	ICPH No.	% Disease reaction during crop season					
		F_1 generation			F_2 generation		
		Wilt	SM	Phytophthora blight	Wilt	SM	Phytophthora blight
1.	2671	-	0.92	-	-	2.91	-
2.	2740	-	3.25	-	-	9.11	-
3.	2751	-	0.79	-	-	2.45	-
4.	3359	-	29.60	-	-	7.69	-
5.	3461	-	0.95	-	-	6.73	-
6.	3477	-	3.74		-	4.66	-
7.	3491	-	-		-	0.26	-
8.	3494	-	-	-	-	2.37	-
9.	3497	-	-	-	-	9.28	-
10.	3758	-	-	-	-	0.27	-
11.	3759	-	0.83	-	-	0.59	-
12.	3761	-	30.89	-	-	17.61	-
13.	3762	-	0.81	-	-	5.39	-
14.	3763	-	7.58	-	-	3.67	-
15.	3933	-	8.02	-	-	11.26	-
16.	4012	-	5.83	-	-	5.59	-
17.	4013	-	-	-	-	3.49	-
18.	4017	-	0.72	-	-	9.04	-
19.	4019	-	0.92	-	-	2.06	-
20.	4020	-	-	-	-	-	-
21.	4022	-	-	-	-	-	-
22.	4024	-	11.68	-	-	1.14	-

4.3 Heterosis

Pigeonpea is a partially cross-pollinated species and due to its out-crossing behaviour, strong heterosis in pigeonpea is observed in their F_1 hybrids. Heterosis refers to the superiority of F_1 hybrid in one or more characters over its parents. The term hybrid vigour is frequently used as synonym for heterosis. Generally, it is believed that increased vigour in plant growth and a higher seed production are usually realized in the first filial generation. Heterosis may be positive or negative. Depending upon breeding objectives, both positive and negative heterosis are useful for crop improvement. In general, positive heterosis is desired for yield and negative heterosis for early maturity. A study of this phenomenon is necessary to explore possibility of the exploiting of heterosis in the CMS-based pigeonpea hybrids at commercial level. Heterosis is expressed in three ways, depending on the criteria used to compare the performance of a hybrid. The three ways are: mid-parent, standard variety and better parent heterosis. Better parent and/or standard variety is more effective. Solomon *et al*. (1957) were first to report 25% of hybrid vigour for yield in pigeonpea over the better parent in 10 inter-varietal crosses. Subsequently, pigeonpea scientists published their studies confirming the presence of heterosis for yield in pigeonepa. Saxena and Sharma (1990) reported a considerable additive and non-additive gene action which can be exploited in heterosis breeding. Saxena *et al*. (2006) reported 50 to 100% of standard heterosis in medium duration pigeonpea hybrids over the popular varieties and local checks. Kandalkar (2007) also found up to 156 % of standard heterosis for grain yield in CMS-based medium duration pigeonpea hybrids. Chauhan *et al*. (2008) reported 19.9 to 26.1% heterosis for yield in pigeonpea, and it was related to the increased number of pods plant^{-1}, pod length, and seed size.

In the present study, different levels of heterosis were measured as per cent increase or decrease of hybrids over mid-parent (relative heterosis), better parent (heterobeltiosis) and the standard heterosis for different characters. The research findings for different traits are described below:

4.3.1.1 Days to 50% flowering

ICPH 2671 (-14.76%), ICPH 4012 (-10.88%), ICPH 4020 (-10.25%), and ICPH 3497 (-10.08%) showed negative heterosis over better parent (Table 4.7). All the tested hybrids showed significant heterobeltiosis in negative direction expect ICPH 3491 (-1.37%) which was on par at better parent. The range of heterobeltiosis was from -14.76% (ICPH 2671) to -1.37% (ICPH 3491). For relative heterosis, 13 out of 22 hybrids showed significant negative heterosis. ICPH 2761 (-11.25%) recorded the highest negative value followed by ICPH 3763 (-9.89%). However, ICPH 3933 (1.68%) exhibited positive heterosis but it was on par with the mid parental value. The relative heterosis ranged from -11.25% (ICPH 2671) to 1.68% (ICPH 3933). All the hybrids showed negative heterosis over standard check variety, Asha. Among these, five hybrids ICPH 2671 (-16.09%), ICPH 3762 (-10.25%), ICPH 3763 (-11.33%), ICPH 3933 (-11.12%) and ICPH 4022 (-9.82%) were significantly earlier than the standard check and the rests were on par. The range of standard heterosis was from -2.25% (ICPH 4017) to -16.09% (ICPH 2671).

The estimated heterosis for days to flower character are mentioned in Table 4.7. All the hybrids had desirable negative heterosis for days to flower. Among these, hybrids ICPH 2671, ICPH 3762, ICPH 3763, ICPH 3933, and ICPH 4022 were the top five hybrids with significant negative heterosis. Early to flower and mature is a desirable trait in hybrid pigeonpea in escaping drought and ensuring high yield. Based on the present research findings, the hybrid ICPH 2671 ranked first in higher negative heterosis indicating the presence of exploitable hybrid vigour for early flowering. The significant negative heterosis for this character was also reported by Chaudhari (1979), Singh *et al*. (1989) and Pandey and Singh (2002). Wankhade *et al*. (2005) also reported significant negative heterosis for days to 50% flower in the hybrids based on genetic male-sterility system where as Sarode *et al*. (2009) investigated significant negative heterosis in long duration pigeonpea. Kandalkar (2007) and Shoba and Balan (2010) also reported significant negative heterosis in CMS based hybrids showing preference for the early flowering hybrids.

4.3.1.2 Days to maturity

Negative heterosis in maturity over different levels of heterosis is a desirable heterosis for early maturity. Among the 22 hybrids, the significant negative heterosis over better parent was found in twenty. Hybrid ICPH 3763 (-9.72%) showed the highest negative value followed by ICPH 2671 (-8.92%) and ICPH 3497 (-7.95%) and ICPH 4012 (-7.54%). The hybrids ICPH 2751 and ICPH 3491 showed negative heterosis but these were not significantly different from this better parent (Table 4.7). The negative heterosis over mid-parent was found in 18 out of 22 hybrids. Two hybrids ICPH 2751 (-0.69%) and ICPH 3491 (-0.71%) showed negative heterosis but it was on par with mid-parent (Table 4.7). ICPH 3933 (1.76%) and ICPH 4017 (0.68%) expressed positive heterosis but not significantly different from mid-parent. The range of relative heterosis was -7.71% (ICPH 2671) to 1.76% (ICPH 3933). All the hybrids manifested significant negative heterosis over the check variety Asha except ICPH 4017 (-1.5%). ICPH 2671 (-13.31%) was the earliest to mature followed by ICPH 3763 (-8.82%), ICPH 3933 (-8.82%) and ICPH 3762 (-8.49%).

For maturity, six hybrids ICPH 2671, ICPH 3461, ICPH 3762, ICPH 3763, ICPH 4022 and ICPH 4024 exhibited significant and negative heterosis over the estimation of different range. Heterosis for this trait ranged from -9.72 to -1.58%, -7.71 to 1.76% and -13.31 to -1.50% over better, mid and standard parent, respectively. Extent of negative heterosis for days to maturity was reported by Chaudhari (1979) and Pandey and Singh (2002). The crosses maturing early involved at least one early maturing parent. Similar results were also reported by Phad (2003) and Kandalkar (2007), Sarode *et al*. (2009), and Shoba and Balan (2010).

4.3.1.3 Plant height

ICPH 3758 (-6.64%) and ICPH 4020 (-7.24%) recorded the significant negative heterobeltiosis. Eight hybrids ICPH 3759 (7.22%), ICPH 2671 (4.44%), ICPH 4012 (3.79%), ICPH 3494 (2.41%), ICPH 3761 (2.37%), ICPH 3763 (1.96%), ICPH 2740 (1.52%), and ICPH 4013 (1.03%) showed positive heterosis. The rest of the hybrids manifested non-significant negative heterosis (Table 4.7). Out of 22 hybrids, ICPH 2671 (11.35%), ICPH 3933 (23.94%) and ICPH 3759 (8.28%) showed significant positive heterosis over mid parent. Seven hybrids ICPH 3461, ICPH 3497, ICPH 3758, ICPH 4017, ICPH 4019, ICPH 4020, and ICPH 4024 exhibited negative heterosis in plant height (Table 4.7). The range of relative heterosis was from -3.95% (ICPH 4020) to 23.94% (ICPH 3933). These hybrids ICPH 3359 (8.91%), ICPH 3762 (7.66%), and ICPH 4019 (7.53%) manifested significant positive heterosis over standard check. Seven hybrids ICPH 3758, ICPH 3763, ICPH 3933, ICPH 4017, ICPH 4020, ICPH 4022, and ICPH 4024 showed negative heterosis over standard check but they were non-significant.

Six hybrids ICPH 2671, ICPH 3494, ICPH 3759, ICPH 3761, ICPH 4012, and ICPH 4013 exhibited significant and positive heterosis in heterobeltiosis, relative and standard heterosis. Heterosis for plant height ranged from -7.24 to 7.22% for heterobeltiosis, -3.95 to 23.94% for relative heterosis, and -6.88 to 8.91% for standard heterosis, respectively. Significant positive heterosis for plant height was reported by several workers including Solomon *et al*. (1957), Singh (1971), Sharma *et al*. (1973), Veeraswamy *et al*. (1973), Chaudhari (1979) and Jain and Saxena (1990). Pandey and Singh (2002) reported negative standard heterosis for plant height in pigeonpea. The negative heterosis in the context of breeding dwarf genotype will be desirable. However, later Wankhade *et al*. (2005), Sarode *et al*. (2009), and Shoba and Balan (2010) also reported significant positive heterosis for plant height.

4.3.1.4 Primary branches

Four hybrids ICPH 3359 (-23.34%), ICPH 3491 (-24.24%), ICPH 3933 (-31.84%) and ICPH 4012 (-27.52%) showed significant negative heterosis over better parent. Twelve hybrids showed positive heterosis but only ICPH 3759 (24.50%) exhibited significant positive heterobeltiosis. The range of heterobeltiosis was from -31.84% (ICPH 3933) to 24.50% (ICPH 3759). Thirteen out of 22 hybrids recorded positive heterosis over mid-parent. Among these, only two hybrids ICPH 2671 (21.35%) and ICPH 4012 (27.06%) showed significantly superior over mid-parent. Six hybrids ICPH 3359 (-13.95%), ICPH 3491 (-10.37%), ICPH 3497 (-30.72%), ICPH 3761 (-11.17%), ICPH 4012 (-18.56%) and ICPH 4022 (-10.60%) exhibited significant negative heterosis. The range of relative heterosis was from -30.72% (ICPH 3497) to 27.06% (ICPH 3759). Out of 22 hybrids, 12 had negative heterosis over standard check and the rest 10 hybrids manifested positive heterosis. ICPH 2671 (18.47%), ICPH 2740 (13.19%), ICPH 2751 (19.79%) and ICPH 3497 (22.16%) showed significant positive heterosis over standard variety. Three hybrids ICPH 3933 (-27.7%), ICPH 4012 (-16.62%) and ICPH 4022 (-17.68%) recorded significant negative heterosis over Asha (Table 4.7).

Among the 22 hybrids, ICPH 2671, ICPH 2740, ICPH 2751, ICPH 3758, ICPH 3759, ICPH 3763, ICPH 4017 and ICPH 4019 manifested positive heterosis over mid, better parents and standard variety, respectively. For the number of primary branches, the range of heterosis over better, mid and standard parent was from -31.84 to 24.50%, -30.72% to 27.06% and -27.7 to 22.16%, respectively. Hybrids ICPH 2671, ICPH 2751 and ICPH 3759 were the top ranking crosses with positive heterosis. Significant negative heterosis for branches was also reported by Solomon *et al*. (1957), Chaudhari (1979), Narladkar and Khapre (1996), Pandey and Singh (2002), Wankhade *et al*. (2005), and Sarode *et al*. (2009). However, Shoba and Balan (2010) reported significant positive and negative heterosis in CMS/GMS based pigeonpea hybrids.

4.3.1.5 Pod length (mm)

ICPH 3491 showed significant negative heterosis over both mid and better parents. Other hybrids were at par with better parent. The range of heterobeltiosis was from -12.45% (ICPH 3491) to 4.56% (ICPH 4024). Similarly, ICPH 3491 (-9.42%) showed significant negative heterosis over mid-parent. The rest of the hybrids were not significantly different with mid-parent in positive and negative direction. The range of relative heterosis was from -9.42% (ICPH 3491) to 6.75% (ICPH 4024). Hybrids ICPH 2671 (9.66%), ICPH 2740 (11.97%), ICPH 3477 (9.05%), and ICPH 3759 (10.6%) showed significant positive heterosis over Asha. Three hybrids ICPH 3491 (-1.91%), ICPH 3497 (-1.42%), and ICPH 3933 (-4.32%) showed negative heterosis but it was not significantly superior over the standard variety (Table 4.8).

ICPH 3491 manifested significant negative heterosis in the length of pods over mid and better parent. Lower value of positive and negative heterosis was observed for this character. The range of heterosis over better, mid and standard parents was from -12.45 to 4.56%, -9.41 to 6.75% and -4.32 to 11.97%, respectively. Hybrids ICPH 3491 and ICPH 3933 showed negative heterosis over better, mid parents and standard variety. Low level of heterosis was observed in this character as compare to other traits. Hiremeth and Talwar (1971), Singh *et al*. (1972) reported that low genetic advance for pod length.

4.3.1.6 Pod width (mm)

Of the 22 hybrids under study, ICPH 2671 (-9.28%), ICPH 3477 (-11.29%) and ICPH 3933 (-16.44%) showed significant negative heterosis over better parent. All the hybrids were non significant in relative heterosis for pod length. The range of relative heterosis was from -5.96 (ICPH 3933) to 5.44% (ICPH 3497). Hybrids ICPH 2671 (-8.84%) and ICPH 3461 (-9.61%) showed significant negative heterosis over Asha. However, ICPH 3497 (11.16%) exhibited significant positive heterosis. The range of standard heterosis was from -9.61 to 11.16% (Table 4.8).

Among 22 hybrids, 10 showed negative heterobeltiosis, relative heterosis and standard heterosis. Significant negative heterosis in pod width over better and standard parent was found in hybrids ICPH 2671, ICPH 3477 and ICPH 3933. The range of heterosis was from -16.44 to 3.22% for heterobeltiosis, -5.95 to 5.44% for relative heterosis, and -9.61 to 11.16% for standard heterosis. Sidhu and Sandhu (1981) reported that pod width was governed by additive gene effect.

4.3.1.7 Pod clusters plant^{-1}

Seven hybrids showed negative heterosis over better parent. Among these, ICPH 2751 (49.09%), ICPH 3494 (-67.17%) and ICPH 4019 (-42.25%) recorded significant negative heterosis over better parent. Hybrids ICPH 2671 (102.13%) and ICPH 3933 (150.61%) showed significant heterobeltiosis in positive direction (Table 4.8). The range of heterobeltiosis was from -67.17 to 150.61%. Two hybrids ICPH 2671 (125.70%) and ICPH 3933 (175.93%) showed significant positive heterosis over mid-parent while four hybrids ICPH 2751 (-35.97), ICPH 3491 (-23.96), ICPH 3494 (-58.82%), ICPH 4019 (26.03%) manifested significant negative in relative heterosis. The range of relative heterosis was from -58.82 (ICPH 3494) to 175.93% (ICPH 3933). ICPH 2740 (186.82%), ICPH 3359 (178.29%), ICPH 3461 (138.76%), ICPH 3497 (142.48%), ICPH 3761 (109.66%), ICPH 4012 (143.93%) and ICPH 4017 (133.74%) exhibited significant standard heterosis in positive direction. Two hybrids, ICPH 3763 (-10.59%) and ICPH 4019 (-7.49%) had negative heterosis but it was on par with Asha. The range of standard heterosis was from -10.59 (ICPH 3763) to 186.82% (ICPH 2740).

Estimated heterosis over better, mid, and standard parents are presented in Table 4.5.2. Based on overall performance, ICPH 2671 and ICPH 3933 showed significant positive heterosis and ICPH 2751, ICPH 3494 and ICPH 4019 manifested significant negative heterosis in pod clusters plant^{-1} over mid and better parental values. Thirteen out of 22 hybrids showed positive heterosis in pod clusters over mid-parent, better parent and standard check. The *per se* range of heterosis over better, mid and standard parent was from -67.17 to 150.61%, -58.82 to 175.93% and -10.59 to 186.82%, respectively. A wide range of heterosis was observed for this character. Ram *et al*. (1976b); Veeraswamy *et al*. (1973); Malhotra and Sodhi (1977); Ram *et al*. (1976a) reported that pod clusters plant^{-1} has significant association with seed yield.

4.3.1.8 Pods plant^{-1}

Three hybrids ICPH 2671 (113.46%), ICPH 3359 (58.84%) and ICPH 3477 (79.05%) showed significant positive heterosis over better parent. Eight hybrids ICPH 2751, ICPH 3494, ICPH 3759, ICPH 3761, ICPH 3763, ICPH 4013, ICPH 4019, ICPH 4020 and ICPH 4024 showed negative heterosis but they were not significantly different from the better parent. A considerable amount of heterobeltiosis was observed for pod plant^{-1} and it varied from -38.40 (ICPH 3494) to 113.46% (ICPH 2671). Similarly, significant positive heterosis over mid-parent was observed in ICPH 2671 (114.75%), ICPH 2740 (72.58%), ICPH 3359 (99.68%), ICPH 3477 (120.74%), ICPH 4017 (54.11%) and ICPH 4022 (83.47%). Four hybrids ICPH 2751, ICPH 3494, ICPH 4013 and ICPH 4019 showed negative heterosis for pods plant^{-1} (Table 4.8). Eighteen hybrids manifested positive heterosis over Asha. Among these, 10 hybrids ICPH 2671 (83.04%), ICPH 2740 (104.13%), ICPH 3359 (139.85%), ICPH 3477 (126.5%), ICPH 3491 (78.40%), ICPH 3497 (89.68%), ICPH 3761 (98.77%), ICPH 4017 (149.19%), ICPH 4010 (69.25%), ICPH 4022 (65.31%) exhibited significant standard heterosis in desirable direction (Table 4.8). The range of standard heterosis was from -18.5 (ICPH 4019%) to 149.19% (ICPH 4017%).

In the present study, the positive and significant estimates of relative heterosis, heterobeltiosis and standard heterosis were noticed in hybrids ICPH 2671, ICPH 2740, ICPH 3359, ICPH 3477, ICPH 4017, and ICPH 4022. Number of pods plant^{-1}, a major yield component exhibited higher magnitude of heterosis as compared to other traits. A considerable amount of heterosis ranged from -38.40 to 113.46%, -21.88 to 120.47% and -24.44 to 149.19% over better, mid and standard parent respectively. Five hybrids ICPH 2671, ICPH 2740, ICPH 3359, ICPH 3477 and ICPH 4017 exhibited higher positive with respect to mid parent, better parent, and standard variety. These observations are in agreement with Singh (1971), Veeraswamy *et al*. (1973), Chaudhari (1979), Patel and Patel (1992), Pandey and Singh (2002) and Kandalakar (2007). Narladkar and Khapre (1996) reported that heterosis for grain yield was due to total number of pods plant^{-1}.

4.3.1.9 Seeds pod^{-1}

ICPH 2671 (16.51%) exhibited significant positive heterosis over better parent. The rest hybrids showed positive and negative heterosis but they were on par at better parent. Out of 22 hybrids, 12 showed negative heterosis over better parent. The range of heterobeltiosis was from -6.60 (ICPH 3494) to 16.51% (ICPH 2671). For relative heterosis, ICPH 2671 (17.82%), ICPH 3497 (6.29%) and ICPH 3763 (7.29%) manifested significant positive heterosis. The other tested hybrids were on par with mid-parent and showed slightly amount of positive and negative heterosis (Table 4.9). Three hybrids ICPH 2671 (9.84%), ICPH 3477 (8.23%) and ICPH 3762 (8.43%) exhibited significant and positive heterosis over standard variety. ICPH 2751 showed similar value with Asha and there was no heterosis over standard check. Six hybrids showed negative heterosis and the rests manifested positive heterosis over standard check but they were on par to Asha.

In the present study, ICPH 2671 manifested positive and significant heterosis over mid-parent, better parent and standard variety. The number of seed pod^{-1} is also an important character, which contributes to the higher yield. ICPH 2671 recorded significant positive heterosis over better, mid and standard parents. The range of heterosis in the present findings was from -6.60 to 16.51%, -4.19 to 17.82% and -3.61 to 9.84%. Hybrid ICPH 2671 had significant positive heterosis over different levels indicating more hybrid vigour in F_1. Phad (2003) reported seeds pod^{-1} as an important character, which is positively correlated with grain yield. Wankhade *et al*. (2005) reported significant positive heterosis for seeds pod^{-1}.

4.3.1.10 100 seed weight (g)

Hybrids ICPH 3477 (18.75%), ICPH 3758 (15.69%), and ICPH 4022 (13.46%) showed significant positive heterosis and ICPH 3933 (-17.33%) had significant negative heterosis over better parent (Table 4.9). The rest of the hybrids were on par to better parent. The range of heterobeltiosis was from -17.33% (ICPH 3933) to 18.75% (ICPH 3477). Hybrids ICPH 3359 (21.74%), ICPH 3477 (18.75%), ICPH 3497 (25.00%), ICPH 4020 (17.95%), and ICPH 4022 (15.69%) recorded significant positive heterosis over mid-parent. Only two hybrids, ICPH 3933 (-3.12%) and ICPH 3759 (-1.85%) showed negative heterosis but they were not significantly different from mid-parental value. ICPH 2671 (17.31%), ICPH 3758 (13.46%), ICPH 3933 (19.23%), ICPH 4020 (13.38%), and ICPH 4022 (13.46%) showed significant positive heterosis over Asha. Four hybrids showed

negative heterosis but they were not significantly superior over the standard variety, Asha (Table 4.9). The range of standard heterosis was from -3.85 (ICPH 3461 and ICPH 4019) to 17.31% (ICPH 2671).

In the present investigation, 3 hybrids ICPH 3477, ICPH 3758 and ICPH 4022 showed significant positive heterosis over mid parent, better parent and standard check. The range of heterobeltiosis for 100 seed weight varied from -17.33 to 18.75%, -3.12 to 25.00% for relative heterosis, and -3.85 to 19.23% for standard heterosis. The hybrids ICPH 3477 and ICPH 3758 had significant positive heterosis over better and mid parents. Chaudhari (1979), Reddy *et al*. (1979), Manivel *et al*. (1999), Deshmukh *et al*. (2001), Wankhade *et al*. (2005) and Kandalkar (2007) recorded positive standard heterosis in pigeonpea for 100 seed weight.

4.3.1.11 Seed yield plant^{-1} (g)

The range of heterobeltiosis varied from -53.76% (ICPH 4013) to 129.18% (ICPH 2671). ICPH 2671 showed significant positive heterosis over better parent. Hybrids ICPH 2751 (-42.28%), ICPH 3494 (-46.35%), ICPH 4013 (-53.76%), and ICPH 4020 (-54.39%) showed significant and negative heterosis over better parent. Hybrid ICPH 2671 (168.33%) exhibited significant relative heterosis in positive direction. ICPH 4013 (-46.35%) and ICPH 4020 (-37.63%) had significant negative heterosis over mid-parent. The rest hybrids were on par at mid-parent. ICPH 2671 (76.21%), ICPH 2740 (104.12%), ICPH 3359 (136.65%), ICPH 3477 (118.84%), ICPH 3497 (97.22%), ICPH 3761 (97.52%), and ICPH 4017 (154.66%) showed significant positive heterosis over Asha (Table 4.9). Two hybrids ICPH 3494 (-5.96%) and ICPH 4024 (-5.94%) manifested non-significant negative heterosis over Asha. The range of standard heterosis was from -5.96 (ICPH 3494) to 136.65% (ICPH 3359).

Among the 22 hybrids tested seven combinations ICPH 2671, ICPH 2740, ICPH 3359, ICPH 3477, ICPH 3497, ICPH 3761, and ICPH 4017 showed considerable amount of positive heterosis over mid-parent, better parent and standard check. Based on the present investigation, a wide range of positive and negative heterosis was observed in seed yield plant^{-1}. The estimated range of heterosis over better, mid, and standard parents was from -53.76 to 129.18, -46.66 to 168.03%, and -5.96 to 154.66%, respectively. Yadav and Singh (2004), Sekhar *et al*. (2004) and Wankhade *et al*. (2005) reported positive standard heterosis for seed yield plant^{-1} in pigeonpea. The positive heterosis could be useful for

further exploitation (Wanjari *et al*., 2007). In the present study, heterosis in yield plant^{-1} was positively associated with heterosis in number of primary branches plant^{-1}, pods plant^{-1}, and pod clusters indicating relative merit of these traits.

4.3.1.12 Seed yield (kg ha^{-1})

Six hybrids ICPH 2671 (148.94%), ICPH 2740 (49.89%), ICPH 3477 (48.54%), ICPH 3491 (50.99%), ICPH 4017 (55.82%) and ICPH 4022 (127.33%) showed significant positive heterosis in desirable direction over better parent. ICPH 2751 (-29.75%) and ICPH 3494 (-29.34%) and ICPH 3763 (-37.72%) showed significant negative heterosis. The range of heterobeltiosis was from -37.72% (ICPH 3763) to 148.94% (ICPH 2671). For relative heterosis, eight hybrids ICPH 2671 (190.09%), ICPH 2740 (68.26%), ICPH 3477 (71.76%), ICPH 3491 (66.87%), ICPH 4017 (69.46%) and ICPH 4022 (144.65%) manifested significant positive heterosis. Although six hybrids showed negative heterosis for seed yield, they were on par to mid-parent (Table 4.9). Out of 22 hybrids, nine ICPH 2671 (208.44%), ICPH 2740 (121.45%), ICPH 3477 (119.45%), ICPH 3491 (134.17%), ICPH 3497 (88.93%), ICPH 3761 (102.17%), ICPH 3933 (80.47%), ICPH 4017 (184.9%), ICPH 4022 (155.64%) exhibited significant standard heterosis. Two hybrids ICPH 3763 (-29.93%) and ICPH 4024 (-1.28%) showed negative heterosis over standard check (Table 4.9).

Hybrids ICPH 2671, ICPH 2740, ICPH 3477, ICPH 3491, ICPH 4017, and ICPH 4022 exhibited significant positive heterosis over mid parent, better parent and standard check indicating the presence of exploitable heterosis in pigeonpea. These hybrids also had significant heterosis for the yield component trais such as the number of primary branches, pod clusters, pods plant^{-1}, seeds pod^{-1} and yield plant^{-1}. Component analyses of hybrids have shown high yield in the heterotic crosses to be closely associated with heterosis for pods plant^{-1}, number of primary branches, and plant height, that all contribute to increased total biomass (Reddy *et al*., 1979; Marekar, 1981; Venkateswarlu *et al*., 1981; Saxena *et al*., 1986a; Cheralu *et al*., 1989). Similar results were reported by Solomon *et al*. (1957), Singh (1971), Sharma *et al*. (1973), Reddy (1976), Saxena (1977), Chaudhari (1979), Jain and Saxena (1990), Narladkar and Khapre (1996), Verullkar and Singh (1997), Hooda *et al*. (1999), Pandey (1999), Pandey and Singh (2002) and Yadav and Singh (2004). Also Srivastava *et al*. (1997) reported the heterotic advantage in 182 superior experimental hybrids at different center revealed that 77 hybrids (42.3%) gave yield advantage between

21 to 40% and 46 hybrids (25.2%) in range of 41 to 60%. About 8.7% hybrids expressed more than 100% increase in yield. In the present study, ICPH 2671 showed 148.94% heterobeltiosis, 190.09% relative heterosis, and 208.44% standard heterosis, respectively. Similarly, ICPH 2740, ICPH 3477, ICPH 3491, ICPH 3761, ICPH 4017, ICPH 4020, and ICPH 4022 exhibited above 100% heterosis over standard variety, Asha. Sekhar *et al*. (2004) reported standard heterosis over 40% in pigeonpea. Kandalkar (2007) reported significant positive heterosis (-61.2 – 155.7%) for grain yield in CMS based hybrids of pigeonpea. In general, positive and high magnitude of heterosis for grain yield plant^{-1} was noticed and this may be due to the heterosis contributed by one or more yield contributing characters (Chandirakala *et al*., 2010). Similar restults were also found in the present study. Heterosis in seed yield was positively related with higher number of primary branches, pod clusters, pod plant^{-1}.

Table 4.7. Heterobeltiosis, relative heterosis, and standard heterosis in CMS-based pigeonpea hybrids at Patancheru, 2010 *kharif* season

Sr.	ICPH	Days to 50% flowering			Days to maturity			Plant height (cm)			No. of primary branches		
no.	no.	BP H	MP H	Std H	BP H	MP H	S H	BP H	MP H	S H	BP H	MP H	S H
1	2671	-14.76**	-11.25**	-16.09**	-8.92**	-7.71**	-13.31**	4.447	11.35**	0.65	11.69	21.35*	18.47**
2	2740	-5.38**	-4.75**	-6.36**	-5.04**	-4.56**	-5.99	1.515	3.67	4.42	6.45	6.98	13.19
3	2751	-4.03*	-2.28	-5.28**	-1.88	-0.69	-4.49	-0.127	2.14	2.21	12.38	15.67	19.79**
4	3359	-6.16**	-4.23*	-3.11	-5.57**	-3.68**	-4.16	-1.108	1.89	8.91**	-23.24**	-13.95	-13.72
5	3461	-4.54*	-2.17	-7.22**	-4.14**	-2.46*	-7.49**	-5.319	-2.38	4.03	-8.99	1.14	-6.60
6	3477	-6.54**	-4.92**	-5.49**	-4.83**	-3.71**	-4.99	-0.758	1.29	2.08	-8.44	-3.02	-2.64
7	3491	-1.37	-0.48	-6.36**	-1.58	-0.71	-6.66	-1.625	2.14	2.21	-24.24**	-10.37	-7.65
8	3494	-9.85**	-6.22**	-7.01**	-6.10**	-3.88**	-5.16	2.411	2.48	4.81	-13.38	-5.61	4.22
9	3497	-10.08**	-4.71**	-5.49**	-7.95**	-3.57**	-5.66	-2.375	-1.88	1.43	0.22	-30.72**	22.16**
10	3758	-10.1**	-4.64**	-6.14**	-5.74**	-2.13*	-4.33	-6.642*	-1.3	-1.43	4.66	7.91	0.79
11	3759	-6.95**	-3.29	-7.87**	-5.71**	-2.77*	-6.49	7.222	8.28*	0.26	24.50*	27.06**	13.98
12	3761	-6.65**	-2.99	-4.63**	-5.32**	-3.72**	-5.32	2.372	4.51	0.91	-14.35	-11.17	-5.54
13	3762	-10.3**	-6.76**	-10.25**	-4.68**	-3.42**	-8.49**	-2.009	0.30	7.66**	6.16	11.04	-4.49
14	3763	-13.9**	-9.89**	-11.33**	-9.72**	-6.41**	-8.82**	1.959	2.51	-2.01**	3.15	16.44	3.69
15	3933	-9.71**	1.68	-11.12**	-6.49**	1.76	-8.82**	-1.617	23.94**	-5.19**	-31.84**	-1.08	-27.7
16	4012	-10.88**	-5.54**	-7.87**	-7.54**	-3.09**	-6.16	3.796	4.14	2.99	-27.52**	-18.56*	-16.62
17	4013	-5.83**	-3.33	-7.01**	-3.75**	-2.50*	-5.99	1.031	1.36	1.82	5.23	5.52	-1.72
18	4017	-5.72**	-1.33	-2.25	-3.74**	0.68	-1.5	-1.318	-0.93	-2.73	5.57	8.86	15.04*
19	4019	-6.58**	-1.75	-4.2	-5.45**	-2.14*	-4.66	-2.358	-0.30	7.53	2.63	4.69	2.90
20	4020	-10.25**	-3.86*	-5.28**	-6.95**	-2.29*	-4.16	-7.245*	-3.95	-6.88	6.63	7.09	-2.37
21	4022	-5.44**	-4.66**	-9.82**	-3.32**	-3.06**	-7.82**	-1.913	0.70	-6.75**	-18.11	-10.60	-17.68
22	4024	-7.70**	-4.22*	-8.74**	-6.22**	-3.13**	-7.15**	-0.647	-0.07	-0.26	2.90	3.65	-6.33

Where, *, ** = significantly different at 5% and 1% level, respectively

BP H = better parent heterosis, MP H = mid-parent heterosis, S H = standard heterosis

Table 4.8. Heterobeltiosis, relative heterosis, and standard heterosis in CMS-based pigeonpea hybrids at Patancheru, 2010 *kharif* season

Sr.	ICPH	Pod length (mm)			Pod width (mm)			Pod cluster plant^{-1}			Number of pods plant^{-1}		
no.	no.	BP H	MP H	Std H	BP H	MP H	S H	BP H	MP H	S H	BP H	MP H	S H
1	2671	2.897	6.519	9.66**	-9.282*	-5.51	-8.84**	102.13	125.70**	71.32	113.46*	114.75*	83.04**
2	2740	2.963	3.925	11.97**	1.138	2.21	-7.92**	29.67	38.92	186.82**	61.37	72.58*	104.13**
3	2751	-3.806	-1.127	0.08	-4.75	-0.39	-4.98	-49.09	-35.97	73.9	-26.77	-5.99	6.46
4	3359	2.973	5.953	6.87	-0.32	3.58	-1.97	75.41	50.21	178.29**	58.84*	99.68**	139.85**
5	3461	-1.547	-0.033	2.54	-1.17	0.39	-9.61**	56.61	96.44	138.76	24.94	51.91	25.98
6	3477	-5.581	-2.754	9.05**	-11.29**	-3.98	-6.74**	17.72	20.32	160.39**	79.05*	120.74**	126.5**
7	3491	-12.455**	-9.418**	-1.91	-4.25	-1.98	3.12	-24.87	-23.96	56.07	28.10	43.96	78.40**
8	3494	2.597	5.123	6.05**	-2.07	-1.40	-2.31	-67.17	-58.82	12.14	-38.40	-21.88	-10.44
9	3497	-5.712	-5.591	-1.42	3.22	5.44	11.16**	8.99	12.72	142.48**	36.20	46.66	89.68**
10	3758	-0.513	2.988	4.08**	0.08	3.65	-0.47	38.49	54.73	57.62	27.13	39.70	29.92
11	3759	-0.242	3.583	10.6**	-1.94	0.59	0.44	19.78	28.69	40.83	-3.68	10.34	18.31
12	3761	4.461	4.569	2.17	-1.08	1.11	-5.91**	-5.48	15.79	109.66	-14.05	8.50	98.77**
13	3762	-6.837	-1.632	5.17	-7.07	-2.82	-6.84**	-0.34	1.99	51.94	21.98	32.10	45.26
14	3763	-2.796	-0.134	0.34	-4.54	-2.62	-3.73	-34.59	-4.68	-10.59	-31.78	3.26	-24.44
15	3933	-7.468	-5.629	-4.32	-16.44**	-5.95	-0.56	150.61*	175.93	112.4	33.11	52.90	12.77
16	4012	-3.975	-0.425	2.11	-3.87	-2.03	-7.96**	56.55	70.09	143.93**	29.59	37.48	39.78
17	4013	0.259	2.349	3.79	-3.62	-1.51	-6.82**	10.28	16.93	45.99	-9.29	-0.28	35.91
18	4017	2.945	5.394	5.54	-4.46	-2.92	-6.14**	39.74	51.98	133.74	32.36	54.11*	149.19**
19	4019	1.507	2.602	8.54**	3.13	5.27	-0.46	-42.26	-26.03	-7.49	-29.15	-18.02	-18.5
20	4020	-3.382	0.439	7.38	-3.67	4.39	10.8**	-3.63	16.01	71.32	-12.50	7.03	69.25
21	4022	4.301	5.435	4.16	2.37	5.39	3.23	18.72	47.93	62.27	49.24	83.47*	65.31
22	4024	4.56	6.751	7.73	1.87	2.96	-0.36	-14.10	9.74	33.85	-4.25	21.72	-8.58

Where, *,** = significantly different at 5% and 1% level, respectively

BP H = better parent heterosis, MP H = mid-parent heterosis, S H = standard heterosis

Table 4.9. Heterobeltiosis, relative heterosis, and standard heterosis in CMS-based pigeonpea hybrids at Patancheru, 2010 *kharif* season

Sr.	ICPH	Seeds pod^{-1}			100 seed weight (g)			Seed yield plant^{-1} (g)			seed yield (kg ha^{-1})		
no.	no.	BP H	MP H	S H	BP H	MP H	S H	BP H	MP H	S H	BP H	MP H	S H
1	2671	16.51**	17.82**	9.84**	3.39	8.93	17.31**	129.18	168.03	76.20	148.94**	190.09**	208.44**
2	2740	-3.72	-1.71	3.82	10.20	11.34	3.85	34.88	49.15	104.12**	49.89*	68.256**	121.45**
3	2751	-6.04	-3.39	-	5.77	11.11	5.77	-42.28	-23.11	1.17	-29.75	-11.49	14.31
4	3359	-1.35	0.58	2.81	9.80	21.74**	7.69	14.82	58.70	136.65**	5.62	52.13*	91.71**
5	3461	3.45	3.60	5.42	4.17	5.26	-3.85	27.42	51.21	43.39	40.69	71.76*	54.62
6	3477	0.37	1.69	8.23**	18.75*	18.75**	9.62	44.61	81.35	118.84**	48.54*	78.76**	119.45**
7	3491	-5.14	-4.19	-3.61	5.66	7.69	7.69	5.69	23.27	60.83	50.99*	66.87**	134.17**
8	3494	-6.60	-0.30	-0.6	10.64	10.64	0.00	-46.35	-28.62	-5.96	-29.34	-4.42	14.98
9	3497	5.14	6.29*	6.83	7.84	25.00**	5.77	15.33	22.05	97.22	21.82	34.08	88.93**
10	3758	-1.42	1.89	-2.61	15.69*	21.65**	13.46	17.03	21.64	15.86	39.02	41.75	46.34
11	3759	-1.75	-0.98	1.20	-8.62	-1.85	1.92	-6.34	13.59	24.03	-16.49	-10.61	30.50
12	3761	-0.40	1.82	1.00	-5.45	4.00	0.00	-32.38	-6.65	97.52	-0.542	13.36	102.17**
13	3762	5.47	6.09	8.43	-1.89	2.97	0.00	31.44	37.33	61.79	22.63	38.95	76.16
14	3763	3.14	7.29*	-1.00	1.92	8.16	1.92	14.86	66.01	20.32	-37.72	-6.44	-29.93
15	3933	1.38	6.52	3.41	-17.33**	-3.12	19.23**	31.80	61.67	1.34	-1.43	32.77	80.47**
16	4012	1.96	2.87	4.42	8.51	9.68	-1.92	-7.00	3.514	53.64	-8.30	21.99	58.14
17	4013	-3.21	-2.38	3.01	0.00	0.99	-1.92	-53.76	-46.66	48.45	-13.41	-7.04	47.28
18	4017	1.19	1.39	2.61	-1.82	5.88	3.85	31.80	57.05	154.66**	55.82**	69.46**	184.90**
19	4019	-0.81	-0.71	-1.81	-1.96	3.09	-3.85	28.67	45.11	52.21	-12.49	-6.37	1.90
20	4020	-0.19	1.31	1.20	2.99	17.95**	32.64**	-54.39*	-37.63**	30.57	9.98	31.39	121.4**
21	4022	-0.41	5.04	-1.61	13.46*	15.69**	13.46	39.18	62.05	45.80	127.23**	144.65**	155.64**
22	4024	0.79	1.29	2.41	12.77	12.77	1.92	-43.06	-17.93	-5.94	13.74	31.65	-1.28

Where, *,** = significantly different at 5% and 1% level, respectively

BP H = better parent heterosis, MP H = mid-parent heterosis, S H = standard heterosis

4.4 Inbreeding Depression

Inbreeding depression is the lowered fitness or vigour of inbred individuals compared with their non-inbred counterparts. This, in turn, results in a loss of fitness termed inbreeding depression. Inbreeding depression, the depressive effect, is the expression of traits arising from increasing homozygosity (Allard, 1960). The inbreeding depression is better evidence of dominance than heterosis (Compton, 1977). In quantitative genetic theory, inbreeding depression is due to non-additive gene action (Mather and Jinks, 1982). In pigeonpea inbreeding depression does not seem to be significant due to predominant effect of additive gene action (Saxena and Sharma, 1990). Inbreeding depression is usually observed in most of the out-crossing species. Since out-crossing in pigeonpea has been reported by several workers and ranged from 0 to 70% (Bhatia *et al*. 1981; Reddy, 1990; Saxena and Kumar, 2009), an attempt was made to study the perforamnce of inbreeding depression for yield and yield contributing characters. The research findings of the present investigation (Table 4.10) are presented hereunder:

4.4.1 Days to 50% flowering

All the hybrids showed negative inbreeding for days to flower character indicating enhancement of flowering days in F_2 than F_1 except ICPH 3933 and ICPH 4017 which have low level of inbreeding depression 1.36% and 2.01%, respectively. Four hybrids ICPH 3763 (-9.53%), ICPH 2671 (-8.27%), ICPH 4012 (-6.72%), ICPH 4024 (-6.70%) exhibited high level of negative inbreeding depression. Inbreeding depression in this character was not significantly difference because the *t*-test values of ID were lower than the corresponding tabulated *t*-value 2.07 at 5% level and 2.81 at 1%. The range of inbreeding depression from F_1 to F_2 generation for days to flower was -9.53 (ICPH 3763) to 2.01% (ICPH 4017).

Anantharuja and Muthiah (2008) reported up to 47.05 to 64.28% inbreeding depression for days to flower in pigeonpea. In the present study, out of 22 hybrids, 20 had negative inbreeding depression for days to flower but these were statistically non-significant. The *per se* performance of negative heterosis over better, mid, and standard parents was observed for this trait which was desirable for early flowering in F_1s. The magnitude of negative inbreeing depression from F_1 to F_2 indicated the enhancement of days to flower in F_2s. It also showed the preponderance of additive gene effects. Sharma *et*

al. (1973a), Gupta *et al*. (1981), Dahiya and Brar (1977), Dahiya and Satija (1978), Reddy *et al*. (1981a) reported the additive effects of gene action in pigeonpea for this trait.

4.4.2 Days to maturity

Two hybrids ICPH 3933 and ICPH 4017 had lower levels of inbreeding depression 1.09% and 3.21%, respectively. The rest hybrids showed negative inbreeding depression. Among these, hybrids ICPH 2671 (-6.33%), ICPH 3763 (-6.2%), ICPH 4012 (-5.49%), and ICPH 4024 (-5.38%) exhibited more negative inbreeding depression. However, there was no significant difference for maturity. The range of inbreeding depression was from -6.33 (ICPH 2671) to 3.21% (ICPH 4017). All the hybrids showed low magnitude of non-significant negative inbreeding depression except ICPH 3933 and ICPH 4017. Hybrids ICPH 2671, ICPH 3763, ICPH 4012, and ICPH 4024 had significant negative heterosis in F_1s exhibiting early maturity than better, mid parents and standard variety. These hybrids also had negative inbreeding depression and indicated that F_1s were earlier in maturity than F_2s. Similarly like days to flower, maturity duration showed additive gene action for this trait. Anantharuja and Muthiah (2008) reported up to 50.0 to 78.57% of inbreeding depression for maturity. Pandey (1972), Sharma *et al*. (1972) reported additive gene action for maturity. However, Kapur (1977), Sidhu and Sandhu (1981) investigated that days to maturity was governed by non-additive gene action.

4.4.3 Plant height

Eighteen out of 22 hybrids had inbreeding depression. The highest value of inbreeding depression was found in ICPH 4012 (12.34%) followed by ICPH 3933 (11.88%), ICPH 2671 (8.09%), and ICPH 3759 (7.60%). These four hybrids had significant inbreeding depression for plant height. Hybrids ICPH 3497 (-0.88%), ICPH 3758 (-0.11%), ICPH 4020 (-0.84%) and ICPH 4022 (-1.25%) showed negative inbreeding depression but they were not significant different. The range of inbreeding depression was from -1.25 (ICPH 4022) to 12.34% (ICPH 4012).

ICPH 3933 and ICPH 4012 showed 11.88% and 12.34% of inbreeding depression, respectively. The results indicated that there was no difference in performance of plant height between F_1 and F_2 generations showing additive gene effects. Sharma (1981) reported the importance of both additive and dominance gene effects in plant height. Gumber and Singh (2006) reported -23.0 to 78% of inbreeding depression and Anantharuja

and Muthiah (2008) discovered up to 23.80 to 86.95% of inbreeding depression, respectively.

4.4.4 Number of primary branches

There was significantly different inbreeding depression for number of primary branches. Among the 22 hybrids, the significant inbreeding depression was found in ICPH 2671 (24.42%), ICPH 2740 (17.27%), ICPH 2751 (17.08%), ICPH 3494 (15.91%), ICPH 3759 (22.99%), ICPH 3497 (21.83%), ICPH 3763 (21.30%), ICPH 3762 (16.74%), ICPH 4017 (14.55%), and ICPH 4024 (18.29%). The range of inbreeding depression was from -18.16 (ICPH 4020) to 24.42% (ICPH 2671).

Number of primary branches plant^{-1} is an important yield component in pigeonpea. Gumber and Singh (1996) and Anantharuja and Muthiah (2008) reported -1.67 to 15.33% and 17.39 to 57.14% of inbreeding depression in pigeonpea, respectively. In the present study, the range of inbreeding depression was from -18.16 to 24.42% showing significant different between F_1s and F_2s. Ten hybrids out of 22 exhibited significant inbreeding depression. Chaudhari *et al*. (1980) reported additive gene effects for this trait.

4.4.5 Pod clusters plant^{-1}

High magnitude of positive and negative inbreeding depression was observed for the number of pod clusters. Five hybrids ICPH 4012 (68.44%), ICPH 3359 (59.85%), ICPH 2740 (54.90%), ICPH 3477 (54.15%), and ICPH 4017 (52.70%) had highest value of inbreeding depression. The range of inbreeding depression was from -64.50 (ICPH 3494) to 68.44% (ICPH 4012).

Number of pod cluster plant^{-1} on the pod bearing branches constituted the component characters for number of pods plant^{-1} and it is an important yield attributing character. Anantharuja and Muthiah (2008) indicated 28.57 to 47.05% of inbreeding depression for pod cluster. Singh and Narayanam (1993) reported that if the heterosis is negative in F_1 and increase in F_2, it indicates presence of additive genes. If high heterosis is followed by inbreeding depression, it indicates the presence of non-additive gene action. In the present investigation, inbreeding depression ICPH 2671, ICPH 2740, ICPH 3359, ICPH 3461, ICPH 3477, ICPH 3758, ICPH 3759, ICPH 4012, ICPH 4013, ICPH 4017, and ICPH 4024 had high inbreeding depression coupled with different levels of high heterosis. The results indicated non-additive gene action. In case of hybrid Hybrid ICPH 3763 showed

high inbreeding depression and negative heterosis over better, mid parents and standard variety. Hence, it seems to be governed by additive genes. The present findings indicated both additive and non-additive genes effects are major for pod clusters.

4.4.6 Pods plant^{-1}

High value of inbreeding depression was observed for pods plant^{-1} except ICPH 3494 (-0.67%) which had negative inbreeding depression. However, none of these were significant. In the present investigation, seven hybrids ICPH 2740 (72.07%), ICPH 3359 (66.28%), ICPH 4024 (63.27%), ICPH 3763 (59.54%), ICPH 3477 (57.84%), ICPH 3461 (56.77%), and ICPH 4017 (54.34%) had highest value of inbreeding depression (Table 4.10). The extent of inbreeding depression ranged from -0.67 (ICPH 3494) to 72.07% (ICPH 2740).

Gumber and Singh (1996) and Anantharuja and Muthiah (2008) reported -40.00 to 20.30% and 33.33 to 48.05% of inbreeding depression for pods plant^{-1}, respectively. In the present study, ICPH 2671, ICPH 2740, ICPH 3359, ICPH 3461, ICPH 3758, ICPH 3933, ICPH 4012, and ICPH 4017 exhibited high heterosis over their respective better parent, mid parent and standard variety and high inbreeding depression. These results indicated non-additive gene action for pod plant^{-1} (Singh and Narayanam, 1993). This was agreement with Sidhu and Sandhu (1981). However, Saxena *et al*. (1981b) reported additive gene action. Saxena *et al*. (1981b). However, Sidhu and Sandhu (1981) reported non-additive gene action and Kapur (1977) both additive and non-additive gene action.

4.4.7 Pod length

Out of 22 hybrids, 19 hybrids showed significant inbreeding depression showing non-additive gene action in this character (Table 4.10). The range of inbreeding depression was from -6.11 (ICPH 3933) to 7.63% (ICPH 4017). Anantharuja and Muthiah (2008) reported 10.86 to 57.14% of inbreeding depression for pod length. In the present study, hybrids ICPH 2671, ICPH 2740, ICPH 3497, ICPH 3758, ICPH 3759, and ICPH 4019 showed significant of inbreeding depression with high standard heterosis indicating non-additive gene action. However, hybrid ICPH 3491 showed negative heterosis and also negative inbreeding depression due to fixation of genes in F_2 showing additive gene action. Based on the results, it may seem pod length was to be governed by both additive and non-additive gene effects.

4.4.8 Pod width

The significant inbreeding depression was found in seven hybrids ICPH 3359 (7.07%), ICPH 3497 (3.44%), ICPH 3761 (3.81%), ICPH 4012 (3.12%), ICPH 4019 (4.33%), and ICPH 4020 (4.75%). Three hybrids ICPH 3763 (-10.06%), ICPH 3494 (-8.8.57%), and ICPH 3933 (-6.73%) showed negative inbreeding depression.

Eight hybrids (ICPH 3359, ICPH 3497, ICPH 3758, ICPH 3761, ICPH 4012, ICPH 4013, ICPH 4019 and ICPH 4020) showed significant inbreeding depression. Significant negative heterosis and inbreeding depression was observed in seven hybrids (ICPH 2751, ICPH 3477, ICPH 3491, ICPH 3494, ICPH 3763, ICPH 3933 and ICPH 4024) for pod width. Relationship between negative heterotic response and inbreeding depression suggested the importance of non-additive genes in controlling this phenomenum. The results indicated that pod width may be governed by non-additive gene action.

4.4.9 Seeds pod^{-1}

ICPH 3497 (8.77%) and 3762 (6.67%) exhibited significant inbreeding depression. Out of 22 hybrids, ICPH 2751 (-0.90%), ICPH 3477 (-5.29%), and ICPH 3491 (-0.94%) showed significant negative inbreeding depression (Table 4.10). The range of inbreeding depression in seeds pod^{-1} was from -5.29 (ICPH 3477) to 8.73% (ICPH 3497).

Anantharuja and Muthiah (2008) reported 47.61 to 78.26% of inbreeding depression. Out of 22 hybrids, 17 showed significant inbreeding depression. Hybrid ICPH 267 and 3497 had significant positive heterosis and inbreeding depression indicating non-additive gene ation. However, Pandey (1972), Saxena *et al*. (1981b) and Mohamed *et al*. (1985) reported additive effects for this trait. Venkateswarlu and Singh (1982), and Kapur (1977) reported both additive and non-additive gene action for seed pod^{-1}.

4.4.10 100-seed weight

Out of 22 hybrids, two ICPH 3359 (19.61%) and ICPH 3497 (14.61%) had significant inbreeding depression. In ICPH 3461 and ICPH 4017, the 100-seed weight of F_1 and F_2 were similar and there was no inbreeding depression. Eight hybrids showed negative inbreeding depression (Table 4.10). Among these, two hybrids ICPH 4019 (-12.00%), ICPH 3494 (-11.53%) had significant negative inbreeding depression exhibiting bold seed in F_2. The range of inbreeding depression was from -12.00 (ICPH 4019) to 19.61% (ICPH 3359).

Anantharuja and Muthiah (2008) reported 42.85 to 56.62% of inbreeding depression for 100-seed weight. The significant inbreeding depression was found in ICPH 3359 and ICPH 3497 which had significant heterosis over mid-parent indicating non-additive genes. According to Singh and Narayanam (1993) reported that if the performance is same in F_1 and F_2, it revealed the presence of additive genes. Two hybrids ICPH 3461 and 4017 had similar seed size in F_1 and F_2 showing additive genes. Based on the present investigation, this trait may be governed by both additive and non-additive gene action. Similarly, Dahiya and Brar (1977), Gupta *et al*. (1981), Venkateswarlu and Singh (1982) reported the importance of both additive and non-additive gene actions. Nevertheless, Pandey (1972), Sharma *et al*. (1972), Sharma *et al*. (1972b), Sidhu and Sandhu (1981), Reddy *et al*. (1981b), Saxena *et al*. (1981b) and Mohamed *et al*. (1985) reported additive gene effects and Reddy *et al*. (1979) pointed non-additive effects.

4.4.11 Seed yield plant^{-1}

There was considerable amount of inbreeding depression in all the tested hybrids for seed yield plant^{-1}. Among the 22 hybrids, fourteen [ICPH 2671 (46.64%), ICPH 2740 (73.28%), ICPH 3359 (60.60%), ICPH 3461 (57.97%), ICPH 3477 (50.92%), ICPH 3491 (50.78%), ICPH 3497 (44.69%), ICPH 3758 (50.65%), ICPH 4013 (53.44%), ICPH 4024 (68.66%), ICPH 4019 (58.35%), and ICPH 4017 (55.52%)] had significant inbreeding depression and heterosis (Table 4.10). The lowest level of inbreeding depression was found in ICPH 3933 (13.26%) and ICPH 3494 (14.51%). The average inbreeding depression varied from 13.26 (ICPH 3933) to 73.28% (ICPH 2740).

Considering seed yield plant^{-1}, both positive and negative inbreeding depression values were recorded. Out of 22 hybrids, 14 showed 44.69 to 73.28% of significant inbreeding depression under study. It was due to significantly reduction in pods plant^{-1} in

F_2 generation. These hybrids also indicated significant heterosis over their respective mid, better parent and standard variety on individual yield in F_1s. The results indicated the predominance of non-additive gene action. Anantharuja and Muthiah (2008) reported 22.20 to 43.47% of inbreeding depression for seed yield plant^{-1}.

4.4.12 Seed yield (kg ha^{-1})

Hybrids ICPH 2671 (41.13%), ICPH 2740 (52.33%), ICPH 4024 (41.23%) exhibited the highest level of inbreeding depression indicating significant low yield in F_2 population (Table 4.10). Although high level of inbreeding depression was observed for seed yield, there was no significantly different from each other. In 10 hybrids, negative inbreeding depression was noticed for seed yield. Among these, ICPH 3762 (-55.20%) showed the highest value in negative way followed by ICPH 3494 (-48.66%) and ICPH 4019 (-46.36%). The range of inbreeding depression was from -55.20% (ICPH 3762) to 52.33% (ICPH 2740).

Both positive and negative inbreeding depressions were found in seed yield. Twelve out of 22 hybrids exhibited positive heterosis and inbreeding depression ranging from 7.64 to 52.33%. This finding indicated non-additive genes for seed yield. The rests showed -55.20 to -6.85% of negative inbreeding. Based on these research findings, seed yield may be governed by non-additive genes. Similar results were reported by Dahiya and Brar (1977), Sidhu and Sandhu (1981), Laxman Singh and Pandey (1974), Reddy *et al*. (1979), Dahiya and Satija (1978). However, Pandey (1972), Sharma *et al*. (1973 a), Chaudhari *et al*. (1980), Laxman Singh and Pandey (1974) reported additive gene action. Reddy *et al*. (1981b), Venkateswarlu and Singh (1982) investigated the predominace of both additive and non-additive gene effects. The results on inbreeding depression suggested that genes affecting yield showed high levels of non-additive gene action. This high magnitude of inbreeding depression in yield was mainly due to depression in expression of major yield components such as number of pods plant^{-1}, seeds pod^{-1} and 100 seed weight.

Table 4.10. Inbreeding depression for yield and yield related traits in CMS-based pigeonpea hybrids at Patancheru, 2010 *kharif* season

Sr. no.	ICPH no.	Days to 50% flowering	Days to maturity	Plant height (cm)	No. of primary branches	Pod cluster plant^{-1}	Number of pods plant^{-1}	Pod length (mm)	Pod width (mm)	Seeds pod^{-1}	100 seed weight (g)	Yield plant^{-1} (g)	Grain yield (kg ha^{-1})
1	2671	-8.27	-6.33	8.09	24.42**	49.90	39.27	0.73**	-0.52	4.66**	-8.16	46.64*	41.13
2	2740	-4.59	-3.90	3.14	17.27*	54.90	72.07	3.78**	-0.78	3.48**	-1.89	73.28**	52.33
3	2751	-3.38	-2.27	4.17	17.08*	17.32	36.37	1.41**	-5.16**	-0.90*	5.45	30.50	-31.64
4	3359	-4.63	-3.47	3.57	-2.11	59.85	66.28	2.45**	7.07**	5.57**	19.61**	60.60**	24.68
5	3461	-3.29	-3.24	0.86	4.75	48.72	56.77	1.96**	-1.85*	0.29	0.00	57.97*	20.37
6	3477	-5.82	-4.03	3.39	1.71	54.15	57.84	-0.55	-3.21**	-5.29**	3.47	50.92*	8.91
7	3491	-2.18	-1.78	3.37	-12.22	8.59	53.84	-2.05	-3.36**	-0.94**	3.54	50.78*	12.24
8	3494	-4.97	-3.16	5.73	15.91*	-64.50	-0.67	3.61**	-8.57**	2.12**	-11.53*	14.51	-48.66
9	3497	-3.76	-2.82	-0.88	21.83**	27.43	47.96	2.65**	3.44**	8.77**	14.61*	44.69*	-14.30
10	3758	-6.13	-2.61	-0.11	1.22	50.21	48.28	6.19**	5.17**	3.72**	6.71	50.65*	15.93
11	3759	-4.37	-3.56	7.60	22.99**	43.05	46.95	3.46**	1.55	5.06**	-3.85	52.65*	-10.50
12	3761	-3.18	-2.98	3.51	0.59	37.84	40.17	1.38**	3.81**	0.30	5.77	35.86	-21.73
13	3762	-6.15	-4.00	4.91	16.74*	22.58	14.39	0.38	1.80*	6.67**	-1.85	21.57	-55.20
14	3763	-9.53	-6.20	1.97	21.30**	51.76	59.54	1.61**	-10.06**	3.34**	7.47	27.28	18.87
15	3933	1.36	1.09	11.88	-7.55	35.69	18.29	-6.11**	-6.73**	3.50**	8.03	13.26	-6.85
16	4012	-6.72	-5.49	12.34	-7.69	68.44	41.71	3.35**	3.12**	5.48**	9.76	38.97	-23.77
17	4013	-2.78	-1.59	1.18	5.76	41.86	50.07	2.71**	1.93*	0.88**	-2.00	53.44*	-12.05
18	4017	2.01	3.21	1.97	14.55*	52.70	54.34	7.63**	-3.06**	2.64**	0.00	55.52*	15.37
19	4019	-3.22	-2.62	5.24	5.15	-9.30	12.57	5.38**	4.33**	1.84**	-12.00*	58.35*	-46.36
20	4020	-1.64	-0.35	-0.84	-18.16	34.19	41.75	1.69**	4.75**	3.57**	7.22	29.96	7.64
21	4022	-1.30	-0.18	-1.25	-10.00	38.72	50.07	3.68**	1.27	5.81**	-1.73	53.71*	29.16
22	4024	-6.70	-5.38	4.00	18.29*	51.49	63.27	2.62**	-3.36**	6.18**	7.47	68.66**	41.23

Where, *,** = significantly different at 5% and 1% level, respectively

4.5 Genetics of Fertility Restoration

Three lines system of hybrid technology, which is based on cytoplasmic-nuclear male-sterility, is expected to make a quantum increase in production and boost the productivity of pigeonpea yield. Cytoplasmic male-sterility is under extra-nuclear genetic control (under the control of the mitochondrial or plastid genomes). They show non-Mendelian inheritance and are under the regulation of cytoplasmic factors. In this system, male sterility is inherited maternally and is never lost or diluted in the succeeding generations of reproduction. The success in development of pigeonpea hybrids largely depends on availability of effective restorers and precise basis knowledge on the genetics of fertility restoration of such line. The fertility restorer (*Rf* or *Fr*) genes in the nucleus suppress the male-sterile phenotype and allows the production of high yielding CMS-based hybrids. Therefore, the incorporation of fertility restorer gene(s) into the CMS lines is essential in the hybrid pigeonpea breeding technology. To understand CMS-*Rf* system, the genetics of fertility restoration was studied in four hybrids ICPH 2671 (ICPA 2043 x ICPL 87119), ICPH 2740 (ICPA 2047 x ICPL 87119), ICPH 3359 (ICPA 2047 x ICPL 20107), and ICPH 4012 (ICPA 2092 x ICPL 20186) which possessed genetics diversity of parental lines. Their gene action on fertility restoration was studied through segregation for male-fertility and male-sterility in F_1, F_2 and back cross populations. The F_2 and BC_1F_1 populations segregated into fully male-fertile, partial male-fertile, and male sterile plants and these were classified into fully mlae-fertile (>80% pollen fertility), partial male-fertile (>10-80% pollen fertility), partial male-sterile (10-40% pollen fertility), and completely male-sterile (0-10% pollen fertility).

In hybrid ICPH 2671, all of 201 F_1 plants showed > 95% of pollen fertility due to the dominance of fertility restoring genes. In the F_2 generation 527 out of 685 plants were fully fertile, while 113 plants were partial fertile and 45 plants as fully male-sterile. This segregation fit well to the expected ratio of 12 fertile : 3 partial fertile : 1 sterile (χ^2 = 2.31 ; P = 0.2 - 0.5). In BC_1F_1 generation, 150 plants out of 289 plants segregated into fully fertile, 73 plants into partial fertile and 66 plants into sterile. This result fitted well with the expected 2:1:1 (fertile : partial male-fertile : sterile) ratio (χ^2 = 0.76 ; P = 0.5 – 0.8) and confirmed dominance epistasis gene interaction governed the pollen fertility in ICPH 2671 (Table 4.11). Similar results were found in ICPH 2740. All F_1 plants were male-fertile and fertility restoration was governed by dominance genes. Out of 641 F_2 plants evaluated, 471

plants were fully fertile, while 132 plants expressed as partial fertility and the rest 38 plants as fully male-sterile. This segregation fit well with the ratio of 12:3:1 (fertile : partial male-fertile : sterile) where χ^2 = 1.36 ; P = 0.5. In BC_1F_1 generation where 241 plants were grown, 110 plants were fully male-fertile; 69 plants partial fertile and 62 plants as fully male-sterile. These segregation pattern fit well with the expected ratio of 2 fertile: 1 partial male-fertile: 1 sterile (χ^2 = 2.24 ; P = 0.2 – 0.5) and confirmed dominant epistasis gene interaction in ICPH 2740 (Table 4.11).

In hybrid ICPH 3359, due to dominant gene action in fertility restoration, all F_1 plants were fully fertilie. A total of 671 plants were grown in F_2 generation. This population segregated into 390 fully male-fertile, 226 partial male-fertile and 55 plants as fully male-sterile. This segregation fit well with the expected ratio of 9 fertile : 6 partial male-fertile: 1 sterile (χ^2 = 7.10 ; P = 0.2 – 0.05). In BC_1F_1 generation, out of a total of 231 plants grown 54 plants were fully male-fertile, 116 were partial fertile and 61 plants were fully male-sterile. This segregated a ratio of 1 fertile : 2 partial male-fertile: 1 sterile (χ^2 = 0.43 ; P = 0.8). This segregation pattern showed that fertility restoration was governed by dominant genes with semi-dominant epistatic interaction (Table 4.12). In hybrid ICPH 4012, the fertility restoration was governed by dominant gene action and all 195 F_1 plants were fertile. Among 626 F_2 plants, 359 plants segregated into fertile, while 111 segregants were observed as partial fertile and 156 plants as sterile. This observation fit well with the segregation pattern of 9 fertile : 3 partial male-fertile: 4 sterile (χ^2 = 0.48 ; P = 0.5 – 0.8). In BC_1F_1 generation a total of 212 plant and among these 55 plants segregated into fertile, 40 plants into partial fertile and 117 plants as sterile expressing the expected ratio of 1 fertile : 1 partial male-fertile: 2 sterile (χ^2 = 4.41 ; P = 0.8). This segregation confirmed the recessive epistasis gene interaction of pollen fertility in ICPH 4012 (Table 4.12).

In the present investigation, the fertility restoring action of one the genes alone conferred partial pollen fertility and suggested that the mode of action of the two genes varied from cross to cross. For instance, ICPH 3359 exhibited epistasis with incomplete dominance (F_2 ratio, 9:6:1); and ICPH 4012 recessive epistasis gene interaction (F_2 ratio, 9:3:4), and ICPH 2671 and ICPH 2740 dominant epistasis gene interaction (F_2 ratio 12:3:1). In hybrid rice, hypothesis for digenic inheritance proposed by Bharaj *et al*. (1991) assumed that Rf_1 and Rf_2 as the two dominant alleles of the two restorer genes, the plants having dominant alleles of the two genes in homozygous or heterozogous condition (Rf_1-

Rf_2-) will be fertile. The plants having dominant alleles of the other gene (*Rf_1-rf_2rf_2 or $rf_1rf_1Rf_2$*-) will behave as partially male-sterile or partially male-fertile, and vice versa. The plants homozygous for the recessive alleles of both the genes (*$rf_1rf_1rf_2rf_2$*) will be completely male-sterile. In the case of epistasis with dominant gene interaction (F_2 ratio 12:3:1 and BC_1 ratio 2:1:1) as observed in the two hybrids (ICPH 2671 and ICPH 2740), the plants having dominant alleles of the two genes in either homozygous or heterozygous condition (*Rf_1-Rf_2*-) and those having dominant allele of one of the two genes in homozygous or heterozygous condition by homozygous for the other gene (*Rf_1-rf_2rf_2 or $rf_1rf_1Rf_2$*-) will be fertile completely, depending on the strength of the gene, thus grouped into one group. This showed the predominance of the stronger gene in its ability to restore fertility.

Similarly, in ICPH 3359 where the fertility restoration was governed by dominant genes with semi-dominant epistatic interaction (F_2 ratio 9:6:1, BC_1 ratio 1:2:1), the plants where the recessive gene is allelic for any of the two genes and homozygous or heterozygous for the dominant alleles of the other gene (*Rf_1-rf_2rf_2* and *$rf_1rf_1Rf_2$*-) were semi-fertile. In ICPH 4012, where the fertility restoration was governed by dominant genes with recessive epistatic interaction (F_2 ratio 9:3:4, BC_1 ratio 1:1:2), the plants homozygous for the recessive alleles of any one of the two genes but homozygous or heterozygous for the dominant alleles of the other gene (*Rf_1-rf_2rf_2* or *$rf_1rf_1Rf_2$*-) were sterile depending upon which of the two genes is stronger or weaker. The results of this study revealed that fertility restoration in pigoenpea hybrids appeared to be governed by two genes with epistatic interaction that differed from cross to cross which shows the possibility of existence of the most appropriate combination of the two fertility restoring genes.

Monogenic inheritance (F_2 ratio = 3 fertile : 1 sterile and back-hybrid 1 sterile : 1 sterile) for fertility restoration was also observed in short duration pigeonpea (Saxena *et al*. 2005b; Dalvi *et al*., 2008b; and Saxena *et al*., 2011). Dalvi *et al*. (2008b) reported the monogenic gene action (3 fertile : 1 sterile in F_2 and 1 fertile : 1 fertile in BC_1F_1), two dominant duplicated gene action (15 fertile : 1 sterile in F_2; 3 fertile : 1 sterile in BC_1F_1), and complementary gene action (9 fertile : 7 sterile in F_2; 1 fertile : 3 sterile in BC_1F_1), respectively, in short-duration pigeonpea hybrids. The presence of two dominant genes with one basic and one inhibitory gene action in ICPA 2067 was reported by Saxena *et al*. (2010). Saxena *et al*. (2011) reported both the mono genic and digenic inheritance of fertility restoration in extra-early-maturing and two duplicate dominant genes in late-

maturing hybrid. Shrikant (2011) investigated the monogenic as well as digenic control of fertility restoring gene depending on the nuclear background of CMS-line and fertility restorer in medium-duration pigeonpea hybrids. In the present findings, since all of female parental lines were based only on A_4 cytoplasm the differences in the type of gene interaction could presumably be due to the influence of restorer line and/or a probable variation expression of the weaker gene in different genetic backgrounds.

Table 4.11. Segregation pattern of fertility restoration

Sr. no	Hybrid no.	Generation	Phenotype	Observed value (O)	Expected value (E)	Deviation (D = O-E)	$D^2 = (O-E)^2$	Chi square (D^2/E)	Genetic ratio	Level of Probability
1.	ICPH 2671	F_1	Fertile	201	201	-	-	-	**1:0**	
	(ICPA 2043 x ICPL 87119)									
		F_2	Fertile	527	513.75	13.25	175.56	0.34		
			Partial fertile	113	128.44	-15.44	238.39	1.86		
			Sterile	45	42.81	2.19	4.80	0.11		
			Total	**685**	**685.00**	**0.00**	**418.75**	**2.31**	**12 : 3: 1**	0.2 - 0.5
		BC_1F_1	Fertile	150	144.50	5.50	30.25	0.21		
			Partial fertile	73	72.25	0.75	0.56	0.01		
			Sterile	66	72.25	-6.25	39.06	0.54		
			Total	**289**	**289.00**	**0.00**	**69.88**	**0.76**	**2: 1: 1**	0.5 - 0.8
2.	ICPH 2740	F_1	Fertile	233	233	-	-	-	**1:0**	
	(ICPA 2047 x ICPL 87119)	F_2	Fertile	471	480.75	-9.75	95.06	0.20		
			Partial fertile	132	120.19	11.81	139.48	1.16		
			Sterile	38	40.06	-2.06	4.24	0.01		
			Total	**641**	**641.00**	**0.00**	**238.78**	**1.36**	**12 : 3: 1**	0.5
		BC_1F_1	Fertile	110	120.50	-10.50	110.25	0.91		
			Partial fertile	69	60.25	8.75	76.56	1.27		
			Sterile	62	60.25	1.75	3.06	0.05		
			Total	**241**	**241.00**	**0.00**	**189.88**	**2.24**	**2: 1: 1**	0.2 - 0.5

Table 4.12. Segregation pattern of fertility restoration

Sr. no	Hybrid no.	Gene-ration	Phenotype	Observed value (O)	Expected value (E)	Deviation (D = O-E)	$D^2 = (O-E)^2$	Chi square (D^2/E)	Genetic ratio	Level of Probability
3.	ICPH 3359	F_1	Fertile	160	160	-	-		**1:0**	
	(ICPA 2047 x ICPL 20107)									
		F_2	Fertile	390	377.43	12.57	158.00	0.42		
			Partial fertile	226	251.63	-25.63	656.90	2.61		
			Sterile	55	41.94	13.06	170.56	4.07		
			Total	**671**	**671.00**	**0.00**	**985.47**	**7.10**	**9:6:1**	0.2 - 0.05
		BC_1F_1	Fertile	54	57.75	-3.75	14.06	0.24		
			Partial fertile	116	115.50	0.50	0.25	0.00		
			Sterile	61	57.75	3.25	10.56	0.18		
			Total	**231**	**231.00**	**0.00**	**24.88**	**0.43**	**1:2:1**	0.8
4.	ICPH 4012	F_1	Fertile	195	195	-	-		**1:0**	
	(ICPA 2092 x ICPL 20186)									
		F_2	Fertile	359	352.13	6.88	47.27	0.13		
			Partial fertile	111	117.38	-6.38	40.64	0.35		
			Sterile	156	156.50	-0.50	0.25	0.00		
			Total	**626**	**626.00**	**0.00**	**88.16**	**0.48**	**9:3:4**	0.5 - 0.8
		BC_1F_1	Fertile	55	53.00	2.00	4.00	0.08		
			Partial fertile	40	53.00	-13.00	169.00	3.19		
			Sterile	117	106.00	11.00	121.00	1.14		
			Total	**212**	**212.00**	**0.00**	**294.00**	**4.41**	**1:1:2**	0.05

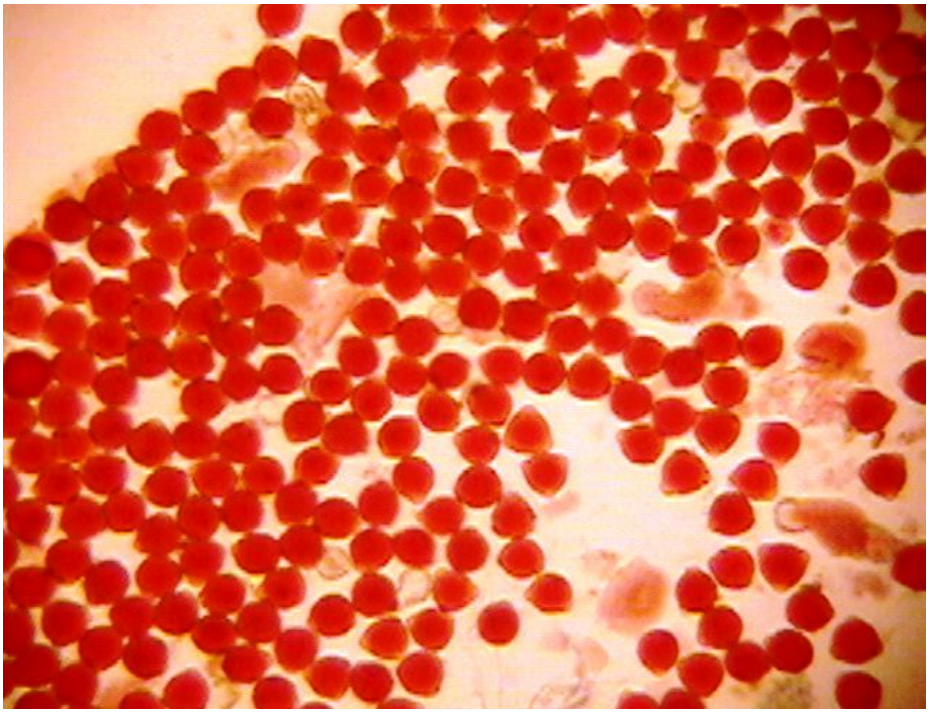

Figure I. (a)

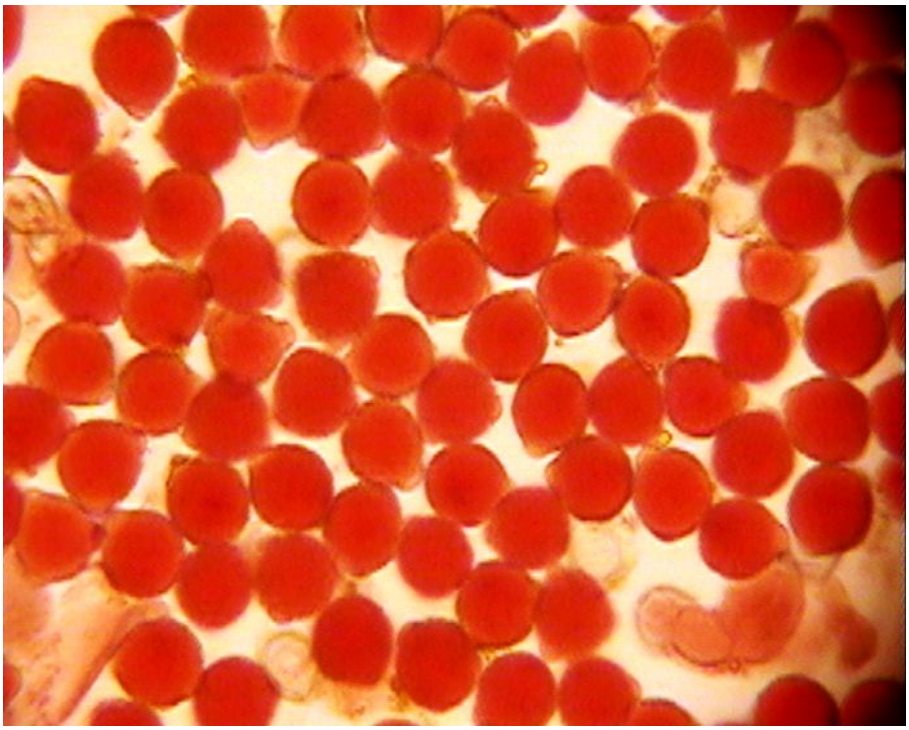

Figure I. (b)

Figure I. (a) and (b): Mature anthers of male-fertile plant

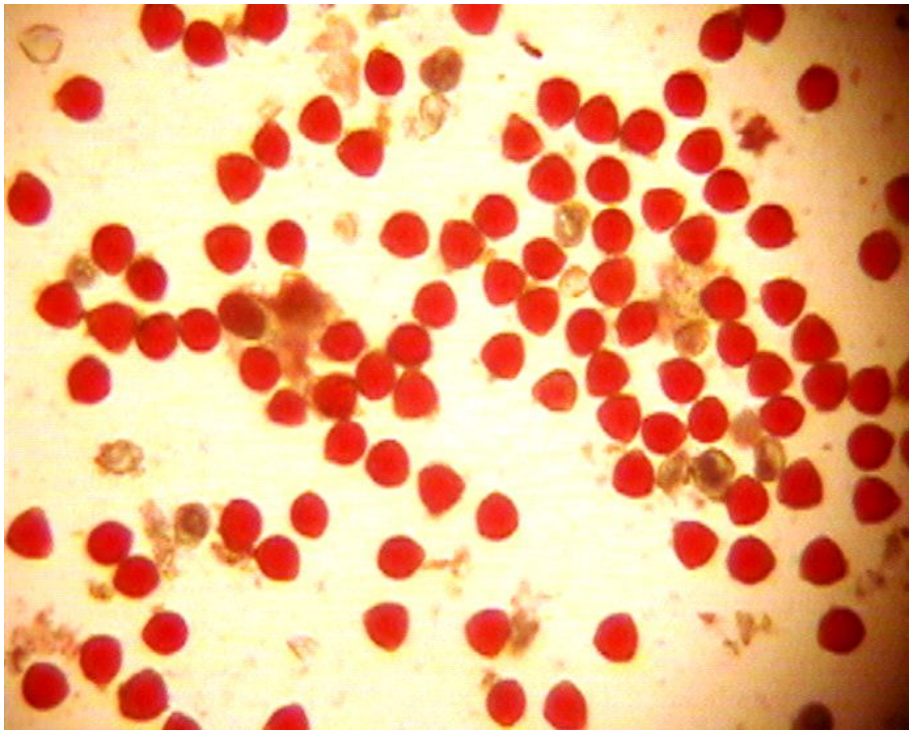

Figure II. Mature anthers of partial male-fertile plant

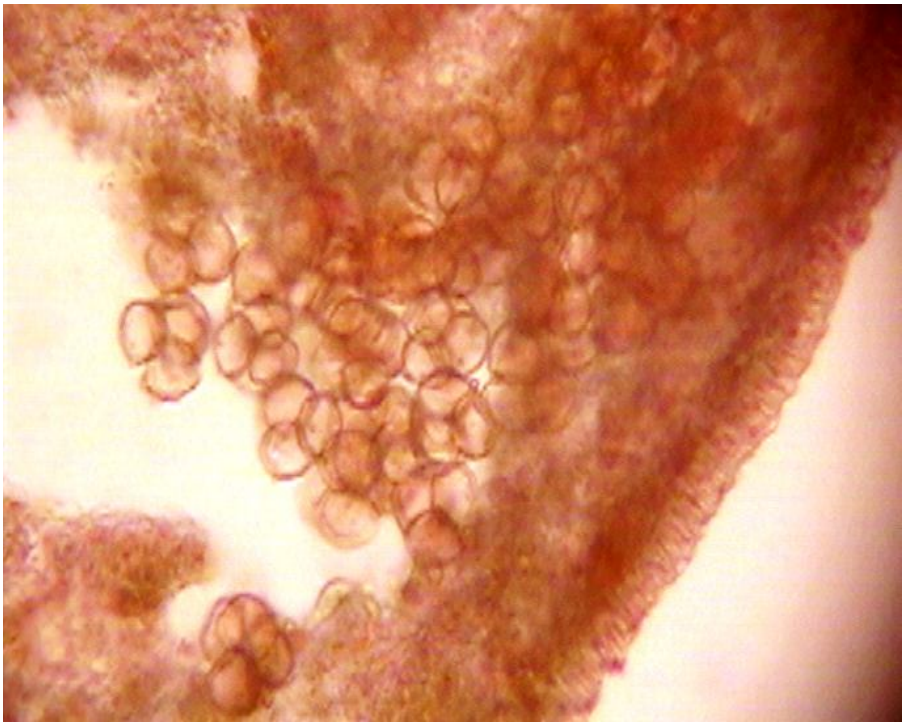

Figure III. Mature anthers of male-sterile plant

Chapter V

SUMMARY AND CONCLUSTIONS

The present investigation entitled, "Studies on hybrid vigour and inbreeding depression in CMS-based pigeonpea (*Cajanus cajan* (L.) Millspaugh) hybrids" was aimed to evaluate the extent of hybrid vigour in cytoplasmic-nuclear male-sterility (CMS) based pigoenpea hybrids. The study was also aimed to find out the inbreeding depression of these hybrids. For this study 22 medium duration disease resistance pigeonea hybrids were selected on the basis of their performance in the multi-locational trials conducted by ICRISAT during the past three years. For developing these hybrids a short duration (ICPA 2078) and four medium duration (ICPA 2043, ICPA 2047, ICPA 2048, and ICPA 2092) male-sterile lines with A_4 cytoplasm were used. These were crossed to 14 known restorer parents. These were ICPL 20093, ICPL 20096, ICPL 20098, ICPL 20107, ICPL 20108, ICPL 20111, ICPL 20116, ICPL 20120, ICPL 20123, ICPL 20125, ICPL 20129, ICPL 20136, ICPL 20186, and ICPL 87119. Among these, four hybrids (ICPH 2671, ICPH 2740, ICPH 3359, and ICPH 4012) were selected to study the genetics of fertility restoration by using their segregation data in F_1, F_2, and BC_1F_1 generations. All the 22 hybrids along with their F_2 populations, female, and male parents, and standard variety as check were planted in a randomized complete block design with three replications at ICRISAT, Patancheru. Each F_1, female and male parental lines, and standard check were grown in three row plots of 4 m length. The inter- and intra-row spacing was kept at 75 cm and 30 cm, respectively. Observations were recorded on five competitive plants in each plot of F_1, female and male parental lines and standard check. In each F_2 plot 40 competitive plants were selected randomly for recording data. The observations were recorded on yield and yield contributing characters that included days to 50% flower, days to mature, plant height (cm), number of primary branches, number of pods plant^{-1}, number of pod clusters plant^{-1}, pod length (mm), pod width (mm), seeds pod^{-1}, 100 seeds weight (g), seed yield plant^{-1} (g), seed yield plot^{-1} (g), and seed yield (kg ha^{-1}). Statistical analysis was undertaken according to Gomez and Gomez (1984). The heterosis was estimated over mid parent, better parent, and standard check variety. To study genetics of fertility restoration each plant of F_1, F_2, BC_1F_1,

female and male parental lines and standard variety were assessed for their pollen-fertility by visual observation. To identify male-sterile and male-fertile plants, the pollen grains of the plants were tested by using 2% aceto-carmine solution at the initial flowering stage. Data on segregation for fertility restoration was used to study the fitness of good. The findings of the present study are briefly summarized, below:

5.1. Mean performance of parents and hybrids

The analysis of variance revealed that variation among the tested genotypes was highly significant for all the characters except for the number of pod clusters. All the female plants flowered earlier than the male parents. Hybrids ICPH 2671 was earliest to flower and mature and it was followed by ICPH 3933, ICPH 3763, ICPH 3762, and ICPH 4022. In F_2 generation ICPH 3933, ICPH 2671, and ICPH 4022 were earlier in flowering and also maturity. The parental lines ICPB 2047, ICPB 2048, ICPB 2092, ICPL 20108, ICPL 20120 and hybrids ICPH 2740, ICPH 3461, ICPH 3762, ICPH 3359, ICPH 4012 in F_1 and ICPH 3461 and ICPH 3359 in F_2 generation were significantly superior to the check for plant height.

The parents ICPB 2047, ICPB 2048, ICPL 20107, ICPL 20111, and ICPL 20186 were higher in *per se* performance for the number of primary branches. Hybrids ICPH 2740, ICPH 3497, ICPH 2751, ICPH 2671, ICPH 3759, ICPH 4017 in F_1 and ICPH 4020 in F_2 were significantly higher in number of primary branches as compared to the standard variety, Asha. The female parents ICPB 2047, ICPB 2048, male parent ICPL 20107, and hybrids ICPH 2740, ICPH 3477, ICPH 3497, ICPH 3461, and ICPH 3359 were significantly higher for pod clusters plant^{-1} than the check. The parents ICPL 20107, ICPL 20111, ICPL 20129 and hybrids ICPH 2740, ICPH 3477, ICPH 3497, ICPH 3359, ICPH 2671, ICPH 4017, and ICPH 3761 had significantly higher number of pods plant^{-1} than the check. The parents ICPL 20108, ICPL 20129 and hybrids ICPH 2740, ICPH 3477, ICPH 3359, ICPH 2671, ICPH 3759 in F_1 and ICPH 3477 in F_2 had significant higher value in pod length than the check. For pod width, ICPB 2078, ICPL 20129 and hybrids ICPH 3497 and ICPH 4020 recorded significant higher value in pod width than the check. The parents ICPB 2047, ICPB 2048, ICPL 20098 and hybrids ICPH 3477, ICPH 2671, ICPH 3762 in F_1 and ICPH 3477 in F_2 population had more number of seeds pod^{-1} than the check. The parents ICPB 2078, ICPL 20129 and hybrids ICPH 3933, ICPH 2671, ICPH 4020 in F_1 and

ICPH 2671, ICPH 4020, and ICPH 4022 in F_2 had larger seeds than the check. More grain yield plant^{-1} was recorded by the parental lines ICPB 2048, ICPL 20107, ICPL 20123 and hybrids ICPH 2740, ICPH 3477, ICPH 3497, ICPH 3359, ICPH 2671, ICPH 4017, and ICPH 3761. For seed yield (kg ha^{-1}), hybrids ICPH 2671 produced the highest yield followed by ICPH 4017, ICPH 4022, and ICPH 3491.

5.2 Heterosis

Early flowering and maturity are desirable traits in hybrid pigeonpea to escape drought and adaptation to the moisture-stress environments. Hence negative heterosis for days to flower and maturity is desirable. Hybrid ICPH 2671 ranked first for higher negative heterosis indicating exploitable hybrid vigour for maturity. Also six hybrids ICPH 2671, ICPH 3461, ICPH 3762, ICPH 3763, ICPH 4022 and ICPH 4024 exhibited significant and negative heterosis. It was observed that the crosses maturing early involved at least one early maturing parent. Heterosis for plant height ranged from -7.24 (ICPH 4020) to 7.22% (ICPH 3759) for heterobeltiosis, -3.95 (ICPH 4020) to 23.94% (ICPH 3933) for relative heterosis and -6.88 (ICPH 4020) to 8.91% (ICPH 3359), respectively. For the number of primary branches, the range of heterosis over better, mid and standard parent was from -31.84 (ICPH 3933) to 24.50% (ICPH 3759), -30.72% (ICPH 3497) to 27.06% (ICPH 3759) and -27.7 (ICPH 3933) to 22.16% (ICPH 3497). Hybrids ICPH 2671, ICPH 2751 and ICPH 3759 were the top ranking crosses in positive heterosis. Thirteen hybrids showed positive heterosis in pod clusters over mid-parent, better parent and standard check. The *per se* performance of heterosis over better, mid and standard parent was from -67.17 (ICPH 3494) to 150.61% (ICPH 3933), -58.82 (ICPH 3494) to 175.93% (ICPH 3933) and -10.59 (ICPH 3763) to 186.82% (ICPH 2740), respectively.

Number of pods plant^{-1}, a major yield component exhibited higher magnitude of heterosis as compared to other traits and the heterosis ranged from -38.40 to 113.46%, -21.88 to 120.47% and -24.44 to 149.19% over better, mid and standard parent, respectively. Five hybrids ICPH 2671, ICPH 2740, ICPH 3359, ICPH 3477 and ICPH 4017 exhibited higher positive heterosis on all the three bases of estimation viz., mid parent, better parent and standard parent, respectively. Significant negative heterosis in pod width over better and standard parent was found in ICPH 2671, ICPH 3477 and ICPH 3933. The range of heterosis was from -16.44 (ICPH 3933) to 3.22% (ICPH 3497) for heterobeltiosis,

-5.95 (ICPH 3933) to 5.44% (ICPH 3497) for relative heterosis, and -9.61 (ICPH 3461) to 11.16% (ICPH 3497) for standard heterosis. ICPH 3491 manifested significant negative heterosis in the length of pod over mid and better parent. The range of heterosis over better, mid and standard parents was from -12.45 (ICPH 3491) to 4.56% (ICPH 4024), -9.41 (ICPH 3491) to 6.75% (ICPH 4024) and -4.32 (ICPH 3933) to 11.97% (ICPH 2740), respectively. ICPH 3491 and ICPH 3933 showed negative heterosis over different level of heterosis. The number of seed pod^{-1} is also an important character, which contributes to the higher yield. ICPH 2671 recorded significant positive heterosis over better, mid and standard parents. The range of heterosis in the present finding was from -6.60 (ICPH 3494) to 16.51% (ICPH 2671), -4.19 (ICPH 3491) to 17.82% (ICPH 2671) and -3.61 (ICPH 3491) to 9.84% (ICPH 2671). Hybrid ICPH 2671 had significant positive heterosis over different levels indicating more hybrid vigour in F_1. The range of heterosis for 100 seed weight varied from -17.33 (ICPH 3933) to 18.75% (ICPH 3477) for heterobeltiosis, -3.12 (ICPH 3933) to 25.00% (ICPH 3497) for relative heterosis and -3.85 (ICPH 3461 and ICPH 4019) to 19.23% (ICPH 3933) for standard heterosis. The hybrids ICPH 3477 and ICPH 3758 had significant positive heterosis over better and mid parents. Based on the present investigation, wide range of positive and negative heterosis was observed in seed yield $plant^{-1}$. The estimated range of heterosis over better, mid, and standard parents was from -53.76 (ICPH 4020) to 129.18 (ICPH 2671), -46.66 (ICPH 4013) to 168.03% (ICPH 168.33), and -5.96 (ICPH 3497) to 154.66% (ICPH 4017), respectively. In general, positive and high magnitude of heterosis for grain yield $plant^{-1}$ was noticed and this may be due to the heterosis contributed by one or more yield contributing characters. The estimated heterosis for seed yield was from -37.72 (ICPH 3763) to 148.94% (ICPH 2671) in heterobletiosis, -11.49 (ICPH 2751) to 190.09% (ICPH 2671) in relative heterosis and -29.93 (ICPH 3763) to 208.44% (ICPH 2671) in standard heterosis. Hybrid ICPH 2671 exhibited high heterosis in seed yield followed by ICPH 2740, ICPH 3477, ICPH 3491, ICPH 4017 and ICPH 4022.

5.3 Inbreeding depression

There was non-significant inbreeding depression for days to flower because the calculated *t*-test values of inbreeding depression (ID) were lower than the corresponding tabulated *t*-value 2.07 at 5% level and 2.81 at 1%. The range of inbreeding depression was from -9.53 (ICPH 3763) to 2.01% (ICPH 4017). In the present investigation, non-significant inbreeding depression indicated the preponderance of additive gene effects. Similar results were observed for days to maturity showing additive gene action in this trait. All the hybrids showed lower level of non-significant negative inbreeding depression except ICPH 3933 and ICPH 4017 which had positive inbreeding depression. The range of inbreeding depression for plant height was from -1.25 (ICPH 4022) to 12.34% (ICPH 4012). There was no significant inbreeding depression at 5% or 1% level. The results indicated that there was no difference in performance of plant height between F_1 and F_2 generations showing additive gene effects. For number of primary branches plant^{-1}, 10 hybrids exhibited significant inbreeding depression and ICPH 2671(24.42%) manifested high level of significant inbreeding depression followed by ICPH 3497 (21.83%), ICPH 3759 (22.99%), and ICPH 3763 (21.30%). In case of number of pod cluster plant^{-1} on the pod bearing branches, inbreeding depression ranged from -64.50 (ICPH 3494) to 68.44% (ICPH 4012), however, none of these hybrids showed significant.

For number of pods plant^{-1} ICPH 2671, ICPH 2740, ICPH 3359, ICPH 3461, ICPH 3758, ICPH 3933, ICPH 4012 and ICPH 4017 exhibited high level of heterosis over their respective better parent, mid parent and standard variety, and inbreeding depression. This finding indicated non-additive gene action. ICPH 3494 (-64.50%) exhibited highly negative inbreeding depression with significant negative heterosis indicating additive gene action for pods plant^{-1}. In the present tudy, 19 hybrids showed significant inbreeding depression for pod length. The range of inbreeding depression was from -6.11 (ICPH 3933) to 7.63% (ICPH 4017). Hybrids ICPH 2671, ICPH 2740, ICPH 3497, ICPH 3758, ICPH 3759, and ICPH 4019 showed significant of inbreeding depression with high standard heterosis indicating non-additive gene action. However, hybrid ICPH 3491 showed negative heterosis and also negative inbreeding depression due to fixation of genes in F_2 showing additive gene action. Based on these results, it seems to be governed by both additive and non-additive gene effects. Eight hybrids (ICPH 3359, ICPH 3497, ICPH 3758, ICPH 3761, ICPH 4012, ICPH 4013, ICPH 4019 and ICPH 4020) showed significant inbreeding

depression for pod width. Significant negative heterosis and inbreeding depression was observed in seven hybrids (ICPH 2751, ICPH 3477, ICPH 3491, ICPH 3494, ICPH 3763, ICPH 3933 and ICPH 4024) for pod width. Pod width may be governed by both additive and non-additive gene effects. Three hybrids, demonstrated significant negative inbreeding depression for seeds pod^{-1} and the rest 17 showed significant inbreeding depression. The maximum inbreeding depression with significant heterosis was recorded in ICPH 3461. The present investigation indicated the importance of both additive and non-additive gene action for $seedspod^{-1}$. There was no inbreeding depression for 100-seed weight in ICPH 3461 and ICPH 4017 indicating additive genes. The significant inbreeding depression was found in ICPH 3359 (19.61%) which had significant heterosis over mid-parent and expressed non-additive genes. This trait appears to be governed by both additive and non-additive gene action. For seed yield $plant^{-1}$, both positive and negative inbreeding depression values were recorded in all the hybrids. Out of 22 hybrids, 14 showed 44.69 to 73.28% of significant inbreeding depression under study. The results indicated the predominance of non-additive gene action. For seed yield, 12 hybrids exhibited positive heterosis and inbreeding depression ranging from 7.64 to 52.33%. The rest hybrids showed -55.20 to -6.85% of negative inbreeding depression indicating. The results on inbreeding depression suggested that genes affecting yield showed both the additive and non-additive gene action. This high magnitude of inbreeding depression in yield was mainly due to depression in expression of major yield components such as number of pods $plant^{-1}$, seeds pod^{-1} and 100 seed weight.

5.4 Genetics of fertility restoration

Two hybrids ICPH 2671 (ICPA 2043 x ICPL 87119) and ICPH 2740 (ICPA 2047 x ICPL 87119) had epistasis with dominant gene interaction (F_2 ratio 12:3:1 and BC_1 ratio 2:1:1). In hybrid ICPH 3359 (ICPA 2047 x ICPL 20107), the fertility restoration was governed by dominant genes with semi-dominant epistatic interaction (F_2 ratio 9:6:1, BC_1 ratio 1:2:1). In ICPH 4012, where the fertility restoration was governed by dominant genes with recessive epistatic interaction (F_2 ratio 9:3:4, BC_1 ratio 1:1:2). The results of this study revealed that fertility restoration in pigoenpea hybrids appeared to be governed by two genes with epistatic interaction. ICPH 2671 and ICPH 2740 which have the same restorer but different male sterile lines segregated in the ratio of 12:3:1 in F_2 and 2:1:1 in BC_1

generation showing digenic dominant epistatic interaction, respectively. ICPH 3359 showed a segregation ratio of 9:6:1 and 1:2:1 in F_2 and BC_1 generation indicating two major genes governing fertility restoration showing epistasis with incomplete dominance while ICPH 4012 segregated in the ratio of 9:3:4 and 1:1:2 in F_2 and BC_1F_1 erations for pollen fertility/sterility.

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APPENDIX I

Monthly weather data during crop season recorded at ICRISAT, Patancheru, 2010-11

Latitude :17.53^{o}N Longitude : 78.27^{o}E Altitude : 545m

Year	Month	Rain (in mm)	Evaporation (in mm)	Max Temperature (in^{o}C)	Min Temperature (in^{o}C)	Rel Humidity1 at 07:17 (in%)	Rel Humidity2 at 14:17 (in%)	Solar Radiation (in mj/ m^{2})	Bright Sunshine (in Hrs)
2010	June	139.8	230.3	34.82	24.58	80.76	50.53	17.8	5.73
2010	July	274.8	114.5	29.27	22.61	91.96	73.9	13.25	2.99
2010	August	434.89	104.79	29.59	22.38	93.9	71.54	15.79	4.75
2010	September	132.2	100.39	29.63	22.27	94.13	72.2	15.02	4.56
2010	Octoboer	108.89	102.99	29.85	20.46	94.29	58.12	15.76	6.19
2010	Novermber	17.9	84.49	28.56	19.48	95.59	62.39	13.48	5.89
2010	December	12.5	102.29	27.27	13.15	93.77	44.77	14.92	7.3
2011	January	0	129.3	28.81	10.9	94.9	36	17.4	9.08
2011	February	0.4	148.2	30.84	15.36	88.17	33.32	18.06	9.01

**Data shows the sum of Rainfall & Evaporation and mean of the remaining parameters*

APPENDIX II

Daily weather data during the crop season recorded at ICRISAT, Patancheru, 2010-11

Date (mm/dd/yyyy)	Rain (in mm)	Evap (in mm)	Max Temp (in^{o}C)	Min Temp (in^{o}C)	Rel Humidity1 at 07:17 (in%)	Rel Humidity2 at 14:17 (in%)	Solar Radiation (in mj/ m^{2})	Bright Sunshine (in Hrs)
5/27/2010	0	17.0	40.7	27.2	71.0	34.0	25.2	11.5
5/28/2010	0	13.8	39.8	27.6	65.0	35.0	25.2	11.4
5/29/2010	0	13.4	40.8	27.5	49.0	20.0	25.0	11.2
5/30/2010	0	15.2	41.6	28.5	58.0	24.0	24.4	11.3
5/31/2010	0	14.1	41.2	28.2	54.0	26.0	21.5	8.2
06-01-2010	0	11.6	40.6	28.2	63.0	25.0	22.4	8.2
06-02-2010	0	12.0	40.8	26.4	68.0	24.0	19.1	8.8
06-03-2010	0	10.2	37.8	26.8	70.0	45.0	13.7	2.4
06-04-2010	24.8	12.9	39.4	21.8	65.0	38.0	21.5	8.1
06-05-2010	0	9.4	37.6	26.4	65.0	42.0	21.6	6.3
06-06-2010	0	12.5	38.0	27.0	70.0	42.0	24.6	10.2
06-07-2010	0	11.9	37.2	27.1	72.0	44.0	21.5	9.3
06-08-2010	0	13.0	37.7	27.6	65.0	36.0	23.1	9.2
06-09-2010	1.8	12.2	38.2	24.5	82.0	36.0	23.3	11.3
06-10-2010	2	5.7	33.8	24.4	81.0	57.0	10.1	0.4
06-11-2010	3	5.8	36.8	23.5	90.0	40.0	19.6	5.5
06-12-2010	6.2	5.8	36.0	24.2	88.0	43.0	19.2	5.7
6/13/2010	10.8	6.0	34.8	22.2	95.0	55.0	17.6	7.0
6/14/2010	0	4.1	31.7	24.6	84.0	63.0	15.1	1.6
6/15/2010	4.4	3.4	30.8	23.4	85.0	79.0	10.9	1.8
6/16/2010	0.2	6.0	33.4	23.8	85.0	53.0	15.2	6.2
6/17/2010	0	8.9	33.0	24.2	81.0	54.0	18.3	6.2
6/18/2010	4	5.0	33.3	23.5	87.0	48.0	19.0	6.9
6/19/2010	62	6.8	34.2	22.3	93.0	51.0	14.7	2.3
6/20/2010	17.4	4.8	31.0	23.0	97.0	63.0	14.8	2.8
6/21/2010	3.2	2.2	29.3	23.5	90.0	73.0	13.0	0.4
6/22/2010	0	5.3	30.4	24.5	85.0	73.0	15.5	1.9
6/23/2010	0	5.4	33.3	24.0	87.0	56.0	17.3	5.1
6/24/2010	0	7.0	32.2	24.0	87.0	58.0	15.4	5.5
6/25/2010	0	3.8	30.7	23.5	85.0	61.0	10.2	0.3
6/26/2010	0	6.4	33.7	23.5	85.0	54.0	16.6	5.7

Where, mm = month, dd = date, yy = year

Evap = Evaporation, Temp = temperature

APPENDIX II (Contd.)

Date (mm/dd/yyyy)	Rain (in mm)	Evap (in mm)	Max Temp (in^{o}C)	Min Temp (in^{o}C)	Rel Humidity1 at 07:17 (in%)	Rel Humidity2 at 14:17 (in%)	Solar Radiation (in mj/ m^{2})	Bright Sunshine (in Hrs)
6/27/2010	0	7.1	33.7	24.8	80.0	49.0	18.5	6.9
6/28/2010	0	8.0	34.8	24.6	80.0	50.0	20.0	8.9
6/29/2010	0	10.1	36.2	25.2	77.0	49.0	23.1	11.3
6/30/2010	0	7.0	34.4	25.0	81.0	55.0	19.3	5.9
07-01-2010	4.8	4.8	34.5	21.5	97.0	51.0	13.8	5.0
07-02-2010	52.8	4.8	30.8	21.9	95.0	77.0	12.3	1.1
07-03-2010	0.4	3.7	26.4	22.9	91.0	92.0	8.7	0.7
07-04-2010	0.2	1.6	27.2	22.0	90.0	84.0	8.9	0.0
07-05-2010	0.8	6.2	31.8	23.0	89.0	60.0	20.8	10.1
07-06-2010	27.8	4.3	32.8	22.1	97.0	63.0	19.1	8.8
07-07-2010	42	3.5	28.3	22.0	98.0	86.0	12.2	0.1
07-08-2010	19.6	3.9	28.2	21.5	98.0	78.0	11.2	0.8
07-09-2010	1.1	1.3	26.8	23.0	92.0	86.0	11.1	0.1
07-10-2010	0	5.1	30.8	22.6	90.0	66.0	19.5	5.1
07-11-2010	13.4	5.4	32.5	21.6	98.0	59.0	19.2	10.3
07-12-2010	9	2.7	28.6	22.8	98.0	75.0	9.9	0.0
7/13/2010	0	2.9	28.8	23.5	82.0	70.0	11.1	0.1
7/14/2010	0	6.6	31.7	24.0	81.0	51.0	21.6	10.0
7/15/2010	0	6.0	31.0	24.0	87.0	63.0	20.1	9.0
7/16/2010	8.4	4.4	31.3	22.5	95.0	60.0	17.8	4.4
7/17/2010	1.9	3.4	28.6	23.8	92.0	89.0	11.7	1.0
7/18/2010	0.4	2.6	28.7	22.6	90.0	80.0	11.2	2.6
7/19/2010	0	4.0	29.2	23.0	90.0	68.0	14.2	5.6
7/20/2010	0	2.5	30.2	24.0	90.0	66.0	12.9	4.2
7/21/2010	5	5.8	31.9	23.0	92.0	61.0	17.9	6.9
7/22/2010	10.8	3.6	28.6	22.5	93.0	75.0	11.4	1.5
7/23/2010	0.3	2.9	28.6	23.2	90.0	71.0	12.1	1.1
7/24/2010	31.6	4.6	31.0	22.5	92.0	66.0	14.0	2.1
7/25/2010	8	2.2	27.2	22.0	95.0	83.0	6.0	0.0
7/26/2010	7.4	1.0	24.4	22.0	90.0	92.0	6.0	0.0
7/27/2010	0	4.3	28.2	23.4	88.0	74.0	16.3	1.5
7/28/2010	0.5	2.7	27.7	23.0	93.0	73.0	11.4	0.1
7/29/2010	21.8	3.2	29.2	21.5	95.0	98.0	10.8	0.2

Where, mm = month, dd = date, yy = year

Evap = Evaporation, Temp = temperature

APPENDIX II (Contd.)

Date (mm/dd/yyyy)	Rain (in mm)	Evap (in mm)	Max Temp (inoC)	Min Temp (inoC)	Rel Humidity1 at 07:17 (in%)	Rel Humidity2 at 14:17 (in%)	Solar Radiation (in mj/ m2)	Bright Sunshine (in Hrs)
7/30/2010	3.6	1.7	25.0	21.7	93.0	95.0	5.5	0.0
7/31/2010	3.2	2.8	27.6	22.0	90.0	79.0	12.3	0.3
08-01-2010	0	3.9	29.3	22.5	88.0	71.0	15.0	7.3
08-02-2010	0	5.0	30.2	22.0	88.0	67.0	17.3	6.7
08-03-2010	0	5.4	30.0	22.5	87.0	64.0	17.7	6.9
08-04-2010	8.8	3.2	28.7	22.4	90.0	70.0	14.5	1.2
08-05-2010	0	5.0	29.4	22.0	90.0	66.0	17.4	4.0
08-06-2010	20	1.7	28.2	21.0	97.0	70.0	9.8	0.0
08-07-2010	9.6	2.7	23.6	20.5	93.0	95.0	4.8	0.0
08-08-2010	0	4.0	28.6	21.5	88.0	65.0	17.6	5.3
08-09-2010	0.2	4.7	31.0	22.0	87.0	60.0	21.8	9.4
08-10-2010	0	5.2	30.7	21.6	91.0	60.0	20.6	11.0
08-11-2010	0	4.8	31.2	23.0	93.0	62.0	21.6	10.2
08-12-2010	11	2.2	29.5	23.8	95.0	73.0	11.3	3.6
8/13/2010	4.3	2.9	30.0	23.2	95.0	97.0	15.7	3.5
8/14/2010	38.2	3.8	30.0	22.2	97.0	77.0	11.5	0.6
8/15/2010	17.1	3.0	29.6	23.5	98.0	73.0	12.7	2.3
8/16/2010	39.2	2.8	30.7	22.8	97.0	70.0	16.2	2.0
8/17/2010	26	3.4	32.2	23.0	98.0	62.0	20.5	7.4
8/18/2010	51	4.2	31.1	20.6	97.0	68.0	16.9	5.6
8/19/2010	19	2.9	30.2	22.8	95.0	71.0	15.8	4.0
8/20/2010	90.7	3.0	30.0	21.3	98.0	73.0	16.6	5.0
8/21/2010	0.2	2.4	28.8	23.4	98.0	76.0	16.9	3.7
8/22/2010	13	4.0	31.4	22.4	97.0	62.0	21.9	9.5
8/23/2010	0	3.6	31.3	23.8	95.0	67.0	21.9	9.3
8/24/2010	5.9	3.5	31.0	22.4	98.0	63.0	19.9	8.6
8/25/2010	8.8	4.5	31.2	22.0	97.0	67.0	22.4	7.4
8/26/2010	43.2	4.4	31.7	22.5	98.0	61.0	19.3	7.7
8/27/2010	12.4	2.2	28.3	22.6	93.0	77.0	10.4	0.4
8/28/2010	0	1.6	29.4	23.0	95.0	67.0	15.7	4.1
8/29/2010	6	2.8	28.8	23.0	92.0	78.0	11.7	0.8
8/30/2010	6.3	1.5	27.4	22.4	95.0	95.0	8.5	0.0
8/31/2010	4	0.5	23.8	22.2	91.0	91.0	5.9	0.0

Where, mm = month, dd = date, yy = year

Evap = Evaporation, Temp = temperature

APPENDIX II (Contd.)

Date (mm/dd/yyyy)	Rain (in mm)	Evap (in mm)	Max Temp (in^{o}C)	Min Temp (in^{o}C)	Rel Humidity1 at 07:17 (in%)	Rel Humidity2 at 14:17 (in%)	Solar Radiation (in mj/ m2)	Bright Sunshine (in Hrs)
09-01-2010	0	3.6	26.5	22.5	91.0	75.0	10.7	0.0
09-02-2010	2	4.1	30.2	22.4	93.0	66.0	16.6	4.8
09-03-2010	0	4.9	30.0	23.2	87.0	70.0	17.9	6.8
09-04-2010	14.6	4.4	29.3	21.5	96.0	65.0	16.8	3.0
09-05-2010	7.3	2.3	26.0	22.0	97.0	81.0	8.6	0.0
09-06-2010	0.6	2.0	27.0	22.4	97.0	81.0	9.2	0.5
09-07-2010	18.2	2.3	27.6	22.4	97.0	93.0	12.4	0.6
09-08-2010	1.4	2.1	27.2	22.4	97.0	78.0	8.6	0.0
09-09-2010	14	2.2	27.8	22.0	95.0	76.0	11.1	0.0
09-10-2010	3.2	2.1	28.3	21.5	93.0	95.0	12.9	3.1
09-11-2010	0	4.2	29.9	22.4	91.0	69.0	18.1	8.2
09-12-2010	0	4.5	30.6	22.3	91.0	63.0	21.7	10.2
9/13/2010	0	5.1	30.3	24.2	92.0	63.0	23.0	9.5
9/14/2010	0.2	4.0	31.2	22.7	91.0	63.0	14.4	4.4
9/15/2010	7.1	2.1	29.2	22.7	97.0	89.0	9.2	0.8
9/16/2010	9	2.9	29.8	22.0	97.0	69.0	15.8	4.0
9/17/2010	11.5	2.7	29.0	21.0	96.0	73.0	12.4	2.1
9/18/2010	5.3	0.9	27.7	21.5	98.0	81.0	9.8	0.1
9/19/2010	0	2.4	29.3	22.0	93.0	79.0	14.2	2.5
9/20/2010	0	4.0	31.2	22.4	93.0	64.0	20.7	9.1
9/21/2010	0	3.8	31.4	23.0	97.0	63.0	20.4	8.1
9/22/2010	0	4.3	32.2	23.6	92.0	56.0	18.9	6.9
9/23/2010	18	4.8	32.3	21.0	98.0	56.0	16.0	6.3
9/24/2010	13.4	4.1	30.7	21.5	95.0	66.0	15.4	5.4
9/25/2010	0.6	1.9	29.9	21.2	98.0	93.0	10.0	3.7
9/26/2010	0	3.6	30.3	22.5	95.0	66.0	16.7	5.2
9/27/2010	3	3.0	31.2	22.4	90.0	66.0	14.7	6.7
9/28/2010	0	5.6	30.8	22.5	88.0	60.0	20.7	9.6
9/29/2010	0	3.3	30.7	23.6	92.0	62.0	18.1	9.1
9/30/2010	2.8	3.2	31.4	21.5	97.0	85.0	15.7	6.1
10-01-2010	0	4.1	30.3	19.4	89.0	49.0	21.0	8.6
10-02-2010	1.4	2.9	30.0	22.5	95.0	54.0	20.1	9.6

Where, mm = month, dd = date, yy = year

Evap = Evaporation, Temp = temperature

APPENDIX II (Contd.)

Date (mm/dd/yyyy)	Rain (in mm)	Evap (in mm)	Max Temp (inoC)	Min Temp (inoC)	Rel Humidity1 at 07:17 (in%)	Rel Humidity2 at 14:17 (in%)	Solar Radiation (in mj/ m2)	Bright Sunshine (in Hrs)
10-03-2010	0	2.4	29.4	22.5	92.0	65.0	13.5	4.1
10-04-2010	0	3.2	30.2	22.2	95.0	63.0	16.8	7.3
10-05-2010	0.2	2.7	30.3	22.0	98.0	76.0	14.8	7.7
10-06-2010	2.6	2.5	30.8	22.4	98.0	65.0	15.9	5.2
10-07-2010	0	3.0	30.0	21.2	95.0	66.0	15.0	3.5
10-08-2010	0	3.9	31.0	21.2	96.0	60.0	18.8	6.7
10-09-2010	0	2.9	30.0	21.2	95.0	63.0	16.4	6.0
10-10-2010	0	4.0	31.8	19.8	88.0	40.0	20.0	8.1
10-11-2010	0	4.1	31.8	19.8	93.0	44.0	19.2	8.0
10-12-2010	0	4.8	31.2	20.0	96.0	56.0	19.3	8.5
10/13/2010	0	4.6	31.8	18.7	93.0	48.0	18.9	9.2
10/14/2010	0	5.1	32.2	18.5	96.0	34.0	21.1	9.3
10/15/2010	0	4.8	31.8	18.9	89.0	39.0	20.2	9.7
10/16/2010	0	4.9	31.1	21.8	81.0	45.0	15.8	4.1
10/17/2010	14	1.0	24.8	20.5	98.0	87.0	5.9	0.0
10/18/2010	3.8	0.5	23.8	22.0	98.0	95.0	3.9	0.0
10/19/2010	0.2	1.0	25.8	22.6	95.0	89.0	6.6	0.3
10/20/2010	0	2.6	29.6	21.4	95.0	65.0	15.1	4.6
10/21/2010	22	2.4	29.2	21.9	97.0	68.0	9.9	4.4
10/22/2010	0	3.6	31.7	22.1	98.0	58.0	18.2	10.2
10/23/2010	0	2.6	29.8	22.0	95.0	72.0	14.7	5.6
10/24/2010	22.8	3.6	29.6	22.0	98.0	67.0	12.9	4.7
10/25/2010	0.1	2.6	28.8	19.8	98.0	69.0	14.9	4.0
10/26/2010	0	3.5	30.0	19.5	98.0	59.0	17.9	9.1
10/27/2010	0	4.2	30.6	18.4	84.0	43.0	20.1	9.5
10/28/2010	0	6.0	30.7	15.0	98.0	29.0	20.1	9.8
10/29/2010	0	4.6	30.1	14.2	96.0	28.0	20.3	9.8
10/30/2010	0	2.3	28.7	21.0	91.0	42.0	14.1	4.2
10/31/2010	41.8	2.6	28.6	20.0	95.0	64.0	7.4	0.2
11-01-2010	0.3	1.1	25.2	19.8	96.0	79.0	7.8	0.2
11-02-2010	0	1.3	23.6	20.2	93.0	83.0	6.1	0.0
11-03-2010	1.8	1.5	25.7	21.8	96.0	90.0	8.5	0.7

Where, mm = month, dd = date, yy = year

Evap = Evaporation, Temp = temperature

APPENDIX II (Contd.)

Date (mm/dd/yyyy)	Rain (in mm)	Evap (in mm)	Max Temp (inoC)	Min Temp (inoC)	Rel Humidity1 at 07:17 (in%)	Rel Humidity2 at 14:17 (in%)	Solar Radiation (in mj/ m2)	Bright Sunshine (in Hrs)
11-04-2010	0.2	1.3	27.3	20.6	96.0	72.0	9.7	1.0
11-05-2010	0	3.1	29.4	20.3	98.0	61.0	15.8	6.7
11-06-2010	3.6	1.8	28.0	17.3	98.0	83.0	9.7	3.5
11-07-2010	0	2.5	27.0	16.0	94.0	44.0	13.3	3.2
11-08-2010	1.4	1.9	27.3	21.4	95.0	64.0	10.3	1.4
11-09-2010	6.3	1.9	25.6	21.8	93.0	92.0	9.1	1.5
11-10-2010	1	3.2	29.0	21.8	95.0	70.0	14.4	7.2
11-11-2010	0	3.0	29.6	20.0	93.0	65.0	16.7	7.7
11-12-2010	0	3.3	30.6	21.8	97.0	55.0	15.5	9.3
11/13/2010	0	1.6	28.2	20.0	96.0	68.0	12.0	2.7
11/14/2010	0	2.5	30.6	20.2	98.0	60.0	14.1	7.0
11/15/2010	3.3	3.5	30.7	20.5	96.0	54.0	15.9	9.4
11/16/2010	0	3.4	29.0	18.4	98.0	60.0	16.4	9.4
11/17/2010	0	4.0	29.1	22.0	91.0	56.0	15.3	7.6
11/18/2010	0	2.5	26.9	22.0	93.0	71.0	9.1	0.8
11/19/2010	0	1.7	29.2	20.2	98.0	59.0	13.4	5.3
11/20/2010	0	2.6	28.9	19.5	98.0	69.0	13.8	8.1
11/21/2010	0	2.4	30.0	19.5	96.0	62.0	13.4	8.3
11/22/2010	0	3.0	29.8	19.4	98.0	57.0	13.8	7.4
11/23/2010	0	3.5	29.3	19.7	84.0	60.0	15.4	9.1
11/24/2010	0	4.5	30.4	18.7	96.0	50.0	18.4	10.4
11/25/2010	0	3.9	29.8	19.0	98.0	50.0	16.9	8.7
11/26/2010	0	4.1	29.8	16.8	96.0	48.0	15.4	8.6
11/27/2010	0	4.1	29.8	16.8	96.0	48.0	15.4	8.6
11/28/2010	0	3.8	28.8	16.5	96.0	49.0	16.9	6.4
11/29/2010	0	3.8	29.2	16.3	98.0	50.0	15.9	8.4
11/30/2010	0	3.7	29.3	16.4	98.0	43.0	16.3	8.2
12-01-2010	0	4.0	29.2	15.4	98.0	49.0	15.9	8.6
12-02-2010	0	3.5	29.0	17.2	96.0	45.0	15.9	7.7
12-03-2010	0	3.2	28.5	19.5	93.0	58.0	13.4	4.9
12-04-2010	0	3.9	28.7	15.8	96.0	52.0	15.2	6.9

Where, mm = month, dd = date, yy = year

Evap = Evaporation, Temp = temperature

APPENDIX II (Contd.)

Date (mm/dd/yyyy)	Rain (in mm)	Evap (in mm)	Max Temp (inoC)	Min Temp (inoC)	Rel Humidity1 at 07:17 (in%)	Rel Humidity2 at 14:17 (in%)	Solar Radiation (in mj/ m2)	Bright Sunshine (in Hrs)
12-05-2010	0	4.4	28.4	17.4	85.0	46.0	16.2	7.8
12-06-2010	0	5.4	27.8	15.6	84.0	37.0	15.5	6.7
12-07-2010	0	4.5	26.3	17.7	77.0	40.0	10.3	0.6
12-08-2010	8.9	2.0	21.8	18.8	96.0	83.0	3.2	0.0
12-09-2010	0.1	1.4	24.3	19.1	94.0	88.0	5.9	1.2
12-10-2010	0	2.6	27.0	18.1	96.0	63.0	12.9	6.9
12-11-2010	3.4	2.2	28.0	19.5	96.0	61.0	10.7	4.7
12-12-2010	0.1	1.9	28.2	15.2	90.0	74.0	11.5	6.2
12/13/2010	0	4.2	27.4	12.0	98.0	48.0	17.5	9.7
12/14/2010	0	2.8	28.3	14.0	92.0	42.0	16.3	9.0
12/15/2010	0	3.7	27.2	15.5	86.0	51.0	13.8	5.9
12/16/2010	0	3.5	27.2	11.8	93.0	46.0	14.8	6.7
12/17/2010	0	3.3	26.2	9.4	95.0	34.0	17.2	8.8
12/18/2010	0	3.2	26.2	8.0	97.0	29.0	17.8	9.6
12/19/2010	0	3.9	26.2	7.4	95.0	28.0	18.3	9.6
12/20/2010	0	4.2	26.3	6.8	92.0	34.0	18.4	9.8
12/21/2010	0	4.1	27.7	6.6	97.0	24.0	18.2	9.6
12/22/2010	0	3.1	27.1	6.0	97.0	29.0	18.5	9.8
12/23/2010	0	3.0	29.6	8.4	98.0	26.0	18.0	9.6
12/24/2010	0	2.3	29.7	9.0	93.0	22.0	17.8	9.5
12/25/2010	0	2.9	28.2	9.2	97.0	25.0	17.5	9.4
12/26/2010	0	4.4	28.6	9.2	95.0	25.0	17.5	9.4
12/27/2010	0	2.2	27.7	11.7	98.0	36.0	16.9	9.2
12/28/2010	0	4.5	26.4	11.7	98.0	39.0	16.8	9.0
12/29/2010	0	2.5	25.7	12.3	93.0	45.0	16.0	8.4
12/30/2010	0	3.0	25.2	13.6	96.0	59.0	10.1	3.6
12/31/2010	0	2.5	27.5	16.0	96.0	50.0	14.8	7.7
01-01-2011	0	3.2	29.2	16.2	96.0	52.0	14.2	6.4
01-02-2011	0	2.2	26.5	14.2	94.0	63.0	9.6	4.6
01-03-2011	0	2.9	27.4	14.3	84.0	54.0	14.0	6.7
01-04-2011	0	3.6	27.7	14.0	96.0	44.0	15.2	7.0
01-05-2011	0	2.7	26.2	12.4	98.0	59.0	12.9	4.5

Where, mm = month, dd = date, yy = year

Evap = Evaporation, Temp = temperature

APPENDIX II (Contd.)

Date (mm/dd/yyyy)	Rain (in mm)	Evap (in mm)	Max Temp (inoC)	Min Temp (inoC)	Rel Humidity1 at 07:17 (in%)	Rel Humidity2 at 14:17 (in%)	Solar Radiation (in mj/ m2)	Bright Sunshine (in Hrs)
01-06-2011	0	4.2	26.6	4.5	97.0	43.0	16.4	8.2
01-07-2011	0	3.7	25.2	6.5	97.0	25.0	18.6	9.8
01-08-2011	0	3.6	26.5	7.8	92.0	24.0	18.6	9.7
01-09-2011	0	3.1	27.2	8.4	97.0	34.0	17.4	9.3
01-10-2011	0	3.6	27.8	7.5	95.0	32.0	18.0	9.5
01-11-2011	0	4.2	26.7	5.6	97.0	26.0	18.2	9.6
01-12-2011	0	3.2	27.5	5.7	97.0	25.0	18.6	9.7
1/13/2011	0	4.1	28.9	7.5	97.0	24.0	18.5	9.7
1/14/2011	0	5.1	29.9	9.0	97.0	25.0	18.2	9.9
1/15/2011	0	4.0	29.9	10.3	95.0	25.0	18.1	9.7
1/16/2011	0	4.4	29.5	11.4	98.0	28.0	18.9	10.0
1/17/2011	0	3.9	29.2	11.7	93.0	36.0	18.4	9.7
1/18/2011	0	3.8	28.8	11.3	95.0	36.0	17.9	9.7
1/19/2011	0	4.3	30.6	12.4	80.0	28.0	18.8	10.2
1/20/2011	0	4.3	31.0	12.3	98.0	31.0	18.2	10.1
1/21/2011	0	5.3	30.3	10.7	93.0	31.0	18.7	9.6
1/22/2011	0	5.0	29.4	10.2	91.0	29.0	18.6	10.1
1/23/2011	0	4.7	30.1	10.6	98.0	38.0	18.2	10.1
1/24/2011	0	4.6	29.7	11.3	98.0	38.0	18.0	9.5
1/25/2011	0	4.5	29.8	12.5	98.0	38.0	18.0	8.9
1/26/2011	0	5.0	29.2	12.7	98.0	47.0	18.0	9.1
1/27/2011	0	4.9	29.0	10.4	98.0	45.0	18.1	10.1
1/28/2011	0	5.3	30.3	13.6	96.0	37.0	18.5	9.9
1/29/2011	0	5.1	30.7	15.2	92.0	41.0	18.3	9.9
1/30/2011	0	5.4	31.8	14.5	89.0	27.0	18.2	10.3
1/31/2011	0	5.4	30.7	13.4	98.0	31.0	18.2	10.2
02-01-2011	0	5.4	29.4	13.8	92.0	31.0	17.5	9.1
02-02-2011	0	5.7	30.2	13.3	89.0	29.0	17.8	9.8
02-03-2011	0	5.4	29.4	12.5	93.0	30.0	17.7	10.0
02-04-2011	0	5.3	29.8	11.5	93.0	36.0	18.3	10.0
02-05-2011	0	5.9	30.3	10.6	88.0	30.0	18.2	9.9
02-06-2011	0	5.7	30.7	11.3	93.0	23.0	19.3	10.4
02-07-2011	0	4.7	30.3	11.7	98.0	32.0	18.9	10.0
02-08-2011	0	6.0	31.3	12.6	98.0	24.0	19.4	10.0

Where, mm = month, dd = date, yy = year

Evap = Evaporation, Temp = temperature

APPENDIX II (Contd.)

Date (mm/dd/yyyy)	Rain (in mm)	Evap (in mm)	Max Temp (inoC)	Min Temp (inoC)	Rel Humidity1 at 07:17 (in%)	Rel Humidity2 at 14:17 (in%)	Solar Radiation (in mj/ m2)	Bright Sunshine (in Hrs)
02-09-2011	0	4.7	31.7	12.3	82.0	17.0	20.1	9.8
02-10-2011	0	6.0	31.7	13.4	81.0	24.0	19.2	10.0
02-11-2011	0	5.6	30.8	14.7	74.0	27.0	18.6	9.9
02-12-2011	0	6.0	30.7	12.8	83.0	29.0	18.9	9.8
2/13/2011	0	5.6	31.1	13.2	89.0	29.0	18.8	10.2
2/14/2011	0	5.7	31.4	14.0	81.0	29.0	19.3	10.2
2/15/2011	0	6.7	31.8	12.8	69.0	22.0	20.5	10.5
2/16/2011	0	7.6	32.3	16.5	90.0	20.0	21.4	10.7
2/17/2011	0	6.0	30.0	14.7	92.0	37.0	19.1	10.0
2/18/2011	0	4.2	30.7	17.0	92.0	36.0	18.0	9.7
2/19/2011	0	4.1	32.7	17.8	85.0	37.0	16.4	8.5
2/20/2011	0	5.3	32.7	20.0	91.0	39.0	16.8	9.2
2/21/2011	0	5.3	31.9	19.4	90.0	49.0	15.6	9.0
2/22/2011	0	4.0	30.4	19.2	84.0	42.0	17.0	7.1
2/23/2011	0	5.4	29.5	18.6	86.0	47.0	19.1	8.7
2/24/2011	0	4.0	30.4	18.2	92.0	43.0	17.6	7.6
2/25/2011	0.4	4.4	31.0	19.2	91.0	38.0	15.3	6.9
2/26/2011	0	4.5	31.2	20.0	93.0	40.0	16.5	6.0
2/27/2011	0	4.2	29.6	20.7	88.0	52.0	13.6	3.9
2/28/2011	0	4.8	30.7	18.5	92.0	41.0	17.0	5.5

Where, mm = month, dd = date, yy = year

Evap = Evaporation, Temp = temperature