GENETIC DIVERSITY, HETEROSIS AND COMBINING ABILITY STUDIES INVOLVING DIVERSE SOURCES OF CYTOPLASMIC GENETIC MALE STERILITY IN PEARL MILLET [*Pennisetum glaucum* (L.) R.Br.]

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1. INTRODUCTION

Pearl millet [*Pennisetum glaucum* (L.) R.Br.] belongs to family poaceae (graminae) and genus *Pennisetum*. It is a highly cross-pollinated crop with protogynous flowering and wind borne pollination mechanism, which fulfils one of the essential biological requirements for hybrid development. Pearl millet is diploid (2x=14) in nature and is commonly known as bajra, cat tail millet, and bulrush millet in different parts of the world.

Pearl millet is the most drought tolerant warm-season cereal crop predominantly grown as a staple food grain and source of feed and fodder. It provides nutritionally superior and staple food for millions of people living in harsh environments characterized by erratic rainfall and nutrient-poor soil. Infact, Pearl millet is the only suitable and efficient crop for arid and semiarid conditions because of its efficient utilization of soil moisture and higher level of heat tolerance than sorghum and maize (Harinarayana *et al.*, 1999). Farmers prefer the crop as low cost, low risk option not only by choice but also by necessity (Harinarayana, 1987). The grain has higher levels of protein content with balanced amino acids, CHO and fat which are important in the human diet, and its nutritive value is considered to be comparable to rice and wheat. It is also cultivated as green fodder crop in some parts of the country. The green fodder is more palatable because it does not have HCN content as that of sorghum.

Pearl millet is being grown in arid and semiarid regions of the world including West Africa, India and Pakistan with the rainfall ranging from 150-700 mm. India is a major pearl millet producing country with 43.3 per cent of the world area and 42 per cent of world production. It is mainly cultivated in the states of Rajasthan, Maharashtra, Gujarath, Madhya Pradesh, Karnataka, Andhra Pradesh, Uttar Pradesh and Tamil Nadu on a total area of 9.16 million hectare with the production of 8.01 million tonnes. The national average productivity is 850 kg/ha (AICPMIP Annual Report, 2006-07). In Karnataka, pearl millet is one of the major *kharif* crops, grown on an area of 3.71 lakh hectares with an annual production of 2.08 lakh tonnes. The average productivity is 561 kg/ha.

The quantum jump (from 303 kg to 850 kg/ ha) in the productivity of pearl millet was possible mainly through development of hybrids by the utilization of cytoplasmic genetic male sterility system. Burton (1958) was the first to develop cytoplasmic male sterile line Tift 23A.This opened up a new field for hybrid seed production in Pearl millet. In India first Pearl millet hybrid HB-1 was released in 1965 and subsequently number of promising hybrids have been developed and released for general cultivation. However, most of them failed in a short period due to their susceptibility to downy mildew disease. It was later realized that downy mildew susceptibility is associated with Tift 23A cytoplasm, which was common in all the hybrids (Safeeulla, 1977). The utilization of diverse sources of male sterility was then felt necessary and work in this direction led to the identification of several alternative sources like, A_1, A_2, A_3, A_4, A_5, etc.

The diversification of cytoplasmic source not only insures the crop against any catastrophe associated with cytoplasm but also adds flexibility and nuclear diversity to breeding programmes. However, the availability of suitable restorer on these sources is a limiting factor in the development of hybrids. Though the A_4 and A_5 sources were found to be highly stable, their utility is restricted due to non-availability of suitable restorers (Rai *et al.*, 2006). Hence, the work in this direction is essential to make use of diverse sterile sources in the development of new Pearl millet hybrids. For this purpose, it is necessary to explore the restorer genes in the germplasm pool and isolate the good combining restorer for commercial exploitation of heterosis on these diverse sources of cytoplasmic male sterile lines.

For the development of effective heterosis breeding programme in pearl millet, one needs to have information about genetic architecture and estimated prepotency of parents in hybrid combinations. Selection made on phenotypic performance alone does not lead to expected success in hybrid breeding. Therefore, a study on combining ability of parents is essential in choosing parents. Many biometrical procedures have been developed to obtain information on combining ability, a Line x Tester analysis is one among them which is widely used to study combining ability of the parents to be chosen for heterosis breeding. It also provides a guideline to determine the value of source populations and appropriate procedures to use in crop improvement programme. This knowledge in fact helps in exploiting heterosis for commercial purpose.

The recombination of different desirable traits spread over in different diverse genotypes is important for the improvement of yield and its related traits in any crop. The effectiveness of techniques like Mahalanobis's D^2 statistics is to analyze the genetic diversity of population and has been proved useful. It is generally agreed that genetically diverse parents will show the maximum heterosis and offer the maximum chance of isolating transgressive segregants. It serves the purpose of identifying the best recombinants from the populations. The present investigation aims to study the genetic diversity present in the materials.

In general, growth and productivity of pearl millet crop has been hampered by the incidence of diseases and pest. Among several diseases, rust has become a disease of considerable importance in recent years because it severely affects both forage and fodder value and there by limiting the exploitation of heterosis. Pearl millet leaf rust is known to occur in all the areas where the crop is grown. In India it is caused by *Puccinia penniseti* Zimm (= *P. substriata* Ell. and Barth. Var.*indica* Ram. and Cumm.) and there are no indications of racial differentiation (Andrews *et al*., 1985). Occasional out breaks may lead to severe losses in grain yield and forage quality. In the rainy season in India, rust generally occurs after anthesis resulting in little or no reduction in grain yield, though there may be substantial reduction in fodder quality. However, rust is a major grain yield reducer in the post rainy season crop (Andrews *et al*., 1985). Therefore, development of a variety/hybrid for rust resistance is of great importance to increase production and productivity. Therefore, there is a need to study the inheritance pattern of rust resistance in pearl millet as very limited work has so far been carried out on these lines.

Considering the importance of the crop and the above indicated facts, there is need to generate more information on fertility restoration on diverse sources of cytoplasmic male sterility systems, genetic diversity, variability, heterosis, combing ability and rust inheritance pattern.

Keeping these things in view, the present study has been planned with the following objectives.

1. To evaluate the selected germplasm lines for their ability to restore fertility on diverse cytoplasmic sources of male sterility (A_1, A_4 and A_5).
2. To determine the extent of variability and magnitude of genetic diversity in these germplasm.
3. To estimate general combining ability of parents and specific combing ability of hybrids for different traits.
4. To assess the extent of heterosis for grain yield and other important yield contributing components.
5. To study the inheritance pattern of rust resistance.

2. REVIEW OF LITERATURE

Several studies have been carried out for improvement of various qualitative and quantitative characters in pearl millet. The research activities on fertility restoration and maintenance behavior on diverse sources of cytoplasmic male sterility system in pearl millet are limited. On the other hand, the research that has been done on genetic diversity, variability, heritability, heterosis and combining ability has been very useful in support of plant improvement activities in pearl millet. In this chapter, attempt has been made to review the available literature on fertility restoration, variability, genetic diversity, heterosis, combining ability and inheritance of rust resistance under following headings.

2.1 Fertility restoration/maintenance behavior on diverse sources of cytoplasmic male sterility system

2.2 Variability, heritability and genetic advance studies

2.3 Genetic diversity studies

2.4 Heterosis

2.5 Combining ability

2.6 Inheritance of rust resistance

2.1 FERTILITY RESTORATION/MAINTENANCE BEHAVIOR ON DIVERSE SOURCES OF CYTOPLASMIC MALE STERILITY

Production of hybrids in pearl millet has become practical since the finding of cytoplasmic genetic male sterility. Burton (1958) developed the first cytoplasmic male sterile line Tift 23A, which opened a new field for hybrid seed production in pearl millet. In India, first pearl millet hybrid HB-1 was released in 1965 and since then a number of good hybrids have been developed and released for commercial cultivation. Large-scale deployment of the single (A_1) CMS source during 1960's in all the hybrids raised a concern regarding its potential vulnerability to pest and diseases. As a result, efforts were continued to search for alternate CMS sources. This led to identification of A_2, A_3 (Athwal, 1961, 1966), A_4 sources from *Pennisetum glaucum* (monodii) accessions (Hanna, 1989), and A_5 CMS sources from gene pool (Sujata *et al*., 1994; Rai, 1995). Based on the fertility restoration pattern on these sources, it was established that A_1, A_2, A_3, A_4 and A_5 were distinctly different CMS systems.

Burton and Athwal (1967) studied the relationship between Tift 23A, L66A and L67A and concluded that these lines carried different cytoplasms and designated them as S_1, S_2 and S_3 respectively. Later, Basavaraj *et al*. (1980) redesignated these sources of sterile cytoplasm as A_1 (Tift 23A) and A_3 (L66A and L67A). Andrews and Rajewski (1994) observed that line NPM3 restored male fertility in 93-97% of the plants in the A_4 and 7-16% in A_1 test crosses and concluded that A_4 system was superior to the A_1 system and fertility was not affected by temperature on A_4 source.

Rai (1995) reported that seven diverse restorer lines of the A_4 system produced hybrids were fertile (68-89% selfed seed set) in contrast, all the hybrids made with isonuclear line with LSGP (A_5) cytoplasm had fertility (>20% selfed seed set).

Yadav and Manga (1995) reported that fertility restoration ability was highly variable for different cytoplasms and of the 12 lines, eleven lines were effective restorers for A_1, six lines restored on A_2 and A_3 and two lines restored on A_4 system.

Rai *et al.* (1996) reported the hybrids of 15 diverse populations made on $81A_1$ and $81A_4$ showed that each population had restorers and maintainers on both the cytoplasm and that the frequency of maintainers of A_4 was as high as that of A_1 cytoplasm.

Yadav (1996) showed that, the mean grain yield of hybrids possessing A_2, A_3 and A_4 cytoplasm was either similar to or significantly higher than hybrids with A_1 cytoplasm. Hybrids based on A_3 and A_4 cytoplasms recorded 8% higher grain yield compared to hybrids based on A_1 cytoplasm.

Rai *et al.* (1998) opined that A_4 and A_5 cytoplasmic male sterility systems provide access to more diverse germplasm and offer new opportunities for greater exploitation of heterosis.

Yadav (1999) studied the combining ability of alloplasmic isonuclear lines and quantified the magnitude of heterosis in hybrids based on different CMS sources. The A_3 and A_4 cytoplasmic sources were significantly better general combiner for grain yield than A_1.

Rai *et al.* (2001) studied the viability of A_4, A_5 and A_v and most widely used A_1 system and reported that A_4 CMS system provide a better alternative to the A_1 system based on seed set percentage under selfing.

In sorghum, Murthy (1986) reported nineteen restorers on A_1, 9 on A_2, while one on A_3 from 37 genotypes. Shaw *et al.* (1988) crossed 10 pure lines to A_1, A_2 and A_3. Maintainers for A_2 and A_3 behaved as maintainers for A_1. Some A_1 restorers were maintainers for A_2 also, while all the lines maintained on A_3. Wang *et al.* (1988) crossed 115 exotic and local cultivars to A_1 and A_2 cytoplasms and found that maintainers/restorers on A_1 also behaved it on A_2 but reverse was not true. Secrest and Atkins (1989) recorded 21 lines on A_2, 11 on A_3 and only 4 on A_4 as restorers out of 217 inbred lines. Kishan and Borikar (1989) assessed the fertility restoration by crossing 19 male parents to nine diverse exotic and Indian male sterile lines. All the 19 parents restored on A_1, eight restored on A_2 (>60 per cent), while two parents showed partial restoration on A_3 cytoplasm (<60%).

Nagur and Menon (1974c) noticed differential response of partial fertility and completely fertile classes of hybrids under different environmental condition. Ritchy (1986) found that fertile hybrids on A_2 cytoplasm in 1980 became partially male sterile in 1984.

2.2 VARIABILITY, HERITABILITY AND GENETIC ADVANCE

The most important objective in any crop improvement programme is to increase the yield, which depends mainly on the magnitude of genetic variability present in the crop. The determination of genetic variability and its partitioning into various components is essential for understanding the genetic nature of yield and its components. Yield in pearl millet is the product of its component characters such as ear head length, ear head girth, ear head weight, and number of seeds per ear head. These in turn are influenced by number of other characters like days to flowering, productive tiller per plant, plant height etc. Any change in yield has to be brought from one or more of its components

The degree to which the variability of quantitative characters is transmitted to the progeny is referred to as heritability. The quantitative characters are governed by large number of genes and further influenced by environment. The phenotype observed is not transmitted entirely to the next generation. Therefore, it is necessary to know the proportion of observed variability that is heritable.

It is not possible to estimate narrow sense heritability in a collection of genotypes, as it requires the establishment of half sib and full sib relations. Hence, estimation of broad sense heritability (i.e. the proportion of total variance observed in a population which is due to the additive gene action) is useful. Heritability value helps the breeder in knowing the index of transmissibility, method of mating and to pre-assess the result of selection for particular characters in various types of progenies. Estimating heritability along with genetic gain is usually more useful in predicting the resultant effect from selecting the best individual (Johnson *et al*., 1955). The available review pertaining to the genetic variability, heritability and genetic advance in pearl millet is presented below.

2.2.1. Days to 50% flowering

High genetic variation for days to 50% flowering was reported by Yadav *et al*. (2001), Yogendra Sharma (2002) and Lakshmana *et al*. (2003). However low PCV and GCV was observed by Kulkarni *et al*. (2000) and Solanki *et al*. (2002).

Bhamre *et al*. (1983) and Kulkarni *et al*. (2000) observed high heritability value for days to 50% flowering, high heritability and low genetic advance as per cent mean was recorded by Lakshmana and Guggari (2001). High heritability and high genetic advance were registered by Berwal *et al*. (2001). Moderate heritability was reported by Singh and Gupta

(1979), Kunjir and Patil (1986a) and Navale *et al*. (1991), while low to moderate genetic advance was reported by Mahawar *et al*. (2003).

2.2.2. Days to maturity

Low GCV and GA were reported by Mannan and Razzaque (1980). A wide range of variation was recorded by Hepziba *et al*. (1993). High to moderate estimates of heritability and genetic advance were observed by Berwal *et al*. (2001)

2.2.3 Plant height

High GCV, PCV coupled with high estimate of heritability with high genetic advance were recorded by Aryana *et al*. (1996). High PCV, GCV and genetic advance were reported by Lakshmana *et al*. (2003) and Borkhataria *et al*. (2005). In another study, Lakshmana and Guggari (2001) observed high GCV and heritability.

High heritability was recorded by Singh and Gupta (1979), Shinde *et al*. (1984), Kunjir and Patil (1986a), Berwal *et al*. (2001) and Saraswathi *et al*. (1995), while Navale et *al*. (1991) and Yadav *et al*. (2001) reported low to moderate heritability. High heritability value coupled with high genetic advance was registered by Kunjir and Patil (1986a) and Hepziba *et al*. (1993). Low to moderate genetic advance was noted for plant height by Mahawar *et al*. (2003).

2.2.4 Productive tillers per plant

Wide range of PCV and GCV were observed by Kunjir and Patil (1986a), Hepziba *et al*. (1993) and Yogendra Sharma (2002), while low PCV and GCV were recorded by Aryana *et al*. (1996).

Low to moderate heritability and genetic advance were reported by Mukherji *et al*. (1980), Pethani and Kapoor (1990) and Yogendra Sharma (2002), while Berwar *et al*. (2001) recorded high to moderate heritability and genetic advance. High broad sense heritability was reported by Shinde *et al*. (1984) and low to moderate genetic advance was recorded by Mahawar *et al*. (2003).

2.2.5 Ear length

High phenotypic coefficient variation was reported by Mannan and Razzaque (1980). Kunjir *et al*. (1986a) observed wide range of PCV and GCV. High GCV and PCV coupled with high heritability and genetic advance were reported by Hepziba *et al*. (1993) and Lakshmana and Guggari (2001).

Singh and Gupta (1979) and Shinde *et al*. (1984) reported high heritability, while low to moderate heritability values were recorded by Mukherji *et al*. (1980), Dang *et al*. (1985), Kunjir and Patil (1986a) and Navale *et al*. (1991).

2.2.6 Ear girth

Borkhataria *et al*. (2005) reported a wide range of variation for ear head girth. Singh and Gupta (1979) reported high heritability, while moderate heritability values were recorded by Bhamre *et al*. (1983) and Kunjir and Patil (1986a).

2.2.7 Flag leaf area

Aryana *et al*. (1996) observed high phenotypic and genotypic variation, high estimates of heritability with high genetic advance for flag leaf area.

2.2.8 Peduncle Length

No reports are available.

2.2.9 Ear weight

High phenotypic and genotypic coefficient of variation and heritability were observed by Lakshmana and Guggari (2001). High heritability was recorded by Shinde *et al*. (1984).

2.2.10 Grain yield per ear

No reports are available.

2.2.11 Grain yield per plant

High magnitude of phenotypic and genotypic coefficient of variation was reported by Mannan and Razzaque (1980), Hepziba *et al*. (1993), Saraswathi *et al*. (1995), Kulkarni *et al*. (2000), Solanki *et al*. (2002) and Borkhataria *et al*. (2005).

High heritability estimate was recorded by Mukherji *et al*. (1980), Shinde *et al*. (1984) and Dang *et al*. (1985), while low to moderate heritability values were reported by Singh and Gupta (1979), Bhamre *et al*. (1983), Kunjir and Patil (1986a) and Navale *et al*. (1991). High GCV coupled with high heritability and high genetic advance were observed by Lakshmana and Guggari (2001) and Solanki *et al*. (2002). On the other hand, high PCV coupled with high heritability and high genetic advance were reported by Lakshmana *et al*. (2003).

2.2.12 1000-grain weight

Low PCV and GCV were reported by Mannan and Razzaque (1980). Kunjir and Patil (1986a) observed high heritability with high GA. High heritability for 1000-grain weight was reported by Shinde *et al*. (1984) and Solanki *et al*. (2002), while moderate heritability was reported by Bhamre *et al*. (1983).

2.3 GENETIC DIVERSITY

The concept of D^2 statistics for measuring the divergence between the two populations was introduced by Mahalanobis's (1928, 1936). It gives a result based on the magnitude of divergence and is independent of size of samples.

Mahalanobis *et al*. (1949) applied the D^2 statistic in a detailed study of anthropometrics data of Uttar Pradesh, classifying it into twenty three groups and into three major clusters i.e. Brahmin (B-cluster) at the top of Hindu social hierarchy, comprising nine groups, the Artisans (A-cluster) in the middle consisting of four groups and the Triyal cluster (T-cluster) at the bottom comprising of ten groups.

Genetic divergence is a result of changes in the gene frequencies of different populations due to evolutionary forces. While the frequency of given gene in turn is a function of its contribution in the total adoption of individuals in natural populations. The individuals showing more fitness contribute more than those having less fitness to the population gene pool.

Allard (1961) concluded that genetic diversity and productivity were complexly related, while divergence and stability appeared to be more simply related. Wallace (1963) pointed out the importance of geographic barrier in changing breeding structure, while Jain *et al*. (1981) concluded that geographical barriers preventing gene flow or intense natural or human selection for diverse, adaptive gene complexes may be responsible for the genetic diversity.

Mahalanobis D^2 statistic is a proven powerful tool in quantifying the degree of divergence between biological populations at the genotypic level and to access relative contribution of different components to the total divergence (Singh and Choudhary, 1979; Arunachalam, 1981; Jatasra and Paroda, 1983).

Murthy and Arunachalam (1966) reported that D^2 was not related to ecogeographical diversity in wheat, sorghum and soybean, and stated that in different environments genetic drift and selection cause more diversity among genotypes.

Murthy and Tiwari (1967) studied genetic diversity in a population of 64-dwarf pearl millet and reported that geographical diversity is not related to genetic diversity. He further indicated that the most potent factor for divergence in the dwarf derivation appeared to be tiller number at inter and intra cluster level of differentiation.

Joshi (1979) stated that genetic diversity involving genetically diverse parents in crossing would be advantageous as it would provide an opportunity for bringing together gene constellations of divergent origin. Isolation in space and time results in locking up genes in different constellations and these should be brought together in hybridization.

Singh and Gupta (1979) estimated the genetic diversity among 34 pearl millet strains in two different environments varying in level of fertilizer application. They pointed out that diversity was more fully expressed in normal environment without fertilizer and also indicated that some characters like number of leaves per plant, leaf length, 1000-seed weight and tiller number were very potent in contributing to diversity.

Mukherji *et al*. (1981) studied the genetic divergence in fifty-one inbreds of pearl millet and reported that geographical distance was not related to genetic divergence. The inbreds were grouped into 14 different clusters. Plant height, ear length, ear girth and test weight were significantly and positively associated with grain yield per plant.

Singh *et al*. (1981) also studied the genetic divergence in 9 pearl millet inbreds and their 36 F_1 hybrids, and observed that genetic divergence is not essentially related to geographic diversity.

Thete and Bapat (1986) analysed data on yield per plant and 13 related traits in 45 diverse varieties using D^2 statistics. The varieties were grouped into 12 clusters with substantial genetic divergence between them. Geographical diversity was not related to genetic diversity. The main traits contributing towards diversity were internode number, stem girth, leaf length, ear length, number of fertile tillers, total leaf number, grain yield/main culm, grain yield/plant and especially height and ear length.

Joshi *et al*. (1988) carried out D^2 and canonical analysis from data on 13 yield components in 92 entries (*Pennisetum americanum*) derived from Indian x Indian and Indian x African crosses. Eleven clusters were identified, with the largest containing 32 entries. No relationship was found between genetic and geographical diversity.

Singh (1988) examined 34 *Pennisetum typhoides* strains for genetic diversity for 13 quantitative characters under four environments. Data was analyzed using Mahalanobis D^2 statistic. Considerable diversity was present between the strains and up to 13 clusters were identified. An environment with high soil fertility and a late sowing expressed the most diversity.

Biswas and Sasmal (1990) studied genetic diversity in seven rice varieties and their twenty-one hybrids. The twenty-eight genotypes were grouped into six clusters. Shoot fresh weight was identified as the main factor contributing the genetic diversity.

Yadav (1994) studied 50 accessions of pearl millet (*Pennisetum glaucum*), 17 from India and 33 from seven African countries. Based on D^2 analysis, the genotypes were grouped into ten clusters. Of the 14 accessions from Ghana, all but one was grouped together in a single cluster, whereas the 17 accessions from India were spread over seven clusters. Likewise, four accessions of Nigerian origin fell into four different clusters. The results indicated that geographical diversity could not be taken as the sole criterion of genetic diversity.

Dave and Joshi (1995) observed no relationship between geographic and genetic divergence in pearl millet. The clustering pattern was affected by environment and the role of different characters varied with shift in season. The size of D^2 statistic had no effect on the magnitude of heterosis for the attributes studied.

Hepziba *et al*. (1995) evaluated ninety-five pearl millet genotypes (48 from India, 23 from Ghana, 19 from Togo, 2 from Burkina Faso and one each from UAS, Nigeria and Mexico) for seven yield related traits. The genotypes were grouped into twenty-seven clusters using canonical and metroglyph analysis and into twenty-six clusters via D^2 analysis with the distribution of genotypes amongst clusters being similar. There was no significant association between genetic diversity and geographic diversity. The grain yield contributed most to the genetic divergence.

Quendeba *et al*. (1995) evaluated ten land race populations, widely grown in African countries, and two experimental F_1 hybrids of pearl millet for thirteen characters. They observed that days to flowering, plant height, stem diameter, primary spike length and grain and spike yield per plant were the major contributors to diversity among the land race populations.

Savery and Prasad (1995) compared forty-one pearl millet genotypes of diverse geographical origin for genetic diversity in nine quantitative traits. Genotypes were divided into fourteen clusters. Clusters XIII and XIV were highly divergent from the other clusters, while only two clusters (IX and XIII) contained genotypes from a single geographical source. Genotypes PT 1595, PT 834/3 and PT 834/1 (cluster VIII) were superior for earliness and PT 1611 and PT 1620 (cluster VI) were superior for ear length and straw yield. These genotypes were recommended for using in breeding programmes.

Suthamathi and Dorairaj (1995) estimated genetic divergence using Mahalanobis D^2 statistic from data on twelve-fodder yield and six fodder quality characters in twenty-eight *Pennisetum glaucum* genotypes evaluated at Coimbatore. The genotypes were grouped into five distinct clusters. Crude protein content of the fodder contributed greatest to genetic divergence. Nine genotypes were identified for further breeding programme.

Tomar *et al*. (1995) carried out cluster analysis of data on ten agromorphological traits in twenty-one *Pennisetum typhoides* genotypes and assigned the genotypes to four clusters, which were unrelated to geographical origin.

Berwal and Khairwal (1997) evaluated forty-two diverse accessions of pearl millet at Hissar for ten yield related traits and were grouped into nine clusters.

Prem Sagar (1997) studied genetic diversity for grain yield at Hissar. They crossed seven hybrids in a diallel fashion to generate twenty-one F_1 and F_2 hybrids. Overall, genetic diversity ranged from –0.31 for the HHB 60 x Pioneer 7601 double cross to 1.50 in HHB 67 x ICMH 451 double cross. Other diverse hybrid combinations were HHB 60 x HHBH 10 (1.49), ICMH 451 x Pioneer 7601 (1.40) and HHB 67 x MLBH 10 (1.05).

Hendre (1998) studied genetic diversity of seventy-five genotypes in pearl millet. The genotypes were grouped into nine clusters. Plant height, panicle width, 1000-grain weight and grain yield were the main characters contributing to the genetic divergence.

2.4 Heterosis

The term heterosis as defined by Shull (1914) refers to superiority of the hybrids over its parents in terms of vigor, growth, yield or other characteristics that result from crossing genetically diverse individuals. The term relative heterosis and heterobeltiosis refer to the heterosis over mid and better parental value respectively.

Burton (1951) was the first to report heterosis in pearl millet for grain yield. The first generation hybrids showing non-allelic interactions were in general superior to non-interacting crosses suggesting non-allelic interactions as a major source of heterosis.

Heterosis over the mid parent, better parent and check variety reported earlier by various scientists are given below.

2.4.1 Days to 50 per cent flowering and maturity

For days to 50 percent flowering and days to maturity, negative heterosis is desirable in pearl millet. Ahluwalia and Patnaik (1963) found that heterosis over better parent for days to flowering ranged from 7 to 23 percent.

Reddy and Arunachalam (1981) reported that heterosis for flowering time was pronounced and about 6-7 percent crosses were heteorotic for it. Similarly, Kushwah and Singh (1992) in a diallel set observed that out of 66 crosses 35 exhibited heterosis over mid parent to an extent of -23 percent for days to flowering.

Chavan and Nerkar (1994) reported -16.4 percent better parent heterosis. Kulkarni *et al*. (1993) recorded -12.5 and -9.4 percent heterosis over mid and better parent, respectively for this trait. Low to medium magnitude of heterosis for flowering was reported by other workers viz, Tyagi *et al.* (1975 b), Bhamre *et al*. (1983), Shinde and Desale (1983), Hapse *et al*. (1986), Kunjir and Patil (1986b), Patel *et al*. (1987) and Ingale *et al*.(1997) for flowering time. However, Ugale *et al*. (1989) did not observe any significant desirable heterosis for days to flowering due to smaller differences in parents.

2.4.2 Plant height

Burton (1951) noticed considerable amount of heterosis for plant height. Singh (1970) in a line x tester set reported that all the hybrids were heterotic over superior parent. Sreenivasulu and Sreeramulu (1980), Subramaniam and Rathinam (1980a), Bhamare *et al.* (1983), Hapse *et al.* (1986), Kunjir and Patil (1986b) and Harer (1990b) observed variable magnitude of heterosis both in positive and negative direction for plant height. Patel *et al.* (1987) recorded heterobeltiosis for plant height in the range of -25 to 56 percent, while Thete *et al.* (1985) and Chavan and Nerkar (1994) observed positive heterobeltiosis for plant height to an extent of 59.4 and 26.0 per cent respectively in line x tester crosses.

Harer *et al.* (1990a) observed that 95 percent of the crosses in a line x tester set and 79 percent of the crosses in a diallel set exhibited positive heterosis for plant height. Kushwah and Singh (1992) observed that 63 out of 66 crosses were heterotic over mid parent for this trait.

Sheoran *et al.* (2000) reported that, the mean values of the hybrids for plant height was higher than those of the better parent, and significant positive heterobeltiosis was recorded.

2.4.3 Productive tillers per plant

Productive tillers are a major grain yield contributing character in pearl millet. Ahluwalia and Patnaik (1963) reported that hybrids showing maximum heterosis for grain yield also exhibited heterosis for tillering. Lal and Singh (1972) also observed similar results. However, Murty *et al.* (1967a) observed limited heterosis for tillering mainly because parents themselves were high in tillering. Tyagi *et al.* (1975b), Subramaniam and Rathinam (1980a), Reddy and Arunachalam (1981), Bhamare *et al.* (1983) and Shinde and Desale (1983) reported medium to high heterosis for tillering.

Harer *et al.* (1990b) and Chavan and Nerkar (1994) recorded heteorobeltiosis to an extent of 87.5 and 48.0 percent respectively, where as Kushwah and Singh (1992) and Kulkarni *et al.* (1993) recorded heterosis to an extent of 93.0 and 61.0 percent, respectively for productive tillers. Manga and Dubey (2004) in a diallel study, observed good amount of heterosis for productive tillers per plant.

2.1.5 Ear length

Murthy *et al.* (1967a) observed substantial heterosis for ear head length, and attributed it to epistasis and non-additive components. Singh (1970), Tyagi *et al.* (1975b), Bhamre *et al.* (1983), Shinde and Desale (1983), Hapse *et al.* (1986), Baviskar (1990) and Kunjir and Patil (1986b) reported varying degrees of heterosis for this trait, Ugale *et al.* (1989) and Chavan and Nerkar (1994), in line x tester crosses recorded heterobeltiosis to an extent of 31.0 and 23.87 percent respectively. Harer *et al.* (1990b) and Kushwah and Singh (1992) reported an appreciable amount of heterosis. Kulkarni *et al.* (1993) observed heterosis and heterobeltiosis to the extent of 31.1 and 30.4 percent respectively, in a diallel crosses for ear head length.

Ingale *et al.* (1997) noted that, 85 percent hybrids showed positive heterobeltiosis for ear length, which was to the tune of 57.26 per cent. Sheoran *et al.* (2000) reported positive and significant heterobeltiosis for this trait.

Ramamoorthi and Govindarasu (2000) recorded PT 3832 x ICMPES 11 as significantly high in all the three types of heterosis for ear length. Manga and Dubey (2004) in a diallel study observed good amount of heterosis for ear length.

2.4.6 Ear girth

Appreciable amount of positive heterosis for ear head girth was observed by most of the previous workers.

Pokhriyal *et al.* (1967) reported 13 per cent heterobeltiosis for ear girth in diallel study. Singh (1970) observed heterobeltiosis in the range of 11.9 and 45.8 per cent.

Ugale *et al.* (1989) reported 22.5 and 16.9 per cent heterosis over mid and better parent respectively, while Kulkarni *et al.* (1993) observed -21.3 to 31.7 percent and -30.1 to

33.2 per cent heterosis over mid and better parent respectively in a diallel crosses. Whereas in line x tester crosses, Chavan and Nerkar (1994) observed heterobeltiosis to an extent of 19.9 percent. Other workers, Tyagi *et al*. (1975 b), Bhamre *et al*. (1983), Hapse *et al*. (1986), Harer *et al*. (1990a), Ingale (1992), Patil *et al*. (1994), Sheoran *et al*. (2000) and Ramamoorthi and Govindarasu (2000) also reported heterotic effects for ear head girth.

2.4.6 Flag leaf area

Shinde and Desale (1983) observed 64 per cent heterosis for flag leaf area in a modified line x tester analysis. Whereas Aryana (1990) and Deshmukh (1996) in a diallel analysis observed heterosis over mid and better parent to an extent of 247.8 and 109.3 per cent respectively. Similarly Kulkarni *et al*. (1993) recorded 103.3 per cent heterosis in a diallel set of India x Exotic inbreds for this character.

2.4.7 Peduncle length

Mahadevappa (1968) in a diallel set noticed that 39 per cent of the crosses exhibited heterosis over better parent for peduncle length.

Subramaniam and Rathinam (1980a) observed that 7 out of 30 hybrids exceeded better parent values for peduncle length.

Kushwah and Singh (1992) were of the opinion that excertion of ear from flag leaf is necessary to keep it free from mould infection. Longer internodes just below the ear would show better excertion. Heterosis for this character was observed to an extent of 76 per cent in 20 out of 66 crosses.

2.4.8 Panicle weight and grain yield per ear

Mahadevappa (1968) in a diallel set reported that 29 percent of the crosses exhibited heterosis over better parent for yield per primary ear. Sreenivasulu and Sreeramulu (1980) in a diallel set recorded 6 per cent average heterobeltiosis for panicle weight. Subramaniam and Rathinam (1980 a) in a diallel experiment observed heterosis over better parent to an extent of 143 per cent for grain yield per primary panicle.

Shinde and Desale (1983) in a line x tester set observed heterosis over better parent in the range of -52 to 70 per cent for ear weight. Similarly, considerable amount of heterosis to an extent of 65 per cent was reported by Bharati (1986) for panicle weight. Ugale *et al*. (1989) recorded heterobeltiosis in the range of -28 to 61 per cent for panicle weight and found that crosses that were heterotic for grain yield were also heterotic for panicle weight. Manga and Dubey (2004) in a diallel study observed considerable heterosis for ear weight.

2.4.9 Grain yield per plant

For grain yield per plant, positive heterosis was recorded by Burton (1951). Ahluwalia and Patnaik (1963) observed heterosis over superior parent to an extent of 69.9 per cent. They noticed that, effects of yield components like length and girth of spike, seed size etc are multiplicative in nature and therefore, concluded that even a slight increase in some of these components would produce high heterosis for grain yield. Similar observations were also made by Ahluwalia and Patnaik (1963), Ugale *et al*. (1989) and Baviskar (1990) for combinations showing significant heterosis for grain yield.

Very high magnitude of heterosis to an extent of 535 per cent for this trait was reported by Tyagi *et al*. (1975b). In a line x tester analysis high amount of heterosis to an extent of 69, 177 and 109.3 per cent was observed by Sarawate *et al*. (1986), Harer *et al*. (1990b) and Chavan and Nerkar (1994) respectively. Pethani and Dave (1992) also reported pronounced grain yield heterosis. In a diallel analysis, Harer *et al*.(1990a) reported grain yield heterosis to an extent of 98 per cent, whereas Kulkarni *et al*. (1993) recorded 208.3 and 170.5 per cent heterosis over mid and better parent respectively in crosses between Indian and exotic pearl millet. Shinde (1995) also found higher magnitude of heterosis for this trait. Sheoran *et al*. (2000) recorded the maximum heterobeltiosis for this character among all the characters studied. Ingale *et al*. (1997) reported positive heterobeltiosis in 62 per cent crosses.

Appreciable amount of heterosis for this trait was also observed by Pokhriyal *et al*. (1967), Subramaniam and Rathinam (1980 a), Bhamre *et al*. (1983), Shinde and Desale

(1983), Hapse *et al*. (1986), Kunjir and Patil (1986b), Ugale *et al*. (1989), Deshmukh (1990), Harer *et al*. (1990 b), Kulkarni *et al*. (1993) and Patil *et al*. (1994). However, Jain *et al*. (1961), Ahluwalia (1962), Shinde *et al*. (1984) and Sreenivasulu and Sreeramulu (1980) observed negative heterosis for this trait.

Ramamoorthi and Govindarasu (2000) observed that hybrid PT3832 x 732B recorded significantly high heterosis for grain yield than all crosses, while Blummel and Rai (2003) reported significant positive as well as negative heterosis. Pethani *et al*. (2004) recorded heterosis over mid parent and better parent for various traits, the hybrid MS 2072A x J-2338 expressed the highest heterotic value for grain yield over mid parent (152.92 %) and better parent (121.45%). Manga and Dubey (2004) in a diallel study, observed high heterosis (96.2 to 300.7%) for grain yield. Yadav (2000) reported heterosis upto 88% for grain yield.

2.4.10 1000-grain weight

Earlier workers observed higher magnitude of heterosis over both mid parent and better parent for this trait.

Singh (1970) recorded positive heterosis over better parent for 250-grain weight. Hapse *et al*. (1986) and Shinde and Desale (1983) in a modified line x tester experiment, recorded higher magnitude of heterobeltiosis. Similarly, Rawat and Tyagi (1989) in a line x tester experiment observed heterosis to an extent of 142 per cent. Kulkarni *et al*. (1993) observed heterosis to an extent of 47.4 and 56.3 per cent respectively over better parent in a diallel for grain size.

Other workers namely, Tyagi *et al*. (1975b), Subramaniam and Rathinam (1980a), Sreenivasulu and Sreeramulu (1980), Kunjir and Patil (1986b), Navale *et al*. (1987), Ugle *et al*. (1989), Aryana (1990), Ingale *et al*. (1997) and Patil *et al*. (1994) observed medium to low heterosis for grain size.

Sheoran *et al*. (2000) reported the positive and significant heterobeltiosis for this trait. Manga and Dubey (2004) in a diallel study observed good amount of heterosis for 1000-grain weight.

2.5 Combining ability

The concept of combining ability in terms of genetic variation was first given by Sprague and Tatum (1942) using single crosses in maize. They defined the term general combining ability as an average performance of a line in hybrid combinations and specific combining ability as the combinations which do relatively better or worse than that would be expected on the basis of the average performance of lines involved.

According to Griffing (1956), the general combining ability is related to additive as well as additive x additive interaction, whereas specific combining ability is related to the dominance variance and all three types of interactions (additive x additive, additive x dominance and dominance x dominance).

Line x tester and diallel are single cross mating designs used for testing both gca and sca. In sorghum, a number of studies have been conducted to assess the gca and sca effects for different characters.

The gca effects were found to be predominant for days to 50 per cent flowering in the study conducted by Jain *et al*. (1961).

Bains *et al*. (1967) in a line x tester experiment reported that mean squares due to gca were important for days to flowering, tiller number, head length and head thickness. On the other hand for a complex character like yield, sca was more important. They also observed that crosses with high sca involved at least one good combining parent.

Phul *et al*. (1973) in a diallel set reported that, magnitudes of gca variances were larger than sca variance for the characters, days to flowering, ear girth and grain yield.

Jain and Majumdar (1975) in a line x tester experiment observed significant differences among hybrids for plant height, ear length and grain yield but not for ear girth.

Tyagi *et al*. (1975 b) in a line x tester experiment reported that variance due to sca was predominant for days to ear emergence, number of ears per plant, ear length, ear diameter and grain yield, indicating importance of non additive gene action. He also suggested that individual performances should not be taken as sole criterion for selection of parents.

Pokhriyal *et al*. (1976) in a line x tester analysis reported high gca variance for days to flower and plant height. However, for grain yield, ear length and tiller number, the sca variance was predominant. Male sterile lines 5054A, 5071A and 5151A were found to be best general combiners for grain yield.

Tyagi *et al*. (1978) in a diallel analysis found highly significant variance for both gca and sca for days to ear emergence, plant height, total and productive tillers, ear length and grain yield per plant.

Sreenivasulu and Sreeramulu (1980) in a diallel experiment observed that gca variance was significant for days to 50 per cent flowering, plant height, number of leaves per plant, stem girth, internodal length, panicle length, panicle girth, panicle weight, grain yield and 1000 grain weight, whereas sca variance was predominant for plant height, number of days to 50% flowering, stem girth and grain yield.

Subramaniam and Rathinam (1980a) in a diallel set observed that both gca and sca effects were highly significant for plant height and panicle length.

Singh *et al*. (1980 b) in a diallel set observed high magnitude of gca variance for plant height, number of tillers and grain yield and predominant sca variance for ear length, ear girth, and 1000 seed weight. They also observed that at least one good general combiner is essential in cross producing high sca effects.

Tyagi *et al*. (1982) in a line x tester experiment in six environments found that sca variance was predominant for grain yield and number of days to first ear emergence. However, for 500 grain weight relative magnitude of gca and sca variances were inconsistent in different environments.

Bhamre *et al*. (1983) in a line x tester set observed that gca variance was significant for days to 50% flowering, plant height, maturity and tiller number, while sca variances were significant for ear head length, ear head girth and 1000 grain weight.

Chawla and Gupta (1983) in a diallel experiment concluded that both gca and sca and *per se* performance be considered for selection of parents and high sca effects, *per se* performance and involvement of one good combiner for selection of crosses.

Mathur and Mathur (1983) in a line x tester set reported that magnitude of sca effects were higher than gca effects for effective tiller, ear length, ear girth, 1000 grain weight and grain yield. Parents showing high sca effects for yield were also found to show high gca effects for one or more yield components, suggesting that gca effects for grain yield were possibly related to gca for yield contributing traits.

Shinde and Desale (1983) in a line x tester analysis reported greater magnitude of gca variances for effective tillers, ear girth, ear weight, 500 grain weight and grain yield. They also observed that, high sca effects for grain yield which was dependent on high sca effects for yield components, especially 500 grain weight and effective tillers.

Dang *et al*. (1985) in a diallel set observed significant gca and sca variances for yield, plant height and head length.

Kunjir and Patil (1986b) in a line x tester analysis found that gca variance was higher for yield components viz. days to 50% flowering, tiller numbers, plant height, ear head girth and 500 grain weight. However, sca variance was predominant for grain yield. Crosses with high sca involved at least one good general combiner. However, few of the poor x poor combinations showed high sca, indicating role of complementary gene action.

Maciel *et al*. (1987) observed significant correlations between parental performance and their gca effects for days to flower and plant height. Gartan *et al*. (1988) in a diallel set observed that, gca and sca variances were highly significant for tiller number, ear length, ear girth, 1000 seed weight and yield per plant. In general, inbreds with high per se performance did not always have high gca effects. Crosses showing high sca effects involved at least one parent with good gca.

Srivastava and Singh (1988) in a diallel experiment reported predominance of gca variances for ear length, ear girth and 500 grain weight and suspected it to be due to wide genetic diversity in the material used. They also reported that productive crosses usually involved good combining parents.

Pethani and Kapoor (1990) in a line x tester analysis experiment under three environments reported that sca variance was highly sensitive to environmental changes for ear bearing tillers, ear length and ear weight, however, gca variance was highly stable for ear length. They noticed mild association between gca effects and per se performance of parents for ear bearing tillers and ear length. They also found that crosses with high sca for grain yield also had high sca for ear bearing tillers.

Navale and Harinarayana (1992) in a diallel set recorded significant variances due to gca and sca effects for days to 50% flowering, days to maturity, ear length and grain yield. For productive tillers and plant height, gca variances were significant. The high sca effects involved combination with good x good, good x medium and poor x medium combining parents indicating presence of higher order interactions for grain yield and other characters.

Kulkarni *et al*. (1993) in a diallel set of white grained (Indian x Exotic) pearl millet genotypes found significant gca variances for earliness, grain number per cm^2 and test weight indicating the predominance of additive gene action. However sca variances were greater than gca variances for all these traits except productive tillers and grain number per cm^2. Six parents showed good correspondance between per se performance and gca effects for grain yield and other characters like earliness, ear length and flag leaf area. They also noted that two crosses possessed high sca effects as well as high per se performance suggesting the possibility of their use in production of good hybrids.

Navale *et al*. (1993) in a diallel study of bold grained genotypes reported that, differences due to gca and sca were significant for days to 50% flowering, plant height, ear length, ear girth, 500 seed weight and grain yield. They also observed that crosses involving medium or small seeded parents recorded high sca effects when compared to bold x bold crosses. Further, they found that crosses with significant sca effects for grain yield involved parents with poor x poor, poor x good and good x good types of gca effects indicating presence of non-allelic interactions.

Chavan and Nerkar (1994) in a line x tester experiment conducted under three environments reported that sca x environment interaction was significant for all traits. The gca variance due to males were much larger than any other component, while the sca variance was predominant for days to 50% flowering, days to maturity, number of leaves per plant, plant height, number of effective tillers per plant, spike length, spike girth, number of grains per cm^2 and grain yield per plant.

Sahane *et al*. (1995) in a line x tester analysis observed that, the mean squares for lines were significant for days to 50% flowering, plant height and ear length, whereas the differences among testers were significant for grain yield and days to 50% flowering, and Line x Tester interaction was significant for grain yield, plant height and ear length.

Sahane *et al*. (1996) in a full diallel set observed that, mean squares due to gca and sca were highly significant for days to 50% flowering, plant height, ear length and ear girth, while mean squares due to gca was significant for days to maturity and mean squares due to sca was significant for grain yield and dry fodder yield.

Azhaguvel and Jayaraman (1998) reported that, variances due to hybrids and line x tester interaction were significant for all characters such as number of productive tillers, panicle length, panicle girth, 100 grain weight and grain yield per plant, whereas, variances due to lines and testers were significant for all above characters, except for grain yield per plant. Latha and Shanmugasundaram (1998) reported that sca variances were higher in magnitude than gca variances for all characters, excepting ear length.

Karale *et al*. (1998) estimated gca and sca variances and revealed that gca variances were higher for days to 50 per cent flowering, plant height, ear length and ear girth, while sca variances were significantly higher for number of productive tillers per plant, 100 grain weight and grain yield per plant.

Mohan *et al*. (1998) carried out (5 x 6) line x tester analysis for 5 important characters and showed that gca variances were highly significant for number of productive tillers, ear girth, ear length and 1000 grain weight, whereas covariance's were significant for grain yield per plant.

Gandhi *et al*. (1999) in line x tester (6 x 10) analysis for combining ability reported that parent PN 3A had significant gca effects and the restorer PNBV 9-21, though produced high mean performance, recorded negative gca effects indicating that high per se performance was not related to high gca effects. Similar results were reported by Pethani and Kapoor (1990). They further found that for grain yield the proportion of high x low crosses was low, indicating that high sca effects might be due to cumulative effects of high combining loci.

Yadav (1999) reported that lines with A_3 and A_4 cytoplasms were significantly better general combiners for grain yield than lines with either A_1 male sterile or fertile cytoplasm.

Yadav *et al*. (2002) observed high sca effect for effective tillers and high gca effect for most of traits under study.

Lakshmana *et al*. (2003) reported significant gca among parents for plant height, ear length, days to 50% flowering and days to maturity. Six crosses showed significant positive specific combining ability effects for grain yield.

Srikant *et al*. (2003) in L x T analysis observed female parents ICMA 93333, ICMA 96111 and RMS-3A and male parents RIB-20K-86 and RIB-3135-18 to be good general combiners. The crosses ICMA-93333 x RIB–3135-18, ICMA-9544 x RIB-3135 exhibited significant sca effect and higher per se performance.

Manga and Dubey (2004) in a diallel study revealed that restorers not only showed high mean performance but also possessed significantly high positive gca for grain yield.

Sushir *et al*. (2005) reported that ICMA 98222 x IPC-gon, followed by ICMA 98222 x IPC-577 exhibited significant and high specific combining ability for grain yield per plant. The gca effects were higher than sca effects for number of productive tillers per plant and ear length, whereas it was reverse for days to 50% flowering, ear girth and grain yield per plant.

Karad and Harer (2005) in a line x tester experiment revealed significant difference for all the ten clusters. Among the females, ICMA-8911 was the best general combiner for yield, ear girth, and 1000-grain weight. The combination ICMA 88006 x IPC 1470 (>27.19%) was the best specific combination for grain yield and weight of productive tillers/plant whereas 841A x IPC-735 was the best specific combination for ear girth and plant height.

Dhuppe *et al*. (2006) in an L x T analysis reported that variance due to lines, testers and L x T were significant. The female parents 88004 A and 405A, male parent IPC-274 Zim D were good general combiners for grain and fodder yield. The crosses 862A x Zim D, 862A x PT 1890 and 841 A x Zim T exhibited high sca effect for most characters in general and grain yield in particular.

2.6 INHERITANCE OF RUST RESISTANCE

Rust (*Puccinia substriata* var. indica) has become a disease of considerable importance in recent years because it severely affects both forage and fodder value. It also causes substantial reduction in grain yield. Understanding the inheritance of rust resistance in pearl millet helps to develop rust resistant pearl millet genotypes. The work on inheritance to rust resistance in pearl millet is very limited. The available literature concerning the inheritance of rust resistance in pearl millet and related crops are presented below.

Andrews *et al*. (1985) observed in F_2 population from susceptible x resistant crosses showed a good fit to a 3 resistant: 1 susceptible ratio and the backcrosses involving susceptible male sterile lines as recurrent parents showed a reasonably good fit to a 1 resistant: 1 susceptible indicating that resistance is conferred by a single dominant gene and susceptibility by its recessive allele and assigned gene symbol Rpp_1 and rpp_1 for these genes.

Hanna *et al*. (1985) reported that resistance was dominant over susceptibility in *Pennisetum americanum* (L.)

Ramamoorthi *et al*. (1995) studied rust inheritance pattern in different generations of twenty crosses and found it to be a dominant trait with monogenic control.

Panna *et al*. (1996) reported that the resistance against rust was found under the control of a single dominant gene in the entries and was found to be governed by two genes (1 dominant, 1 recessive) and the segregation pattern in F_2 of the cross 7042-1-4-4 x 700481-27-5-2 showed duplicate gene action.

Ramamoorthi and Jehangir (1996) reported that rust resistance is monogenically dominant over susceptibility in the crosses involving rust susceptible and a rust resistant inbred of pearl millet.

3. MATERIAL AND METHODS

A brief account of experiments conducted, details of parents selected for the study, hybridization programme, experimental design adopted and statistical procedures followed in the present investigation are outlined as under.

Location

The experiments were conducted at Regional Agricultural Research Station, Bijapur, Karnataka during *kharif* 2004 and in 2005 during summer, *kharif*, and late *kharif*. Geographically, Regional Agricultural Research Station, Bijapur is situated at the latitude of 16°49' N, longitude of 75°43' E and at an altitude of 593 m above mean sea level with the soil type of shallow to deep black. It receives annual rainfall of 594.3 mm. The data on weather parameters such as rainfall, minimum and maximum temperature and relative humidity recorded at the Agro-meteorological observatory, Regional Agricultural Research Station, Bijapur during crop growth period are furnished in Appendix I.

3.1 EXPERIMENT- I

Evaluation of germplasm for their ability to restore fertility on diverse sources of cytoplasmic male sterility.

3.1.1 Material

Three male sterile lines of Indian origin with different cytoplasmic sources viz., $A_{1,}$ A_4 and A_5 were selected as female parents to evaluate the fertility restoration ability in the germplasm. The 105 germplasm collections representing the major pearl millet growing regions of the world were used as male parents. These genotypes were selected based on the morphological and geographical variation from lines supplied by ICRISAT. The description of male and female parents is furnished in Tables 1 and 2.

3.1.2 Crossing Programme (Production of F_1 seeds)

The crossing programme was taken during summer, *kharif* and Rabi 2004 seasons independently. In each season, staggered sowings of parents were done with a view to have synchronized flowering to obtain sufficient seeds. One hundred and five hybrids on each of the CMS sources viz., A_1, A_4 and A_5 were produced. The 105 hybrids of each of the three diverse cytoplasm (total 315 hybrids) were planted in *kharif* and summer of 2005. The hybrids were grown in a single row of 4 m. length with intra row spacing of 15 cm and inter row spacing of 50 cm. Recommended package of practices were followed.

3.1.3 Collection of data

Five plants in each treatment were selfed with brown paper bags before flowering and the same plants were used for recording the following observations.

1. Days to 50 percent flowering

This was recorded as the number of days taken from sowing to the appearance of flower in 50 per cent of plants in a plot

2. Plant height (cm)

Plant height was recorded in centimeters (cm) from ground level to the tip of the main ear at maturity.

3. Percentage of seed setting

At maturity, numbers of seeds were counted out of total number of spikelets per ear head and seed set percentage was calculated (Kishan and Borikar, 1989).

Table 1. Description of CMS lines representing three diverse cytoplasmic sources (Plates 1, 2 & 3)

	Cytoplasm	Line/genotype	Pedigree
1	A_1	Tift 23D2A	Cytoplasm source (A_1) backcrossed to 81B.
2	A_4	Hanna's monodii	Cytoplasm source (A_4) backcrossed to 81B green.
3	A_5	LSGP	Cytoplasm source (A_5) backcrossed to 81 B.

Source: Genetic Resource Enhancement Division, ICRISAT, Hyderabad.

Diverse sources of cytoplasm

Plate 1. A1 cytoplasm

Plate.1. A1 Cytoplasm

Plate 2. A4 cytoplasm

Plate.2. A4 Cytoplasm

Plate 3. A5 cytoplasm

Plate.3. A5 cytoplasm

3.2 EXPERIMENT- II

Studies on genetic variability and diversity

3.2.1 Material

The material for this study comprised of 105 genotypes mentioned in experiment I. The detailed description of these parents has been furnished in Table 2.

3.2.2 Method

The experiment on evaluation of 105 genotypes was laid out in a completely randomized block design with three replications was conducted independently during *kharif* 2004 and 2005. Each treatment (genotype) in each replication was represented by two rows of 4 m length, and the spacing was 50 cm between rows and 15 cm between plants. Seeds were hand dibbled in shallow soil. The recommended package of practices was followed.

3.2.3 Collection of data

Observations were recorded on five randomly labeled competitive plants from each replication. Treatment means were worked out from the data collected on these plants on the following parameters.

1. Days to 50 per cent flowering

This was recorded as the number of days taken from sowing to the appearance of flower in 50 per cent of plants in a plot.

2. Days to maturity

The number of days required from sowing to the physiological maturity of the grain on the observational plants was considered as days to maturity.

3. Plant height (cm)

The height of plant at maturity was measured from ground level to tip of the plant in centimeters (cm).

4. Number of productive tillers per plant

Total number of tillers those having seed bearing ear heads was counted at the time of harvest.

5. Ear head length (cm)

The length of ear head was measured from the base to the tip of the ear head on main tiller at maturity.

6. Ear girth (cm)

The maximum thickness at center of the ear head on main tiller was measured at maturity.

7. Flag leaf area (cm^2)

It was worked out as length x breadth x 0.7236 (Singh, 1970). The leaf length (ligules to tip) and breadth (at the maximum width point) was measured in respect of flag leaf on main tiller at grain setting.

8. Peduncle length (cm)

The length of peduncle was measured from base of the ear head to the point of attachment of peduncle to the main axis.

9. Ear weight (g)

Weight of individual ear head was taken after necessary drying of ear head.

10. Grain yield per ear (g)

The ear heads from individual plants were harvested and threshed and average grain yield/ear head is recorded.

Table 2. Salient features of pearl millet germplasm selected for the study on identification of restorers/maintainers on diverse cytoplasm

S.N	Genotypes	Origin	Salient features				
			Grain color	Ear head character	Bristles	Seed size	Rust reaction
1	IP-9140	India	grey	cylindrical/ semi compact	absent	medium	susceptible
2	IP-9286	Togo	dark grey	cylindrical/compact	absent	medium	susceptible
3	IP-15857	Tanzania	Dark grey	candle/semi compact	absent	medium	susceptible
4	IP-15899	Tanzania	Dark grey	candle/semi compact	absent	medium	susceptible
5	IP-9149	India	grey	cylindrical/compact	absent	medium	susceptible
6	IP-3799	India	grey	candle/compact	absent	small	susceptible
7	IP-3150	India	grey	Candle/compact	absent	small	susceptible
8	IP-10186	Mali	grey	candle/semi compact	absent	medium	susceptible
9	IP-10394	India	grey	cylindrical/semi compact	absent	small	susceptible
10	IP-10820	Sudan	grey	Candle/compact	absent	medium	susceptible
11	IP-15817	Tanzania	grey	Cylindrical/compact	absent	medium	susceptible
12	IP-15220	India	dark grey	candle/loose	absent	medium	susceptible
13	IP-15256	India	grey	candle/compact	absent	small	susceptible
14	IP-17566	Togo	grey	candle/compact	absent	small	susceptible
15	IP-17144	Zimbabwe	grey	candle/semi compact	absent	medium	susceptible
16	IP-15829	Tanzania	grey	candle/semi compact	absent	small	susceptible
17	IP-6510	Mali	grey	candle/semi compact	absent	small	susceptible
18	IP-8276	ICRISAT	grey	Cylindrical/compact	absent	medium	susceptible
19	IP-9416	Ghana	grey	cylindrical/compact	absent	medium	susceptible
20	IP-17493	Togo	dark grey	candle/Semi compact	absent	small	susceptible
21	IP-17028	Zimbabwe	dark grey	candle/loose	absent	bold	resistant
22	IP-10811	Sudan	cream	candle/semi compact	absent	bold	resistant
23	IP-10085	Mali	cream	candle /compact	absent	bold	susceptible
24	IP-15681	Tanzania	dark grey	cylindrical/semi compact	present	bold	susceptible
25	IP-15257	India	dark grey	cylindrical/semi compact	absent	bold	susceptible
26	IP-14942	India	grey	candle/compact	absent	medium	resistant
27	IP-14038	Zimbabwe	grey	candle/semi compact	absent	medium	resistant
28	IP-17979	ICRISAT	grey	candle/semi compact	absent	medium	susceptible
29	IP-17690	Togo	dark grey	cylindrical/semi compact	absent	bold	susceptible
30	IP-17753	Togo	grey	candle/loose	absent	medium	resistant
31	IP-17978	ICRISAT	brown	candle/loose	absent	medium	resistant
32	IP-10945	Sudan	grey	candle/compact	absent	small	susceptible
33	IP-10488	Zimbabwe	grey	candle/compact	absent	small	susceptible
34	IP-8229	ICRISAT	grey	candle/compact	absent	medium	resistant
35	IP-6417	Mali	dark grey	cylindrical/compact	absent	bold	resistant
36	IP-8429	Nigeria	dark grey	candle/semi compact	absent	bold	resistant
37	IP-5275	Nigeria	grey	Cylindrical/semi compact	present	medium	resistant
38	IP-15355	India	dark grey	cylindrical/semi compact	absent	small	resistant
39	IP-15710	Tanzania	grey	cylindrical/compact	absent	medium	resistant
40	IP-14028	Zimbabwe	grey	Candle/semi compact	absent	small	resistant
41	IP-14026	Zimbabwe	grey	candle /compact	absent	medium	resistant
42	IP-11211	India	dark grey	cylindrical/semi compact	absent	bold	susceptible
43	IP-11680	Sudan	grey	cylindrical/semi compact	absent	medium	susceptible
44	IP-11577	Burkinofaso	dark grey	candle/compact	absent	bold	resistant
45	IP-11503	Burkino faso	dark grey	cylindrical/compact	absent	medium	resistant
46	IP-10914	Sudan	grey	global/compact	absent	medium	resistant
47	IP-10839	Sudan	grey	cylindrical/loose	absent	medium	resistant
48	IP-15364	India	dark grey	candle/compact	absent	medium	resistant
49	IP-15273	India	grey	cylindrical/compact	absent	medium	resistant
50	IP-14497	Cameroon	grey	Candle /compact	absent	medium	susceptible
51	IP-14778	Cameroon	dark grey	cylindrical / semi compact	absent	bold	susceptible
52	IP-16196	India	yellow	cylindrical / semi compact	absent	bold	susceptible
53	IP-7440	Tanzania	yellow	candle / compact	absent	bold	susceptible
54	IP-13840	Burkino faso	grey	can/ compact	absent	small	susceptible
55	IP-9301	Togo	grey	cylindrical /comp	absent	medium	susceptible
56	IP-14644	Cameroon	white	candle /comp	absent	medium	resistant
57	IP-4695	India	grey	candle / semi compact	absent	small	resistant
58	IP-4779	India	yellow	candle / semi compact	absent	bold	resistant
59	IP-19321	Namibia	dark grey	cylin/s semi compact	present	Medium	resistant
60	IP-18621	Namibia	white	candle / compact	absent	medium	resistant
61	IP-18625	Namibia	dark grey	candle / compact	absent	medium	resistant
62	IP-8818	Zimbabwe	grey	candle n/ semi compact	absent	medium	resistant
63	IP-16197	India	d.grey	candle / semi compact	absent	medium	susceptible
64	IP-16690	Zimbabwe	grey	candle / compact	absent	medium	resistant

65	IP-13875	Burkino faso	grey	cylindrical /semi compact	absent	small	resistant
66	IP-12779	ICRISAT	grey	cylindrical / semi compact	absent	medium	resistant
67	IP-12768	ICRISAT	dark grey	cylindrical semi compact	absent	medium	resistant
68	IP-6125	Cameroon	dark grey	can/ semi compact	absent	medium	resistant
69	IP-4331	India	grey	candle /compact	absent	medium	resistant
70	IP-13645	India	grey	candle /compact	absent	medium	susceptible
71	IP-17144	Zimbabwe	grey	candle /compact	absent	medium	susceptible
72	IP-10339	Nigeria	dark grey	cylindrical / compact	absent	medium	susceptible
73	IP-4759	India	dark grey	cylindrical / semi compact	absent	medium	susceptible
74	IP-19388	Namibia	grey	candle / compact	absent	small	susceptible
75	IP-18742	Namibia	grey	candle / compact	absent	bold	resistant
76	IP-18657	Namibia	dark grey	candle /semi compact	absent	bold	resistant
77	IP-8540	India	grey	cylindrical /compact	present	medium	resistant
78	IP-16402	Zimbabwe	dark grey	candle /compact	absent	bold	resistant
79	IP-16638	Zimbabwe	grey	candle /compact	absent	bold	resistant
80	IP-13154	Nigeria	grey	candle / semi compact	absent	small	resistant
81	IP-12901	Cameroon	grey	candle / semi compact	present	small	resistant
82	IP-12682	ICRISAT	grey	cylindrical / compact	absent	medium	resistant
83	IP-6460	Mali	grey	candle / compact	absent	medium	rusceptible
84	IP-4169	India	grey	candle / compact	absent	medium	susceptible
85	IP-7468	Tanzania	while	cylindrical / compact	absent	medium	susceptible
86	IP-19246	Namibia	grey	candle /compact	absent	medium	susceptible
87	IP-13833	Burkino faso	dark grey	cylindrical / compact	absent	bold	resistant
88	IP-19067	Namibia	grey	cylindrical / semi compact	absent	medium	resistant
89	IP-10761	Sudan	grey	cylindrical /semi compact	absent	bold	resistant
90	IP-19361	Namibia	grey	cylindrical /compact	absent	bold	susceptible
91	ICMV-221	India	dark grey	candle / compact	absent	bold	resistant
92	IP-18389	Namibia	dark grey	candle/ compact	absent	medium	resistant
93	IP-18800	Namibia	grey	candle /semi compact	absent	medium	resistant
94	IP-8069	ICRISAT	grey	candle / compact	absent	medium	resistant
95	IP-16449	Zimbabwe	grey	cylindrical/compact	absent	medium	resistant
96	IP-16911	Zimbabwe	grey	candle /compact	absent	medium	resistant
97	IP-13137	Nigeria	grey	cylindrical/semi compact	absent	medium	susceptible
98	IP-12474	India	grey	cylindrical/semi compact	absent	medium	resistant
99	IP-6545	Mali	grey	cylindrical/semi compact	absent	bold	susceptible
100	IP-6451	Mali	grey	cylindrical/semi compact	absent	bold	resistant
101	IP-7838	ICRISAT	dark grey	cylindrical/semi compact	absent	medium	susceptible
102	ICTP-8203	India	dark grey	candle / compact	absent	bold	resistant
103	WC-C75	India	grey	cylindrical/ compact	absent	medium	susceptible
104	IP-10085	Mali	grey	cylindrical/semi compact	absent	bold	susceptible
105	IP-19243	Namibia	dark grey	cylindrical/semi compact	absent	medium	resistant

11. Grain yield per plant (g)

The ear heads of all the five plants were harvested and threshed together and average yield per plant was worked out.

12. 1000 grain weight (g)

The weight of random sample of 1000 grains from a plant (average yield/plant) was recorded.

3.2.4 Statistical Methods

3.2.4.1 Analysis of variance

The mean values of the genotypes in each replication were used for the analysis of variance. The replication wise mean values were subjected to randomized complete block design analysis. The significance of the differences among all the genotypes was tested by F-test using the error variance.

ANOVA TABLE

Source of Variation	d.f.	MSS	Cal. F
Replication	(r-1)	RMSS	-
Treatment	(t-1)	TMSS	TMSS/EMSS
Errors	(r-1) (t-1)	EMSS	
Total	(rt-1)		

Where, r = Number of replications

t = Number of treatments (genotypes)

The standard error was calculated as

$$S.Em \pm = \sqrt{\frac{EMSS}{r}}$$

After testing for significance of the differences among the means of different genotypes for each character, further computations were done as detailed below.

3.2.4.2 Estimation of genetic parameters

In order to identify and ascertain the genetic variability among genotypes and to assess the extent of environmental effect on various characters, different genetic parameters were estimated by using following formulae.

3.2.4.2.1 Phenotypic and genotypic variance

These were calculated according to the formula given by Lush (1940) and Choudhary and Prasad (1968).

$$\text{Genotypic variance } (\sigma^2 g) = \frac{TMSS-EMSS}{r}$$

$$\text{Error variance } (\sigma^2 e) = EMSS$$

$$\text{Phenotypic variance } (\sigma^2 p) = \sigma^2 g + \sigma^2 e$$

Where,

TMSS =MSS for treatment

EMSS= MSS for errors

r = Number of replications

3.2.4.2.2 Phenotypic and genotypic co-efficient of variation

The method suggested by Burton and Davane (1952) was followed for computation of these parameters.

$$\text{Phenotypic co-efficient of variation (PCV)} = \frac{\sigma p}{\bar{X}} \times 100$$

$$\text{Genotypic co-efficient of variation (GCV)} = \frac{\sigma g}{\bar{X}} \times 100$$

Where,

σp = Phenotypic standard deviation

σg = Genotypic standard deviation

$\bar{X}$ = Grand mean

GCV and PCV values were categorized as low (0-10%). moderate (10-20%) and high (>20%) as indicated by Siva Subramanian and Menon (1973).

3.2.4.2.3 Heritability:

Heritability in broad sense (h^2) was calculated as the ratio of genotypic variance to the phenotypic variance (Hanson *et al*., 1956).

$$h^2 = \frac{\sigma^2 g}{\sigma^2 p} \times 100$$

Where, $\sigma^2 g$= Genotypic variance

$\sigma^2 p$ = Phenotypic variance

The heritability percentage was categorized as low (0-20%), moderate (20-60%) and high (>60%) as given by Robinson *et al*. (1949).

3.2.4.2.4 Genetic advance (expected response):

This was computed according to the method suggested by Johnson *et al*. (1955).

Genetic advance (GA) = $i\sigma p h^2$

Where,

i = 2.06 when top 5 per cent individuals are selected

σp = Phenotypic standard deviation

h^2 = Heritability in broad sense

3.2.4.2.5 Genetic advance as percentage of mean (GAM):

This was calculated by using the formula given below:

$$GAM = \frac{GA}{\overline{X}} \times 100$$

Where,

GA = Genetic advance

$\overline{X}$ = General mean

Genetic advance as percent of mean was categorized as low (0-10%), moderate (10-20%) and high (>20%) by Johnson *et al.* (1955)

3.2.4.3 Mohalanobis's generalized distance (D^2)

Mahalanobis (1936) D^2 statistics was used for assessing the genetic divergence among the genotypes and the generalized distance between any two populations as given in the following formula,

$$D^2 = \Sigma\Sigma\ _{ij}S_iS_j$$

Where,

D^2 = Square of generalized distance

ij = The reciprocal matrix to the common dispersion matrix

S_i = The difference between the mean values of the two populations for i^{th} character (μi_1 - μj_2)

μ = Vector mean value for all the characters

S_j = (μi_1 - μj_2)

μ = General mean

Since, the formula for computation requires inversion of higher order determinant, transformation of original correlated unstandardized character means (XS) into standardized uncorrelated variables (YS) was done to simplify the computational procedures. The D^2 values were obtained as sum of squares of differences between the pairs of corresponding uncorrelated (YS) values of any two genotypes (Rao, 1952).

3.2.4.3.1 Clustering of D^2 values

All the n (n-1)/2 D^2 values were clustered using Tocher's method as described by Rao (1952).

3.2.4.3.2 Intra and inter cluster distances

The intra and inter cluster distances were calculated by the formula given by Mahalanobis (1928) and Singh and Chaudhary (1979).

$$\text{Square of the intra cluster distance} = \frac{\Sigma D_i^2}{n}$$

Where,

ΣD_i^2 is the sum of distance between all possible combinations of the entries included in cluster.

n = number of all possible combinations

$$\text{Square of the inter cluster distance} = \frac{\sum D_i^2}{n_i n_j}$$

Where,

ΣD_i^2 is the sum of square of distances between all possible combinations ($n_i n_j$) of the entries included in the clusters i and j.

n_i = number of entries in cluster i

n_j = number of entries in cluster j

3.3 EXPERIMENT- III: STUDIES ON HETEROSIS AND COMBINING ABILITY

To derive information on the heterosis and combining ability, line x tester analysis developed by Kempthorne (1957) was followed. Two different Line x Tester experiments (Expt.IIIa and IIIb) were laid out for this purpose.

Expt. IIIa: Influence of different CMS sources on heterosis and combining ability effects for different quantitative characters

3.3.1a Material

This experiment was planned to explore the possibility of using diverse sources of male sterility in the development of hybrids and to know the effect of different cytoplasm on quantitative traits. The material for this study comprised 20 genotypes (3 females and 11 males) selected on the basis of geographical diversity and variability for different morphological characters. The three male sterile lines representing different cytoplasms viz, A_1, A_4 and A_5 under the nuclear background of Tift 23A were used as females, which exhibited several contrasting characters. Each of these three female parents were crossed with 11 pollen parents (IP-9140, 10811, 16197, 12678, 8229, 9149, 873, 804, 577, 7440, 10085) representing wide genetic variability. The detailed description of parents has been given in Table 1 and 2. Crossing programme was taken up in 2004 and the resulting 33 F_1's and 14 Parents (three corresponding B lines and 11 male parents) formed the experimental material.

Expt.IIIb Heterosis and combining ability studies on A_1 source in pearl millet for commercial exploitation

3.3.1b Material

The main objective of this experiment was commercial exploitation of heterosis by using available male sterile lines and known restorers. A total of 12 genotypes of pearl millet were selected based on the geographical diversity and variability for different morphological characters. Four male sterile lines with A_1 source viz., ICMA 94555, JMSA 101, 842A and ICMA 88000 were used as females. Each of these 4 male sterile lines were crossed with 12 known restorers (IPC-577, 804, 873, 827, 1518, 1104, 517, 338, 217, 1361, 827-1 and 1394). A total of 48 F_1's and 12 selfed parent seeds (4 corresponding B lines and 12 known R lines) were collected in separate bags during 2004 summer, *kharif* and rabi. These formed the experimental material.

3.3.2 Method

Layout

The Expt. IIIa comprising 33 F_1's, 14 parents and a check (GHB-558) and Expt.IIIb with 48 F_1's, 15 parents and a check (GHB-558) were laid out separately in RBD with 3 replications during *kharif* 2005.

The seed of each entry was sown in a single row of 4-meter length. Intra row spacing was 15 cm and inter row spacing was 50 cm. The parents were grown in a separate adjoining block. Hybrids (F_1's) and parents were randomized among themselves only. Recommended package of practices were followed to raise the crop. Weeding, inter cultural operation and plant protection measures were taken up as and when needed. Some of the hybrids in Expt.IIIa were sterile (on some of the pollen parents) and such hybrids were pollinated artificially to ensure full seed setting.

3.3.3 Collection of data

Observations were recorded on each of the five randomly selected competitive plants tagged in each replication of all the treatments. The border plants were excluded and data on different traits as described earlier were recorded.

3.3.4 Estimation of heterosis

The magnitude of heterosis in relation to mid parent, better parent, and check values was worked out. These were calculated as percentage increase or decrease of F_1's over the mid parent (MP), better parent (BP) and check (Ch) values following the method of Turner (1953) and Hayes *et al*. (1955).

(a) Heterosis over mid parent (H_1)

$$\% H_1 = \frac{\overline{F_1} - \overline{MP}}{\overline{MP}} \times 100$$

(b) Heterosis over better parent (H_2)

$$\% H_2 = \frac{\overline{F_1} - \overline{BP}}{\overline{BP}} \times 100$$

(c) Heterosis over check (H_3)

$$\% H_3 = \frac{\overline{F_1} - \overline{Check}}{\overline{Check}} \times 100$$

Where,

$\overline{F_1}$ = Mean of F_1

$\overline{MP}$ = Mean of the two parent

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

$\overline{Check}$ = Mean of the check

Test of Significance

The heterosis was tested by least significant difference at 5% and 1% level of significance for error degree of freedom as follows.

For testing heterosis over mid parent

$$S.E\ (diff)\ (MP) = \sqrt{\frac{3Me}{2r}}$$

For testing heterosis over better parent (BP) and standard check

$$S.E\ (diff) = \frac{\sqrt{2Me}}{2r}$$

Where Me = Error mean sum of square

r = number of replication

Critical difference:

C.D = SE (diff) x t (at 5 and 1% level for error df)

Heterosis was considered significant when F_1 – MP or F_1 – BP was higher than critical difference.

3.3.5 Combining ability

In order to test the combining ability effects of parents (gca) and crosses (sca) the combining ability variances were worked out by following Line x Tester analysis suggested by Arunachalam (1989) and Kempthorne (1957).

The analysis was based on the following mathematical model:

$Yijk = \mu + mi\ fj + Sij + eijk$

Where,

μ = population mean

mi = gca effect of i^{th} (male) parent

fj = gca effect of j^{th} (female) parent

Sij = gca of $(I \times j)^{th}$ cross

Eijk = random error effect associated with $(ijk)^{th}$ observation in k^{th} replication.

The RBD analysis of crosses involved in Line x Tester analysis was carried out separately excluding parents for both experiments (Expt.IIIa and IIIb).

ANOVA FOR COMBINING ABILITY

Source	d.f	MSS	Expectations
Replication	(r-1)	-	--
Hybrids	(lt – 1)		
Lines	(l – 1)	M_1	σe^2 + r[cov (FS) – 2 cov (HS)]+ rt[cov (HS)]
Testers	(t – 1)	M_2	σe^2 + r(cov (FS) – 2cov (HS)] + rl[cov (HS)]
Line x Tester	(l-1) (t-1)	M_3	σe^2 + r[(cov(FS) – 2 cov (HS)]
Error	(r-1) (lt-1)	M_4	σe^2

Estimates of variance

The GCA and SCA variances were expressed in terms of covariances of full sibs (FS) and half sibs (HS) as indicated below:

$$\sigma^2 GCA = Cov\ (HS) = \frac{M_1 + M_2 - 2M_3}{r\ (\ l + t)}$$

$$Cov\ (HS)\ lines = \frac{M_1 - M_3}{rt}$$

$$Cov\ (HS)\ testers = \frac{M_2 - M_3}{rl}$$

$$\sigma SCA = Cov\ (FS) - 2\ Cov\ (HS) = \frac{M_3 - M_4}{r} = \sigma^2\ lt$$

The F test was used to test the significance of the variance estimates following Satterth and Waite (1946) and Singh (1976) approximation.

(i) To test σ^2 l, F = M_1/M_3 with DF (1) and DF (3) respectively.

(ii) To test σ^2 t, F = M_2/M_3 with DF (2) and DF (3) respectively.

(iii) To test σ^2 l t, F = ½ $(M_1/M_2)/M_3$ with DF (1) and DF (3) respectively.

(iv) To test σ^2SCA F = M_3/M_4 with DF (3) and DF (4) respectively.

Where, DF (1), DF (2), DF (3) and DF (4) are the degrees of freedom associated with M_1, M_2, M_3 and M_4 respectively.

3.3.5.1 Combining ability

The following effects were calculated from two-way table of lines vs. testers in which each figure was a total over all the three replications.

µ = x…/ltr

gi = xi ../tr – x…/ltr

gj = x.j./ltr – x…/ltr

Sij = xij/r – xi../tr – x.j./lt + x…/ltr

Where, x = Total of all hybrids

xi.. = Total of i^{th} line over all females

x.j. = Total j^{th} tester over all males

xij = Total ij^{th} combination

l = No.of lines

t = Number of tester

r = Number of replications

3.3.5.2 Standard errors of the estimates

The variances of the estimates were calculated following the formula given below. The standard errors of the estimates are the square roots of their variances.

S.E. (gca for line) = $(M_4/rt)^{1/2}$

S.E. (gca for tester) == $(M_4/rl)^{1/2}$

S.E. (sca effect) = $(M4/r)^{1/2}$

Where, M_4 = error variance

r = replication

l = lines

t = testers

The critical differences were calculated by multiplying the standard errors with table‘t’ value at 5 per cent and 1 per cent levels of probability for error degrees of freedom.

Least significant differences between estimates:

To test the significant differences of two estimates, the least significant differences were calculated by the value of ‘t’ at appropriate degrees of freedom for error and standard error of the differences of the two estimates. The standard errors of differences were obtained as follows

S.E. (gi – gj) lines = $(2M_4/rt)^{1/2}$

S.E. (gi – gj) testers = $(2M_4/rl)^{1/2}$

S.E. (Sij – Skl) crosses = $(2M_4/r)^{1/2}$

Proportional contribution of lines testers and their interactions:

Contributions of lines = SS (lines)/SS (crosses) x 100

Contributions of testers = SS (testers)/SS (crosses) x 100

Contributions of LxT = SS (lines x testers)/SS (crosses) x 100

Experiment -IV

Rust inheritance studies

Four pearl millet genotypes, viz., 8IB, P-2933-1, IP-6240-3 and 700481-1-5-3 were procured from ICRISAT. Parent 81B is susceptible to rust where as other three are resistant to rust. All the three resistant donors were crossed to 81B and their reciprocals were produced. The six F_1's were advanced to the F_2 generation and backcrosses were made to have a complete set of F_1, F_2, BC_1 and BC_2.

The experimental material consisting of six generation, viz., P_1, P_2, F_1, F_2, BC_1 and BC_2 belonging to each of the six crosses were laid out in pearl millet improvement project at RARS, Bijapur during 2005 late *kharif* in RBD with 3 replications. Each replication consisted of 28 treatments (four parents. $6F_1$'s, $6F_2$'s, $6BC_1$ and $6BC_2$). A mixture of seed of the most susceptible genotype was used as infector rows after every four rows of the tester lines and around each plot. Rust infected leaves were collected, rinsed in distilled water, urediospore suspension was prepared and sprayed uniformly on all the plants on 30^{th} and 45^{th} days of growth.

Rust disease scoring

The parents, hybrids and each of the segregating populations (F_2, BC_1 and BC_2) of both direct and reciprocal crosses, five leaves per plant were taken randomly to score for the number of rust pustules infected under field condition. Scoring was done by following the method of Mayee and Datar (1986) considering 0 to 3 as resistant types and those from 5 to 9 as susceptible ones.

Reaction	Scale	% of pustules on leaves
Resistance (R)	0-3	1 to 10 %
Susceptible (S)	3-9	>10%

Statistical analysis: Chi-square test was used to assess the goodness of fit for a particular ratio.

4. EXPERIMENTAL RESULTS

The investigations were carried out in a series of experiments to: (i) study the fertility restoration pattern of pearl millet genotypes on different cytoplasmic sources, (ii) assess the nature and extent of genetic variability and diversity in a collection of genotypes from different geographical regions, (iii) estimate the combining ability and heterosis for the economically important traits by employing suitable mating designs, so that the information obtained could be beneficially employed in the formation of future pearl millet improvement programme and (iv) study the inheritance of resistance to rust, which is a major disease that limits the exploitation of heterosis in pearl millet.

The results obtained in the present investigations are presented under the following heads.

4.1 Studies on fertility restoration behaviour of germplasm on different sources of cytoplasmic male sterility system (Expt.- I)

4.2 Assessment of genetic variability and diversity in a collection of pearl millet genotypes (Expt.-II).

4.3 Studies on heterosis and combining ability (Expt.-III)

4.3.1 Influence of different CMS sources on heterosis and combining ability effects for different quantitative characters (Expt.IIIa)

4.3.2 Heterosis and combining ability studies on A_1 source for commercial exploitation (Expt.IIIb)

4.4 Studies on inheritance of rust resistance

4.1 STUDIES ON FERTILITY RESTORATION BEHAVIOUR OF GERMPLASM ON DIVERSE SOURCES OF CYTOPLASMIC-GENETIC MALE STERILITY SYSTEMS

A total of 105 germplasm collections were evaluated for their ability to restore fertility on diverse sources of male sterility *viz.*, A_1, A_4 and A_5 cytoplasm. Restoring ability was assessed mainly based on seed set percentage as revealed by F_1's under selfing and the details are furnished in Table 3. The results obtained are presented under the following sub headings.

4.1.1 A_1 cytoplasm based hybrids

The hybrids corresponding to 38 genotypes exhibited seed setting; of these, 34 hybrids recorded satisfactory (>60%), 4 F_1's showed unsatisfactory seed setting (<60%), while 67 hybrids exhibited no seed setting indicating lack of restoring capability in the corresponding pollen parent. Thirty six per cent of germplasm lines were proved to be restorers on A_1 cytoplasmic source. Seed set percentage of each of the hybrid was determined and the average seed set value revealed by different fertile F_1's was calculated and this value was observed to be 78.51 per cent in case of 38 fertile F_1's in *kharif*. This value was comparatively higher than in summer (63.70%) season. Average seed set revealed by fertile F_1's across two seasons was 71.10 per cent.

When the restorers were compared among themselves for the extent of seed set on A_1 cytoplasm, considerable difference in seed setting within as well as across the seasons was noticed. Some genotypes like IP-10186, IP-10085, IP-17979, IP-12682 and IP-13833 showed consistently (stable) higher values of seed set percentage across two seasons, while some others IP-7838, IP-16197, IP-14026, IP-15681 showed higher but inconsistent seed set across seasons. The seed set in *kharif* was in general higher than in summer.

4.1.2 A_4 cytoplasm based hybrids

The hybrids corresponding to 63 germplasm lines showed seed setting on selfed ear and out of which 52 hybrids recorded more than 60 per cent seed setting, while 11 hybrids showed less than 60 per cent. Only 60 per cent of germplasm lines were found restorers on A_4 sources of male sterility. Forty-two hybrids showed no seed setting. The mean seed set percentage of 63 fertile hybrids was high in *kharif* (76.10%) compared to summer (70.95%). Average seed set revealed by the fertile F_1's across the two seasons was 73.50 per cent.

The restorers manifested considerable difference in seed set even within the season. The range in *kharif* and summer was 40.00 to 98.00 and 35.00 to 91.60 per cent respectively. When over all seed set (over two seasons) was considered, the range was from 40.00 to 93.30 per cent.

The genotypes *viz*., IP-12901, IP-19321, IP-15304, IP-15285, IP-9149 etc, exhibited consistently high values of seed set, while IP-6417, IP-12779 etc, showed inconsistent seed set across seasons.

Highest seed set of 98.00 per cent in *kharif* and 91.60 per cent in summer was recorded in hybrids based on pollen parents IP 12901 and IP 19321 respectively.

4.1.3 A_5 cytoplasm based hybrids

Of the 47 lines that showed seed set on A_5 cytoplasm, 29 exhibited more than 60 per cent seed setting. The remaining 58 lines showed maintainer reaction. Overall, 44.76 per cent of the germplasm lines proved to be restorers. The mean of seed set values revealed by 47 fertile F_1's was 68.72 per cent in *kharif* and 63.29 per cent in summer. Average seed set revealed by fertile F_1's across two seasons was 66.01 per cent.

The restorers on A_5 cytoplasm differed among themselves with respect to magnitude of seed set percentage. The range of seed set in *kharif* and summer was 30.00 to 95.00 per cent and 30.00 to 91.00 per cent respectively. The average seed set percentage across two seasons ranged from 35.00 to 93.00 per cent. In general, restorers exhibited inconsistent values of seed set percentage across two seasons.

The comparison of the observations on seed setting percentage recorded on diverse cytoplasms indicated that, the proportion of lines restoring fertility on A_4 was more as compared to A_1 and A_5 cytoplasmic sources. Of the 105 germplasm tested, 63 restored on A_4 cytoplasm, 47 on A_5 and 31 on A_1 cytoplasm.

Between two seasons, average seed set percentage was higher during *kharif* season than in summer, irrespective of cytoplasmic sources and restorer genotypes.

4.1.4 Effect of season on other plant characters

4.1.4.1 Days to 50 per cent flowering

The A_1 cytoplasm based hybrids varied in 50 per cent flowering from 44 days (A_1 x IP-7468) to 61 days (A_1 x IP-15273) in *kharif* and from 40 days (A_1 x IP-19246) to 60 days (A_1 x IP-15273, A_1 x IP-14497) in summer. The mean number of days to 50 % flowering in *kharif* and summer were 53.06 and 49.20 days respectively, with an overall mean of 51.13.

The A_4 cytoplasm based hybrids ranged from 44 days (A_4 x IP-17690) to 63 days (A_4 x IP-15273) in *kharif*, from 40 days (A_4 x IP-10085, A_4 x IP-19385, A_4 x IP-8540) to 60 days (A_4 x IP-13154) during summer. The mean duration for days to 50% flowering in *kharif* and summer were 51.25 and 47.70 respectively. The overall mean (over two seasons) was 49.48 days.

The duration 50% flowering of the A_5 cytoplasm based hybrids varied from 40 days (A_5 x IP-18800, A_5 x IP-16449, A_5 x IP-16911) to 63 days (A_5 x IP-8229) in *kharif* and from 40 days (A_5 x IP-15899, A_5 x IP-13840, A_4 x IP-14644) to 57 days (A_5 x IP-10186) in summer. The mean number of days in *kharif* and summer were 50.10 and 47.73 days respectively. The overall mean (over two seasons) was 48.91 days.

4.1.4.2 Plant height

The range of plant height for A_1 based hybrids during *kharif* was from 128.0 cm (A_1 x IP-10339) to 181.6 cm (A_1 x IP-10488), while in summer it was from 121.0 cm (A_1 x IP-13154) to 188 cm (A_1 x IP-18625). The mean plant height during *kharif* and summer was 154.38 cm and 154.89 cm respectively.

The plant height of A_4 cytoplasm based hybrids varied from 124.3 cm (A_4 x IP-19067) to 186.6 cm (A_4 x IP-15257) in *kharif* and from 115.6 (A_4 x IP-8229) to 190.6 cm (A_4 x IP-3150)

Table 3. Seed set percentage, days to 50 % flowering and plant height (cm) in F_1 hybrids derived from three male sterile lines having diverse cytoplasm with 105 male parents

S.No.	Characters	Seed Set Percentage									Days to 50 % flowering									Plant height (cm)								
	Female lines	A_1 cytoplasm			A_4 cytoplasm			A_5 cytoplasm			A_1 cytoplasm			A_4 cytoplasm			A_5 cytoplasm			A_1 cytoplasm			A_4 cytoplasm			A_5 cytoplasm		
	Male parent	K	S	M	K	S	M	K	S	M	K	S	M	K	S	M	K	S	M	K	S	M	K	S	M	K	S	M
1	IP-9140	-	-	-	92.00	85.00	88.50	55.00	50.60	52.80	53.00	45.00	49.00	60.00	48.00	54.00	55.00	48.00	51.50	143.00	139.60	141.30	149.30	159.20	154.25	145.50	149.50	147.50
2	IP-9286	-	-	-	62.00	58.00	60.00	62.30	60.30	61.30	53.00	43.00	48.00	55.00	50.00	52.50	48.00	45.00	46.50	140.30	149.00	144.65	153.30	142.60	147.95	155.20	150.10	152.65
3	IP-15857	-	-	-	48.50	51.00	49.75	92.66	85.00	88.83	51.00	48.00	49.50	54.00	45.00	49.50	49.00	44.00	46.50	152.00	149.60	150.80	151.30	149.20	150.25	161.00	159.20	160.10
4	IP-15899	-	-	-	85.00	80.00	82.50	75.00	75.00	75.00	51.00	45.00	48.00	51.00	40.00	45.50	55.00	40.00	47.50	150.60	152.30	151.45	156.00	165.60	160.80	172.00	168.50	170.25
5	IP-9149	-	-	-	94.00	91.60	92.80	-	-	-	50.00	47.00	48.50	51.00	41.00	46.00	51.00	50.00	50.50	151.60	147.00	149.30	151.30	171.40	161.35	145.60	142.60	144.10
6	IP-3799	-	-	-	-	-	-	-	-	-	54.00	45.00	49.50	51.00	44.00	47.50	55.00	48.00	51.50	172.00	151.30	161.65	167.30	179.20	173.25	128.20	136.20	132.20
7	IP-3150	84.00	65.00	74.50	-		-	-	-	-	55.00	55.00	55.00	49.00	55.00	52.00	50.00	55.00	52.50	168.30	149.60	158.95	171.00	190.60	180.80	146.20	141.00	143.60
8	IP-10186	92.00	85.00	88.50	75.00	70.00	72.50	-	-	-	50.00	50.00	50.00	49.00	57.00	53.00	45.00	57.00	51.00	153.00	159.60	156.30	166.60	172.60	169.60	156.80	155.00	155.90
9	IP-10394	-	-	-	85.00	80.00	82.50	56.00	50.00	53.00	51.00	51.00	51.00	55.00	55.00	55.00	45.00	52.00	48.50	161.60	161.80	161.70	143.30	180.20	161.75	163.00	159.80	161.40
10	IP-10820	-	-	-	-	-	-	72.00	71.00	71.50	55.00	52.00	53.50	55.00	48.00	51.50	49.00	51.00	50.00	154.30	170.60	162.45	153.00	173.20	163.10	182.20	172.50	177.35
11	IP-15817	-	-	-	-	-	-	85.66	82.00	83.83	51.00	48.00	49.50	48.00	49.00	48.50	46.00	45.00	45.50	149.60	167.00	158.30	150.30	152.40	151.35	164.20	160.10	162.15
12	IP-15220	92.00	72.00	82.00	-	-	-	-	-	-	53.00	44.00	48.50	49.00	53.00	51.00	47.00	44.00	45.50	160.00	155.00	157.50	148.00	156.80	152.40	169.00	160.20	164.60
13	IP-15256	80.00	60.00	70.00	-	-	-	-	-	-	54.00	47.00	50.50	51.00	53.00	52.00	46.00	44.00	45.00	163.60	165.60	164.60	161.60	158.80	160.20	153.00	152.10	152.55
14	IP-17566	70.00	45.00	57.50	-	-	-	-	-	-	58.00	46.00	52.00	53.00	50.00	51.50	44.00	44.00	44.00	150.00	177.00	163.50	168.00	173.80	170.90	146.00	140.20	143.10
15	IP-17144	55.00	55.00	55.00	-	-	-	-	-	-	58.00	48.00	53.00	53.00	50.00	51.50	48.00	45.00	46.50	154.30	184.30	169.30	148.30	171.00	159.65	148.00	145.60	146.80
16	IP-15829	63.60	60.00	61.80	95.50	86.00	90.75	-	-	-	58.00	50.00	54.00	53.00	45.00	49.00	51.00	46.00	48.50	154.30	178.00	166.15	154.60	158.20	156.40	192.00	180.20	186.10
17	IP-6510	-	-	-	85.00	80.00	82.50	95.00	91.00	93.00	58.00	51.00	54.50	48.00	45.00	46.50	53.00	48.00	50.50	147.00	130.60	138.80	153.00	155.80	154.40	176.00	156.80	166.40

38	IP-15355	-	-	-	60.00	54.00	57.00	95.00	90.00	92.50	55.00	42.00	48.50	50.00	51.00	50.50	46.00	46.00	46.00	131.60	157.00	144.30	147.30	145.80	146.55	171.00	154.80	162.90
39	IP-15700	75-00	50.00	62.50	85.00	81.60	83.30	-	-	-	60.00	40.00	50.00	50.00	51.00	50.50	49.00	48.00	48.50	143.30	152.00	147.65	143.30	136.60	139.95	145.20	145.80	145.50
40	IP-14028	88.00	80.00	84.00	89.00	85.00	87.00	-	-	-	61.00	43.00	52.00	48.00	54.00	51.00	55.00	50.00	52.50	145.00	142.30	143.65	149.60	152.80	151.20	144.00	129.50	136.75
41	IP-14026	90.00	45.00	67.50	75.00	71.00	73.00	-	-	-	55.00	45.00	50.00	48.00	55.00	51.50	50.00	51.00	50.50	147.00	146.00	146.50	152.00	145.20	148.60	142.60	136.50	139.55
42	IP-11211	-	-	-	89.00	81.00	85.00	-	-	-	60.00	47.00	53.50	59.00	55.00	57.00	55.00	53.00	54.00	144.30	153.60	148.95	159.30	160.20	159.75	148.80	145.20	147.00
43	IP-11680	-	-	-	-	-	-	-	-	-	55.00	55.00	55.00	55.00	48.00	51.50	55.00	54.00	54.50	154.30	151.00	152.65	157.60	168.00	162.80	152.00	148.60	150.30
44	IP-11577	-	-	-	-	-	-	-	-	-	55.00	50.00	52.50	45.00	45.00	45.00	53.00	50.00	51.50	162.00	144.60	153.30	152.30	168.20	160.25	156.00	150.40	153.20
45	IP-11503	-	-		-	-	-	-	-	-	58.00	52.00	55.00	45.00	46.00	45.50	54.00	50.00	52.00	171.60	157.00	164.30	144.00	150.00	147.00	145.00	140.00	142.50
46	IP-10919	-	-	-	-	-	-	-	-	-	59.00	53.00	56.00	45.00	45.00	45.00	59.00	48.00	53.50	178.00	141.60	159.80	157.30	147.20	152.25	157.00	155.20	156.10
47	IP-10839	-	-	-	-	-	-	92.00	85.00	88.50	60.00	54.00	57.00	45.00	45.00	45.00	60.00	48.00	54.00	173.00	168.00	170.50	158.30	144.20	151.25	146.20	143.20	144.70
48	IP-15304	54.00	75.00	64.50	95.00	85.00	90.00	-	-	-	61.00	55.00	58.00	60.00	48.00	54.00	53.00	50.00	51.50	143.00	157.00	150.00	147.60	142.20	144.90	148.00	145.00	146.50
49	IP-15273	55.00	50.00	52.50	92.00	85.00	88.50	40.00	30.00	35.00	61.00	60.00	60.50	63.00	49.00	56.00	59.00	51.00	55.00	148.00	154.00	151.00	158.00	155.80	156.90	146.00	148.50	147.25
50	IP-14497	60.60	50.00	56.30	85.00	78.00	81.50	85.00	78.60	81.80	50.00	60.00	55.00	55.00	50.00	52.50	51.00	53.00	52.00	145.30	147.00	146.15	161.30	172.20	166.75	142.00	140.50	141.25
51	IP-14778	90-00	80.00	85.00	75.00	70.00	72.50	-	-	-	60.00	55.00	57.50	55.00	51.00	53.00	53.00	54.00	53.50	141.30	141.00	141.15	149.60	172.60	161.10	188.00	172.50	180.25
52	IP-16096	85-00	85.00	85.00	90.60	84.00	87.30	-	-	-	55.00	54.00	54.50	54.00	55.00	54.50	54.00	50.00	52.00	147.30	151.30	149.30	158.60	181.40	170.00	152.00	152.30	152.15
53	IP-7440	90.00	80.00	85.00	92.60	90.00	91.30	45.00	30.00	37.50	55.00	54.00	54.50	55.00	48.00	51.50	48.00	50.00	49.00	151.00	160.30	155.65	150.30	173.00	161.65	148.00	140.20	144.10
54	IP-13840	85.00	78.60	81.80	85.00	75.00	80.00	50.00	35.00	42.50	56.00	55.00	55.50	49.00	49.00	49.00	48.00	40.00	44.00	153.00	166.60	159.80	151.30	153.00	152.15	146.00	146.80	146.40
55	IP-9306	93.60	81.60	87.60	91.00	85.60	88.30	30.00	45.00	37.50	51.00	50.00	50.50	45.00	50.00	47.50	45.00	41.00	43.00	139.30	162.60	150.95	156.00	148.00	152.00	178.00	146.50	162.25
56	IP-14644	60.00	50.00	55.00	78.00	70.00	74.00	48.00	52.00	50.00	49.00	48.00	48.50	45.00	50.00	47.50	46.00	40.00	43.00	138.30	139.30	138.80	143.30	150.00	146.65	178.00	172.00	175.00
57	IP-4695	-	-	-	85.00	81.00	83.00	85.00	80.00	82.50	49.00	48.00	48.50	49.00	51.00	50.00	45.00	40.00	42.50	146.60	145.00	145.80	144.60	167.80	156.20	145.00	146.50	145.75

58	IP-4779	-	-	-	91.00	84.00	87.50	85.00	75.00	80.00	53.00	49.00	51.00	55.00	50.00	52.50	49.00	48.00	48.50	161.60	149.00	155.30	131.60	168.60	150.10	142.00	142.80	142.40
59	IP-19321	70-00	55.00	62.50	95.00	91.60	93.30	72.00	65.00	68.50	51.00	45.00	48.00	59.00	45.00	52.00	44.00	46.00	45.00	169.30	161.30	165.30	128.30	151.80	140.05	138.00	136.50	137.25
60	IP-18621	-	-	-	-	-	-	50.00	72.00	61.00	53.00	45.00	49.00	59.00	46.00	52.50	45.00	44.00	44.50	178.00	174.00	176.00	154.00	152.80	153.40	136.00	139.80	137.90
61	IP-18625	75.00	60.00	67.50	-	-	-	65.00	61.00	63.00	53.00	45.00	49.00	53.00	48.00	50.50	48.00	46.00	47.00	143.30	188.00	165.65	148.00	141.60	144.80	149.20	152.00	150.60
62	IP-8818	75.00	67.00	71.00	-	-	-	-	-	-	48.00	50.00	49.00	55.00	48.00	51.50	55.00	46.00	50.50	130.00	173.30	151.65	147.60	147.40	147.50	144.20	144.50	144.35
63	IP-16197	84.00	30.50	57.25	65.00	60.00	62.50	-	-	-	48.00	51.00	49.50	49.00	51.00	50.00	50.00	45.00	47.50	139.00	182.00	160.50	145.60	165.60	155.60	146.50	145.00	145.75
64	IP-16690	-	-	-	55.00	50.00	52.50	-	-	-	49.00	53.00	51.00	49.00	50.00	49.50	51.00	45.00	48.00	143.30	173.60	158.45	153.30	157.60	155.45	148.50	146.80	147.65
65	IP-13875	-	-	-	61.00	56.00	58.50	-	-	-	50.00	54.00	52.00	50.00	51.00	50.50	51.00	45.00	48.00	156.00	183.00	169.50	145.60	152.40	149.00	174.20	166.50	170.35
66	IP-12779	-	-	-	90.00	75.00	82.50	95.00	75.00	85.00	51.00	50.00	50.50	50.00	48.00	49.00	51.00	48.00	49.50	158.00	152.00	155.00	140.00	143.40	141.70	140.00	142.50	141.25
67	IP-12768	80.00	75.00	77.50	92.00	86.00	89.00	75.00	65.00	70.00	45.00	51.00	48.00	50.00	49.00	49.50	53.00	48.00	50.50	157.00	156.00	156.50	157.60	157.80	157.70	142.10	145.00	143.55
68	IP-6125	-	-	-	-	-	-	70.60	60.00	65.30	46.00	53.00	49.50	51.00	50.00	50.50	55.00	50.00	52.50	152.60	152.00	152.30	148.30	148.00	148.15	149.80	150.00	149.90
69	IP-4331	-	-	-	-	-	-	88.30	75.00	81.65	55.00	54.00	54.50	51.00	41.00	46.00	55.00	48.00	51.50	145.60	157.00	151.30	167.60	153.00	160.30	152.60	148.00	150.30
70	IP-13645	-	-	-	-	-	-	75.00	91.00	83.00	59.00	58.00	58.50	48.00	45.00	46.50	55.00	48.00	51.50	152.00	157.00	154.50	162.30	141.40	151.85	153.70	146.50	150.10
71	IP-17144	-	-	-	-	-	-	-	-	-	59.00	48.00	53.50	50.00	48.00	49.00	48.00	48.00	48.00	154.30	148.60	151.45	144.60	144.80	144.70	146.80	141.50	144.15
72	IP-10339	-	-	-	-	-	-	-	-	-	50.00	49.00	49.50	51.00	50.00	50.50	49.00	49.00	49.00	128.00	148.60	138.30	148.00	148.40	148.20	155.20	143.50	149.35
73	IP-4759	-	-	-	-	-	-	52.00	45.00	48.50	55.00	50.00	52.50	56.00	43.00	49.50	50.00	50.00	50.00	153.30	133.00	143.15	178.30	178.00	178.15	165.20	158.60	161.90
74	IP-19388	-	-	-	85.00	75.00	80.00	75.00	70.00	72.50	48.00	53.00	50.50	56.00	40.00	48.00	49.00	49.00	49.00	149.60	145.00	147.30	177.60	177.00	177.30	178.20	169.80	174.00
75	IP-18742	-	-	-	92.00	89.00	90.50	63.00	58.00	60.50	45.00	51.00	48.00	56.00	41.00	48.50	49.00	49.00	49.00	142.30	167.60	154.95	164.60	164.60	164.60	133.50	138.50	136.00
76	IP-18657	-	-	-	91.00	85.00	88.00	70.60	62.30	66.45	49.00	47.00	48.00	49.00	43.00	46.00	45.00	45.00	45.00	161.30	150.30	155.80	167.60	167.60	167.60	128.30	136.50	132.40
77	IP-8540	-	-	-	-	-	-	70.00	60.60	65.30	55.00	45.00	50.00	47.00	40.00	43.50	45.00	45.00	45.00	170.00	154.00	162.00	141.60	141.00	141.30	149.00	148.10	148.55

93	IP-18800	-	-	-	-	-	-	55.00	50.00	52.50	49.00	49.00	49.00	51.00	45.00	48.00	40.00	40.00	40.00	140.00	134.60	137.30	150.30	150.30	150.30	166.00	155.80	160.90
94	IP-8069	-	-	-	-	-	-	-	-	-	46.00	51.00	48.50	51.00	45.00	48.00	41.00	41.00	41.00	131.30	150.40	140.85	142.00	142.60	142.30	142.00	143.00	142.50
95	IP-16449	-	-	-	-	-	-	-	-	-	55.00	53.00	54.00	51.00	50.00	50.50	40.00	40.00	40.00	154.00	149.30	151.65	141.30	141.00	141.15	141.00	139.50	140.25
96	IP-16911	-	-	-	65.00	58.00	61.50	-	-	-	59.00	50.00	54.50	48.00	53.00	50.50	40.00	40.00	40.00	159.60	161.00	160.30	153.30	153.00	153.15	153.00	148.50	150.75
97	iP-13137	-	-	-	-	-	-	-	-	-	60.00	54.00	57.00	54.00	54.00	54.00	41.00	41.00	41.00	160.00	144.00	152.00	135.60	134.00	134.80	145.00	144.20	144.60
98	IP-12474	-	-	-	45.00	40.00	42.50	-	-	-	55.00	55.00	55.00	50.00	50.00	50.00	45.00	45.00	45.00	147.60	143.00	145.30	148.00	148.60	148.30	142.00	144.60	143.30
99	IP-6545	80.60	70.00	75.00	40.00	45.00	42.50	-	-	-	49.00	50.00	49.50	60.00	45.00	52.50	45.00	45.00	45.00	152.30	149.00	150.65	160.60	160.60	160.60	162.00	163.20	162.60
100	IP-6451	-	-		-	-	-	-	-	-	49.00	48.00	48.50	55.00	46.00	50.50	45.00	45.00	45.00	161.00	150.00	155.50	169.60	169.60	169.60	171.20	172.50	171.85
101	IP-7838	65.00	85.00	75.00	-	-	-	-	-	-	49.00	49.00	49.00	56.00	47.00	51.50	40.00	40.00	40.00	152.60	140.00	146.30	150.60	150.60	150.60	152.10	153.60	152.85
102	ICTP-8203	75.00	60.00	67.50	-	-	-	90.00	75.00	82.50	55.00	50.00	52.50	55.00	45.00	50.00	40.00	40.00	40.00	162.60	149.00	155.80	151.30	151.30	151.30	148.00	147.50	147.75
103	WCC-75	-	-	-	-	-	-	-	-	-	51.00	43.00	47.00	55.00	48.00	51.50	40.00	40.00	40.00	172.60	158.30	165.45	158.60	158.30	158.45	156.00	156.20	156.10
104	IP-10085	-	-	-	60.00	55.00	57.50	-	-	-	50.00	43.00	46.50	49.00	49.00	49.00	41.00	41.00	41.00	147.60	147.00	147.30	149.30	149.30	149.30	165.20	165.80	165.50
105	IP-19243		-	-	55.00	48.00	51.50	60.00	48.00	54.00	48.00	41.00	44.50	53.00	50.00	51.50	45.00	45.00	45.00	151.30	159.00	155.15	159.60	159.60	159.60	155.80	150.80	153.30
	Mean	78.51	63.70	71.60	76.10	70.95	73.50	68.72	63.29	66.01	50.10	47.73	48.91	51.25	47.70	49.48	53.06	49.20	51.13	154.38	154.89	154.63	154.38	159.00	154.63	153.39	150.30	151.85
	S.D.	33.5	37.7	27.23	39.9	36.7	38	36.3	33.6	34.87	4.85	4.18	3.39	3.85	4.24	2.84	5.36	4.28	4.33	12	12.17	8.95	11.3	18.6	12.51	13.89	10.77	11.96

K*: Kharif*, S: Summer, M :Mean, '–' : Zero seed set percent in summer. The mean plant height during *kharif* and summer was 153.04 cm and 155.99 cm respectively.

In A_5 cytoplasm based hybrids, the plant height ranged from 125.6 cm (A_5 x IP-19045) to 192.0 cm (A_5 x IP-15829) in *kharif* and from 129.5 cm (A_5 x IP-14028) to 180.2 cm (A_5 x IP-15829) in summer. The average plant height during *kharif* and summer was 153.39 and 150.30 cm respectively.

4.2 GENETIC VARIABILITY AND DIVERSITY

4.2.1 Analysis of variance

Analysis of variance for the experiment conducted for two years, involving a set of 105 pearl millet germplasm lines for 12 quantitative characters revealed that the mean sum of squares were highly significant in both the years for all the traits studied, indicating greater diversity among the 105 germplasm lines (Table-4).

4.2.2 Studies on genetic variability

In order to understand the extent of variability, caused by genetic factors, the phenotypic and genotypic variances, phenotypic and genotypic coefficients of variations, broad sense heritability and genetic advances were worked out. The results obtained on these aspects in respect of yield and yield related parameters over two year are presented in Table-5. The mean performance of all the genotypes over two years for various characters is presented in Appendix II and III. Year wise genotypic and phenotypic coefficient of variability, heritability estimates and genetic advance as per cent mean are presented in Figs. 1, 2, 3 and 4.

The study indicated wide range of phenotypic and genotypic variability for various characters in both the years. During 2004, phenotypic coefficient of variation (PCV) ranged from 2.18 (days to maturity) to 23.01 per cent (ear length). High values of PCV were observed for ear length (23.01) and ear girth (22.59). Moderate values of PCV were observed for plant height (18.64), grain yield per plant (18.29) and productive tillers per plant (15.96), grain yield per ear (15.34), 1000-grain weight (12.24) and ear weight (10.68). Low PCV was noticed for days to maturity (2.18) and days to 50 per cent flowering (6.14). In 2005, PCV ranged from 3.45 (days to maturity) to 24.62 per cent (grain yield /plant). High values of PCV were observed for grain yield /plant (24.62). Moderate PCV values were observed for 1000-grain weight (19.69), grain yield /ear (18.62), ear weight (17.25), productive tillers per plant (16.43), ear length (16.14), flag leaf area (14.97) and peduncle length (13.11). Low values of PCV were noticed for days to maturity (3.45) and days to 50 per cent flowering (6.22).

Genotypic coefficient of variation (GCV) ranged from 1.29 (days to maturity) to 21.75 per cent (ear length). In 2004, high values of GCV were exhibited by ear length (21.70). Moderate GCV values were observed for ear girth (18.17), plant height (18.09) and grain yield per plant (17.87), grain yield per ear (13.42), 1000-grain weight (11.95) and ear head weight per ear (9.99). Low GCV values were observed for days to maturity (1.28) and days to 50 per cent flowering (4.47). During 2005, the GCV ranged from 2.51 (days to maturity) to 23.66 per cent (grain yield /plant). High values of GCV were exhibited by grain yield /plant (23.66). Moderate GCV values were observed for 1000 grain weight (19.18), grain yield /ear (17.52), ear length (15.38), flag leaf area (14.57), productive tiller/plant (14.27), ear girth (13.73) and peduncle length (11.98). Low GCV values were observed for days to maturity (2.51) and days to 50 per cent flowering (3.96).

Moderate to high estimates of broad sense heritability was recorded for all the characters under study in both the years. During 2004, broad sense heritability estimates ranged from 35.36 per cent (days to maturity) to 95.50 per cent (grain yield per plant). High broad sense heritability was observed for grain yield per plant (95.50), plant height (94.16), ear length (89.36), ear girth (88.23), 1000-grain weight, flag leaf area (95.00), peduncle length (85.63), grain yield per ear (90.00) and ear weight (76.54). In 2005, broad sense heritability estimates ranged from 40.40 per cent (days to 50% flowering) to 94.90 per cent (1000-grain weight). High broad sense heritability was observed for 1000 grain weight (94.90), flag leaf area (94.60), ear girth (93.40), grain yield /plant (92.30), ear length (90.80), ear weight (89.70) and grain yield /ear (88.50), peduncle length (83.50). Moderate broad sense heritability was observed for to 50% flowering (40.40) and plant height (50.41) (Table.5).

Table 4. Analysis of variance (MSS) for 12 different characters in 105 pearl millet genotypes over two years

Sources of variation	Year	df	Days to 50% flowering	Days to maturity	Plant height (cm)	Prod. tillers /plant	Ear girth (cm)	Ear length (cm)	Flag leaf area (cm^2)	Peduncle length (cm)	Ear weight /ear (g)	Grain yield /ear (g)	Grain yield/ plant (g)	1000 grain weight (g)
Replication	2004	2	1.88	5.04	140.02	1.84	0.10	12.36	170.94	13.31	33.94	7.45	28.52	0.26
	2005		0.37	4.91	51.00	0.14	0.02	3.60	1.96	14.47	25.40	22.06	47.20	1.59
Treatments	2004	104	21.35**	5.87**	3310.33**	0.88**	3.76**	83.12**	431.85**	50.6**	50.47**	39.59**	413.46**	5.89**
	2005		17.72**	18.55**	464.46**	0.31**	3.47**	41.00**	430.00**	22.15**	198.18**	65.23**	623.99**	10.01**
Error	2004	208	4.88	2.23	66.9	0.08	0.16	3.17	21.3	2.68	6.34	3.67	6.39	0.27
	2005		5.84	4.25	114.68	0.03	0.08	1.34	7.92	1.36	7.23	2.68	16.81	0.17
S.E. diff.	2004		1.8	1.22	6.67	0.23	0.32	1.46	3.76	1.33	2.05	1.55	2.06	0.43
	2005		1.70	0.79	7.57	0.12	0.20	0.82	1.99	1.99	11.90	1.15	2.89	0.29
C.D. @5 %	2004		2.5	1.69	9.26	0.32	0.45	2.03	5.22	1.85	2.85	2.17	2.86	0.59
	2005		3.36	1.56	14.92	0.24	0.39	1.61	3.92	1.63	3.75	2.28	5.71	0.58
C.D. @1 %	2004		3.56	2.4	13.16	0.45	0.65	2.89	7.42	2.63	4.05	3.08	4.07	0.84
	2005		4.44	2.05	19.68	0.32	0.52	2.13	5.17	2.14	4.94	3.01	7.53	0.77

** Significant at 1 % level

Table 5. Mean, range and other variability parameters for 12 different characters in pearl millet over two years

Characters	Year	Range	Mean	Variance		Coefficient of Variation		h^2 (bs) %	GA	GAM (%)
				σ^2 p	σ^2 g	PCV	GCV			
Days to flowering	2004	46.33-58.33	52.41	10.37	5.48	6.14	4.47	52.84	3.45	6.58
	2005	44.33-56.33	50.32	9.80	3.96	6.22	3.96	40.40	2.60	5.61
Days to maturity	2004	82.0-88.67	85.05	3.45	1.22	2.18	1.29	35.36	1.35	1.58
	2005	81.67-92.33	86.82	9.01	4.76	3.45	2.51	52.83	3.26	3.75
Plant height (cm)	2004	121.6-301.8	181.76	1148.01	1081.1	18.64	18.09	94.16	65.72	36.15
	2005	147.97-206.27	174.98	231.27	116.59	8.69	6.17	50.41	15.79	9.02
Productive tillers/plant	2004	1.53-3.00	2.25	0.13	0.10	15.96	14.25	79.70	0.59	26.33
	2005	1.47-2.90	2.16	0.12	0.09	16.43	14.27	75.40	0.54	25.00
Ear head girth (cm)	2004	3.80-8.87	6.02	1.36	1.20	22.59	18.19	88.23	2.2	36.67
	2005	5.60-11.00	7.75	1.21	1.13	14.21	13.73	93.4	2.10	27.09
Ear head length (cm)	2004	15.47-38.17	23.722	29.80	26.63	23.01	21.75	89.36	10.42	43.94
	2005	15.67-31.00	23.76	14.69	13.35	16.14	15.38	90.8	7.14	30.08
Flag leaf area (cm^2)	2004	55.05-100.23	78.44	158.14	136.84	16.03	14.91	86.38	23.49	29.95
	2005	54.97-118.20	81.43	148.62	140.69	14.97	14.57	94.6	23.65	29.04
Peduncle length (cm)	2004	20.70-36.40	26.67	18.65	15.97	16.19	14.98	85.63	7.61	28.53
	2005	17.33-28.37	21.97	8.29	6.93	13.11	11.98	83.5	4.93	22.43
Ear head weight/ear (g)	2004	28.83-48.53	38.37	16.82	14.71	10.68	9.99	87.0	7.38	19.25
	2005	32.93-72.10	48.80	70.88	63.64	17.25	16.35	89.7	15.49	31.74
Grain yield/ear head (g)	2004	19.67-36.77	25.77	13.19	11.97	14.09	13.42	90.0	6.78	26.34
	2005	17.30-38.47	26.06	23.53	20.84	18.62	17.52	88.5	8.81	33.80
Grain yield /plant (g)	2004	47.83-89.83	65.15	142.08	135.69	18.29	17.87	95.50	24.26	37.23
	2005	30.70-85.33	60.14	219.20	202.39	24.62	23.66	92.3	28.02	46.59
1000 grain weight (g)	2004	8.63-14.80	11.45	1.96	1.87	12.24	11.95	95.0	2.75	24.04
	2005	6.37-13.70	9.44	3.45	3.29	19.69	19.18	94.9	3.61	38.24

σ^2p- Phenotypic variance
σ^2g- Genotypic variance
GAM-Genetic advance over mean
PCV-Phenotypic coefficient of variation
GCV- Genotypic coefficient of variation
h^2(bs)-Heritability in broad sense
GA- Genetic advance

During 2004, the estimate of genetic advance expressed as percentage of mean (GAM) was ranged from 1.58 (days to maturity) to 43.32 (ear length). A high estimate of genetic advance was noticed for ear length (43.32), plant height (36.15), ear girth (35.21), grain yield per plant (37.23), peduncle length (28.53) and flag leaf area (28.45), grain yield per ear (24.17), productive tillers per plant (26.33), 1000-grain weight (24.04). Moderate genetic advance as per cent mean was obtained for ear weight (19.25). Low genetic advance was expressed by days to maturity (1.58) and days to 50 per cent flowering (6.58). In the year 2005, the GAM ranged from 3.75 (days to maturity) to 46.59 (grain yield /plant). High estimate of GAM was observed for grain yield /plant (46.59), 1000 grain yield (38.24), grain yield /ear (33.80), ear weight (31.74), ear length (30.08) and flag leaf area (29.04), ear girth (27.09), productive tillers/plant (25.00) and peduncle length (22.43). Low GAM was noticed for days to maturity (3.75) and days to 50% flowering (5.16) and plant height (9.02).

4.2.3 Studies on genetic diversity {Mahalanobis's generalized distance (D^2)}

The genetic diversity existing in 105 genotypes under study with respect to 12 different characters was analyzed by using Mahalanobis's generalized distance (D^2).

The mean value of different quantitative characters was utilized for working out genetic distance between pairs of genotypes. Estimation of D^2 values was carried out in three sets of genotypes viz.,(1) Entire collection of maintainers plus restorers, (2) only maintainers and (3) only restorers. The results obtained are presented here in tables 6, 7 and 8.

4.2.3.1 Mahalanobis's generalized distance for restorers + maintainers

The genetic diversity among 105 genotypes was measured by employing D^2 statistic. The correlated unstandardized mean values for all the genotypes for 12 quantitative characters under consideration were transferred into the uncorrelated standardized value. Based on the correlated squares of generalized distance (D^2 values), genotypes under study were grouped into 22 clusters following the method suggested by Tocher (Rao, 1952). Maximum number of genotypes (63) were grouped in cluster II, ten were grouped in cluster III, four each in clusters I, XV and XVII (Table 7). The dendrogram representing of 105 pearl millet germplasm depicting the spatial position of each cluster in relation to others is presented in Fig.5.

The inter cluster distance ranged between minimum of 12.9 (X and XI) and maximum of 249.0 (I and XVII). The inter cluster proximity was seen to be minimum between cluster X and XI as indicated by lowest inter cluster distance of 12.9. Intra and inter cluster D^2 values are presented in Table 6.

4.2.3.1.1 Contribution of different characters towards divergence for restorers + maintainers

The relative ranking of different character components of D^2 has shown that the maximum contribution to the total divergence was made by productive tillers per plant (36.23%). This was followed by days to maturity (32.58%), grain yield per plant (20.26%), 1000-grain weight (9.12%), peduncle length (0.48%), ear length (0.42%), ear girth (0.35%), and grain yield per ear (0.31%). Very little contribution made by the remaining characters (Table 6).

4.2.3.1.1.2 Cluster means

The cluster means in respect of twelve characters are presented in Table 8. The genotypes in cluster XIII, XVI and X were the earliest, while those in XIX, XVIII, I, VI, XII, VI, IV and II were late flowering. Mean values of the remaining clusters were intermediate. With regard to maturity, the individuals of cluster VII, XIII, X, XV and VIII were the earliest, while the genotypes of XIX, IV, XVIII, XII, III and XXII required more number of days for maturity. The genotypes in clusters XIX, XIII and VI were tallest, and cluster IX had the dwarf genotype. The cluster mean for ear length ranged from 15.67 cm to 29.80 cm, which were attained by group XXII and VI respectively. The maximum ear girth was noticed in cluster XVII (9.20) while minimum was observed in cluster V (6.0). Less number of productive tillers per plant was recorded by the individuals in the cluster XIII (1.57), while more number was seen in cluster XVIII (2.90). Regarding peduncle length, cluster XIX had the highest mean value (27.93 cm), while cluster means for flag leaf area was in the range of 54.97(cluster XXI) to 99.40 cm^2 (cluster VI). The mean values for ear head weight per ear was in the range of 35.02 (cluster I) to 60.97 g (cluster XIII).

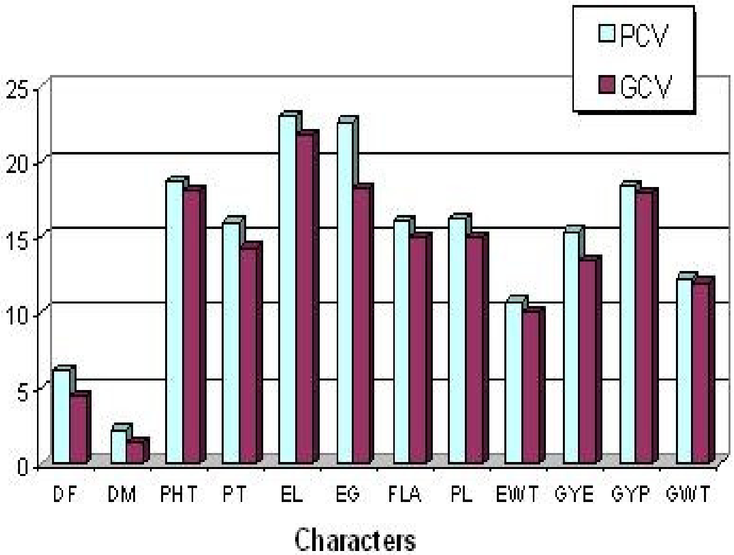

Fig.1. Phenotypic and genotypic coefficient of variability for of different quantitative characters in pearl millet during 2004

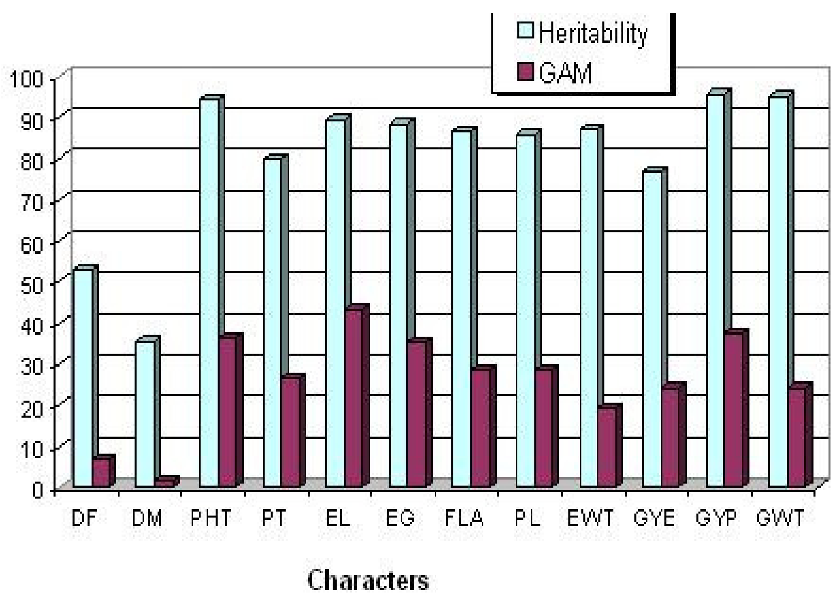

Fig.2. Heritability estimates and genetic advance as per cent of mean for different quantitative characters in pearl millet during 2004

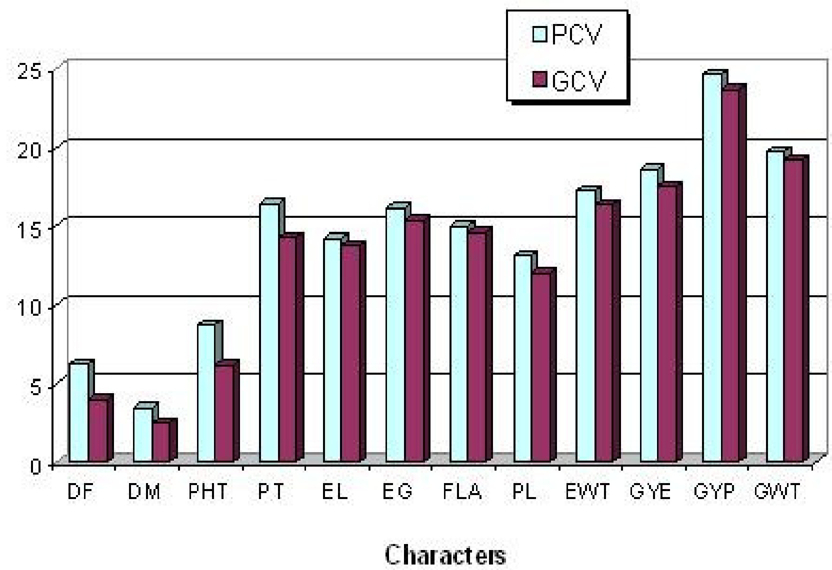

Fig.3. Phenotypic and genotypic coefficient of variability for of different quantitative characters in pearl millet during 2005

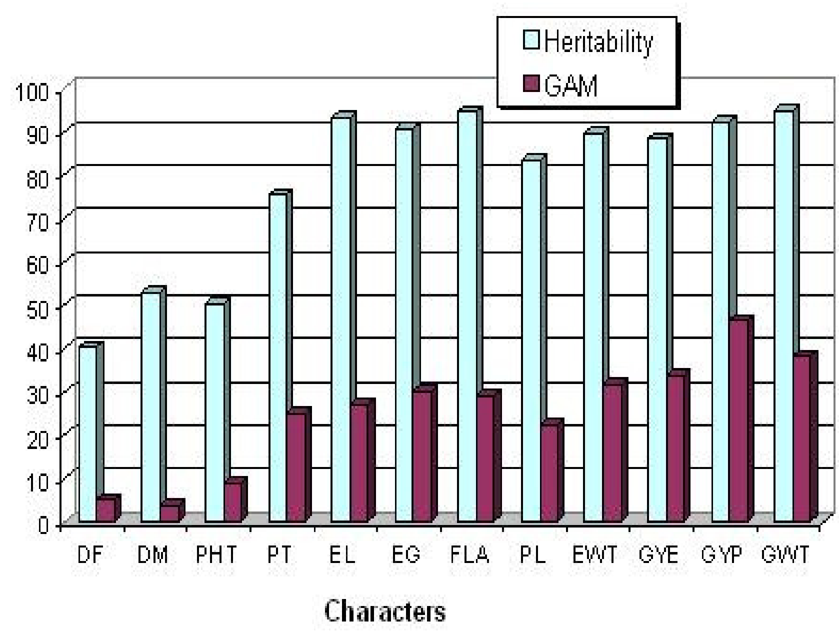

Fig.4. Heritability estimates and genetic advance as per cent of mean for different quantitative characters in pearl millet during 2005

Table 6. Average inter and intra cluster distances for twelve different characters in 105 pearl millet genotypes

Clusters	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII	XVIII	XIX	XX	XXI	XXII
I	6.0	231.8	253.0	218.6	239.9	227.8	232.4	221.9	218.6	218.8	229.2	225.4	221.8	225.0	242.1	236.9	249.0	242.7	231.6	198.3	220.0	141.8
II		23.6	33.5	31.6	31.9	34.4	29.7	30.7	28.3	33.0	28.5	30.5	39.2	31.7	36.7	29.4	33.3	42.4	34.6	57.8	73.5	218.0
II			22.0	51.4	35.0	48.4	32.9	41.3	47.9	51.8	44.1	41.6	50.1	49.7	35.0	35.2	32.5	41.2	42.1	74.0	89.9	235.3
IV				0.00	43.8	30.0	46.6	40.3	14.0	14.7	14.8	41.1	47.4	14.6	52.0	35.4	39.7	57.1	45.0	59.1	67.8	210.2
V					0.00	23.1	42.3	48.6	37.3	36.3	33.4	45.5	57.5	40.4	48.5	44.3	31.6	18.3	22.0	61.2	71.1	226.9
VI						0.00	51.8	51.3	24.0	20.4	21.9	48.3	59.6	28.9	55.9	47.7	36.8	34.7	26.9	56.9	62.8	219.3
VII							0.00	20.3	43.8	49.2	45.3	23.4	27.9	46.3	32.0	29.6	44.0	49.2	43.8	58.5	80.2	215.5
VIII								0.00	38.0	45.9	44.0	14.4	17.6	45.1	28.9	35.7	51.0	54.9	43.6	48.5	78.1	206.8
IX									0.00	15.0	18.0	38.6	46.4	16.8	48.9	35.3	38.1	49.6	37.7	55.0	66.3	211.8
X										0.00	12.9	46.5	55.2	16.9	57.3	40.0	37.7	49.8	40.3	58.6	64.3	213.4
XI											0.00	43.7	52.8	14.8	51.5	34.0	29.2	47.7	39.3	63.4	69.2	220.7
XII												0.00	13.8	45.3	26.7	40.1	51.5	50.4	37.1	42.8	71.1	205.7
XIII													0.00	51.7	31.9	43.2	60.3	63.2	50.0	48.1	76.2	200.4
XIV														0.00	55.2	30.2	33.9	56.1	46.9	66.3	66.1	218.0
XV															24.6	43.3	50.5	51.9	43.3	60.9	87.3	219.9
XVI																0.00	30.5	58.4	53.6	75.1	82.6	224.8
XVII																	21.9	45.3	45.8	79.5	84.0	237.2
XVIII																		0.00	19.6	59.3	78.4	227.4
XIX																			0.00	43.8	66.9	215.1
XX																				0.00	63.2	181.9
XXI																					0.00	200.8
XXII																						0.00

Under lined figures indicates intra cluster distance

Percent contribution of characters towards divergence

Characters	Days to 50 % flowering	Days to maturity	Plant height (cm)	Productive tillers/ plant	Ear length (cm)	Ear girth (cm)	Flag leaf area cm^2)	Peduncle length (cm)	Ear weight (g)	Grain yield per ear (g)	Grain yield per plant (g)	1000 grain Weight (g)
% Contribution	0.13	32.58	0.09	36.23	0.42	0.35	0.00	0.48	0.04	0.31	20.26	9.12

Table 7. Grouping of 105 pear millet genotypes into (restorers+maintainers) different clusters by Tocher's method

Cluster Number	Total Number of genotypes in each cluster	Genotypes included in the clusters	Origin
I	4	IP-9140, IP-9286, IP-15857, IP-15899	India=1, Togo=1, Tanzania=2
II	63	IP-11211, ICTP-8203, WC-075, IP-8540, ICMV-221, IP-15355, IP-15256, IP-4759, IP-15257, IP-14942, IP-10394, IP-3150, IP-4169, IP-15220, IP-15273 IP-12779, IP-7838, IP-17978, IP-12682, IP-8276, IP-8069, IP-12768 IP-17566, IP-17753, IP-9301, IP-17493, IP-17690 IP-10761, IP-10914, IP-10839, IP-10945 IP-15817, IP-15710, IP-15681, IP-15829 IP-10085, IP-6451, IP-6417, IP-10186, IP-6460, IP-6545 IP-12901, IP-14497, IP-6125 IP-14028, IP-16911, IP-16449, IP-8818, IP-16402, IP-14026 IP-19246, IP-17144, IP-18657, IP-18742, IP-19388 IP-5275, IP-19067, IP-13137 IP-11503, IP-13840, IP-10339, IP-13875 IP-8416	India=15 ICRISAT=7 Togo=5 Sudan=4 Tanzania=4 Mali=6 Camerron=3 Zimbabwe=6 Namibia=5 Nigeria=3 Burkino Faso=4 Ghana=1
III	10	IP-14038 IP-16196, IP-4695, IP-4779 IP-17979 IP-14644, IP-14778 IP-19321 IP-7488 IP-8429	Zimbabwe=1 India=3 ICRISAT-1 Camerron=2 Namibia=1 Tanzania=1 Nigeria=1
IV	1	IP-11680	Sudan=1
V	1	IP-10811	Sudan=1

Table 7. Contd…..

Cluster Number	Total Number of genotypes in each cluster	Genotypes included in the clusters	Origin
VI	1	IP-15364	India=1
VII	1	IP-19243	Namibia=1
VIII	1	IP-19361	Namibia=1
IX	1	IP-18800	Namibia=1
X	1	IP-12474	India=1
XI	4	IP-11577, IP-13833 IP-18625 IP-16690	Burkino Faso=2 Namibia=1 Zimbabwe=1
XII	1	IP-16197	India=1
XIII	1	IP-13154	Nigeria=1
XIV	1	IP-18389	Namibia=1
XV	4	IP,13645, IP-4331 IP-17144, IP-16638	India=2 Zimbabwe=2
XVI	1	IP-10826	Sudan=1
XVII	4	IP-17028, IP-10488, IP-18621 IP-7440	Zimbabwe=2 Namibia=1 Tanzania=1
XVIII	1	IP-10085	Mali=1
XIX	1	IP-6510	Mali=1
XX	1	IP-8229	ICRISAT=1
XXI	1	IP-3799	India=1
XXII	1	IP-9149	India=1

Table 8. Cluster means for twelve different quantitative traits in 105 pearl millet genotypes

Clusters	Days to 50 % flowering	Days to maturity	Plant height (cm)	Productive tillers/ plant	Ear length (cm)	Ear girth (cm)	Flag leaf area (cm^2)	Peduncle length (cm)	Ear weight (g)	Grain yield per ear (g)	Grain yield per plant (g)	1000 grain weight (g)
I	51.33	86.83	182.24	2.58	20.98	7.51	85.36	21.10	35.02	22.18	61.72	11.28
II	50.22	86.66	172.97	2.13	23.52	7.68	81.21	21.97	49.80	26.72	62.16	9.63
III	51.17	87.80	176.89	2.07	25.18	7.63	79.03	21.54	48.26	26.00	60.90	8.73
IV	51.67	90.33	168.00	1.93	19.10	7.50	93.00	19.83	47.87	20.20	32.67	7.70
V	50.33	85.00	185.63	2.63	24.23	6.00	87.60	22.43	53.40	30.70	73.67	10.20
VI	51.33	87.67	190.67	2.07	29.80	5.73	99.40	23.37	43.33	20.23	47.97	8.83
VII	50.00	83.33	171.57	2.47	23.23	8.23	92.13	23.27	48.67	23.30	69.10	10.77
VIII	50.00	85.00	170.10	1.97	21.63	8.10	81.03	21.33	42.33	21.73	50.13	9.00
IX	48.67	86.67	160.47	2.00	28.73	8.37	71.50	20.70	43.00	19.83	37.50	7.17
X	46.67	84.67	171.83	2.13	23.83	6.93	73.33	22.37	44.17	21.57	70.30	12.63
XI	48.25	86.00	174.00	2.60	25.20	6.10	78.00	22.20	46.50	24.80	65.90	10.80
XII	51.33	89.00	171.23	2.23	29.17	8.23	67.93	19.03	53.07	21.43	37.53	6.80
XIII	45.00	83.67	190.83	1.57	19.27	6.97	88.17	24.00	60.97	34.67	86.00	13.70
XIV	47.67	86.67	171.00	2.67	23.37	8.07	75.00	20.17	42.03	21.50	50.83	7.70
XV	48.83	84.75	171.47	2.00	24.13	7.00	84.15	19.43	48.69	22.05	45.96	8.02
XVI	46.33	85.00	170.60	2.47	20.87	8.83	69.50	25.33	51.23	25.33	57.93	10.13
XVII	50.33	86.83	176.21	2.08	26.79	9.20	83.13	23.65	49.73	26.73	62.31	8.88
XVIII	52.67	89.00	188.67	2.90	24.83	6.73	99.83	26.63	53.57	27.77	67.00	11.20
XIX	54.00	92.00	203.03	1.93	20.67	9.17	71.13	27.93	42.67	20.20	43.20	6.70
XX	50.67	86.33	189.83	2.30	20.60	8.63	79.50	21.47	51.77	28.67	60.87	11.07
XXI	49.00	85.67	187.13	2.10	22.20	8.63	54.97	26.60	38.47	27.60	70.67	9.03
XXII	47.00	87.33	189.50	2.20	15.67	9.03	91.27	20.10	40.50	27.30	63.37	10.27

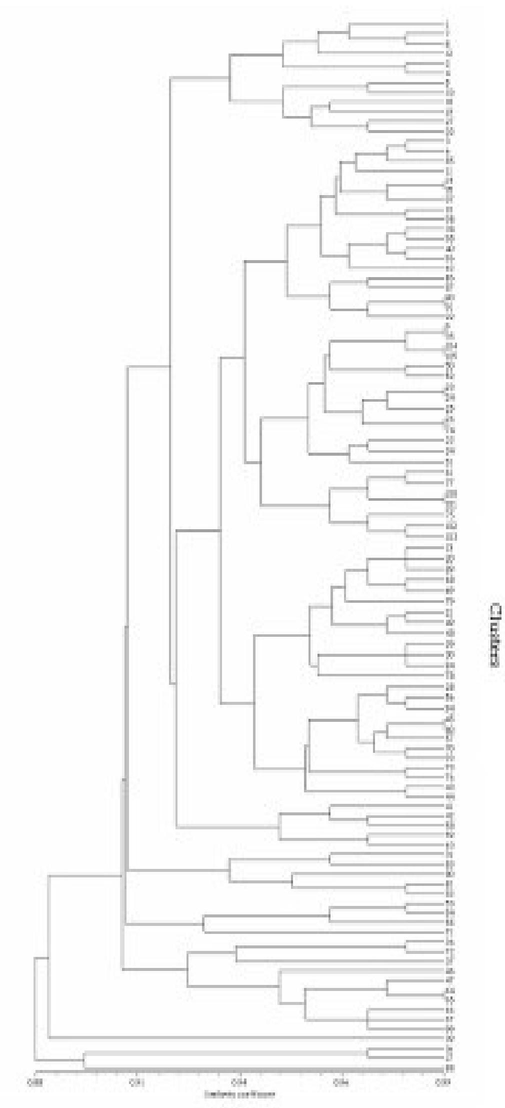

Fig.5 Dendrogram of 105 pearl millet germplasm lines

Fig.5. Dendrogram of 105 pearl millet germplasm lines

The maximum grain yield per ear head was produced by genotypes in cluster XIII (34.67g). The minimum grain yield per ear head was recorded by genotypes in cluster IX (19.83 g). The higher mean grain yield per plant was recorded by the genotypes in cluster XIII (86.00 g), while lower grain yield was noticed in cluster IV (32.67 g). With respect to 1000-grain weight, cluster XIII had highest mean value (13.70g) followed by cluster X (12.63g) and cluster I (11.28g). Cluster XIX had very low mean values for grain weight (6.70g).

4.2.3.2 Mahalanobis's generalized distance (D^2) for maintainers

In this study, 44 maintainer genotypes were assessed for their genetic distance. Based on the D^2 values, the genotypes under study were grouped into 11 clusters. Maximum numbers of genotypes (18) were grouped in cluster II, six each in cluster III and V, four in cluster I (Table 10).

4.2.3.2.1 Contribution of different characters towards divergence (maintainers)

Out of twelve characters, days to maturity (32.16%) was the main contributor towards divergence (Table 9). This was followed by grain yield per ear head (31.92%), peduncle length (20.06%), flag leaf area (6.13%) and ear length (6.00%). Relatively smaller contribution was made by grain yield per plant (1.40%), productive tillers/plant (0.95%), 1000-grain weight (0.85%) and plant height (0.32%).

The resulting average D^2 values within (intra) and between (inter) clusters are also presented in table 9. The distribution pattern of genotypes into various clusters is given in table 10. The dendrogram representing the spatial position of each cluster in relation to others is depicted in Fig. 6.

Intra cluster distance was maximum in cluster V (23.1) that constituted six genotypes, whereas cluster IV comprising two genotypes showed lowest divergence (10.5). Clusters VII, IX, X and XI had no intra cluster distance as each of them had only one genotype.

The inter cluster D^2 values revealed that maximum divergence occurred between clusters I and XI (256.7) while close proximity existed between clusters II and VII (28.5).

Maximum numbers of genotypes (18) were included in the cluster II, six each were grouped under clusters III and V, whereas four genotypes were included in cluster I, two in cluster VIII and one genotype each in cluster VI, VII, IX and X (Table 10).

4.2.3.3.2 Cluster means

The cluster means of twelve characters in respect of maintainers are presented in table 11. The genotypes in cluster VII were the earliest in flowering followed by X and I while those of clusters IX flowered late. The genotypes in cluster IV matured earliest followed by those in clusters VII and IX, while the genotypes in cluster VI matured late. The tallest genotypes joined in the clusters VII, VIII and VI. Cluster IX, which had single variety was the shortest of all. The cluster mean for ear length ranged from 20.97 (clusters VII and X) to 26.92 cm (cluster IV). The mean ear girth ranged from 6.12 (cluster IV) to 9.73 cm (cluster VIII). Cluster X comprising of one genotype (IP-15817) had the highest mean value (2.63) for the productive tillers per plant, while the lowest mean value (1.40) was registered by cluster VII. Regarding peduncle length, the highest mean value (28.03 cm) was registered by single genotype, which formed cluster X, while the shortest peduncle length (17.80 cm) was borne by the individuals of cluster IV. The cluster mean for flag leaf area ranged from 73.67 (I) to 88.10 cm^2 (cluster VI). Cluster IX registered the highest mean value (59.83g) for ear head weight, while genotypes presented in the cluster I had the lowest mean value (43.01 g). Regarding grain yield per ear head, the cultivars in the cluster IX registered highest mean value (31.83 g), while the genotype in the cluster was the lowest yielder (17.30g). Higher mean grain yield per plant was obtained by cluster VIII (63.55 g), while that of cluster VI was the lowest. Cluster X and II registered highest mean value for 1000-grain weight (11.00g), while the lowest mean value was observed in cluster VI (7.00g).

4.2.3.3 Mahalanobis's generalized distance for restorers

A total of 61 restorers were tested for statistical distance. Each genotype produced 60 combinations and 1830 D^2 values were obtained. Based on the D^2 value the genotypes under study were grouped into 19 clusters. Maximum numbers of genotypes (16) were grouped in cluster III, fifteen out of 61 genotypes were grouped in cluster II, five in cluster V and four

Table 9. Average inter and intra cluster distances (D^2 values) for twelve characters in 44 pearl millet maintainers genotypes

Cluster	I	II	III	IV	V	VI	VII	VIII	IX	X	XI
I	12.9	224.5	245.6	239.5	229.7	240.0	234.5	221.0	245.9	235.8	256.7
II		21.6	30.7	40.9	32.4	32.4	30.0	38.4	41.0	36.6	46.3
II			20.4	38.0	37.9	30.8	28.5	48.6	35.9	35.0	30.3
IV				10.5	59.1	47.7	31.8	45.2	65.9	44.7	30.5
V					23.1	31.5	42.8	42.4	33.8	53.1	58.4
VI						00.0	44.5	37.4	45.2	52.6	44.8
VII							00.0	45.5	42.6	33.1	38.8
VIII								22.8	64.6	65.2	57.4
IX									00.0	42.4	57.7
X										00.0	44.5
XI											00.0

Under lined figures indicates intra cluster distance

Percent contribution of characters towards divergence

Characters	Days to 50 % flowering	Days to maturity	Plant height (cm)	Productive tillers/ plant	Ear length (cm)	Ear girth (cm)	Flag leaf area (cm^2)	Peduncle length (cm)	Ear weight (g)	Grain yield per ear (g)	Grain yield per plant (g)	1000 grain weight (g)
% contribution	0.11	32.16	0.32	0.95	6.00	0.00	6.13	20.06	0.00	31.92	1.40	0.85

Table 10. Grouping of 44 pearl millet genotypes (maintainers) into different clusters by Tocher's method

Cluster No	Total Number of genotypes in each cluster	Genotypes included in the clusters	Origin
I	4	IP-3799, IP-3150 IP-10186 IP-10820	India=2 Mali=1 Sudan=1
II	18	IP-17566, IP-17753 IP-11503, IP-13875 IP-10761 IP-17144, IP-16911, IP-16402 IP-13154, IP-13137 IP-19361 IP-6545 ICTP-8203, WC-C75, IP-15520, IP-4331, IP-8540	Togo=1 Burkina faso=3 Sudan=1 Zimbabwe=3 Nigeria=2 Namibia=1 Mali=1 India=5
III	6	IP-17978 IP-10945, IP-10914, IP-11680 IP-6125 IP-4759	ICRISAT=1 Sudan=3 Camerron=1 India=1
IV	2	IP-17144 IP-10339	Zimbabwe=1 Nigeria=1

Table 10. Grouping of 44 pearl millet genotypes (maintainers) into different clusters by Tocher's method

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III	6	IP-17978 IP-10945, IP-10914, IP-11680 IP-6125 IP-4759	ICRISAT=1 Sudan=3 Camerron=1 India=1
IV	2	IP-17144 IP-10339	Zimbabwe=1 Nigeria=1

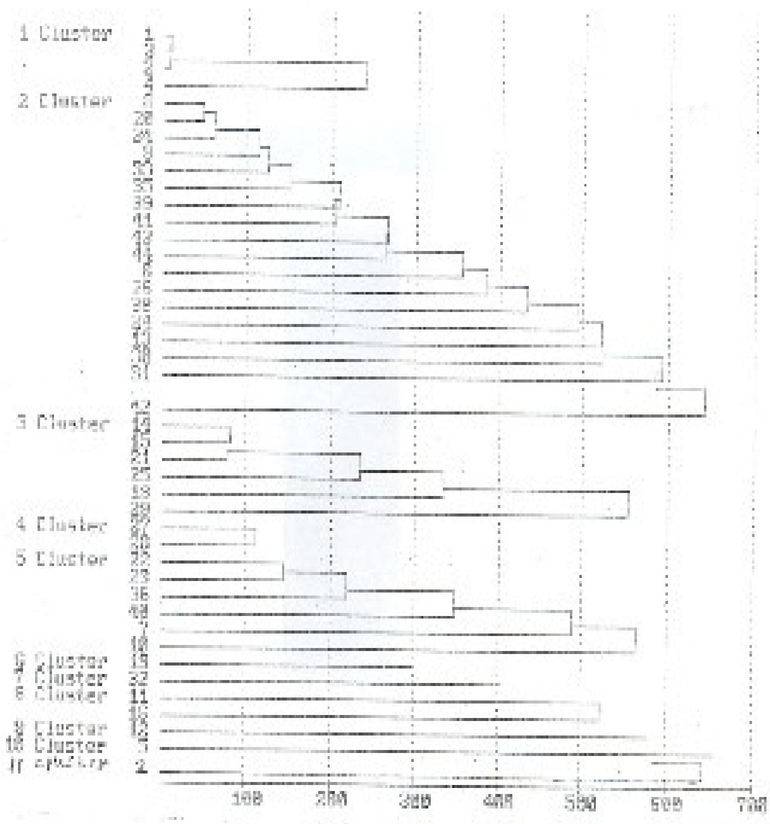

Fig.6. Dendrogram of 44 maintainer lines of pearl millet genotype

Table 11. Cluster means for twelve different growth parameters in 44 pearl millet genotypes

Cluster	Days to 50 % flowering	Days to maturity	Plant height (cm)	Productive tillers/ plant	Ear length (cm)	Ear girth (cm)	Flag leaf Area (cm^2)	Peduncle length (cm)	Ear weight (g)	Grain yield per ear (g)	Grain yield / plant (g)	1000 grain weight (g)
I	48.25	86.00	169.53	2.37	22.38	8.56	73.67	24.78	43.01	26.03	57.63	8.33
II	50.28	86.69	172.41	2.11	22.30	7.46	79.44	21.42	47.12	25.95	62.56	10.34
III	50.22	87.72	178.74	1.96	25.72	7.46	86.64	22.27	47.07	25.93	56.35	8.78
IV	50.33	84.33	174.45	2.37	26.92	6.12	79.43	17.80	55.90	29.28	60.32	9.58
V	49.61	86.33	168.36	2.07	24.91	7.98	78.99	21.43	51.29	26.36	60.36	9.22
VI	50.33	90.00	175.50	2.27	23.80	6.77	88.10	25.00	46.67	17.30	30.70	7.00
VII	44.67	85.00	181.33	1.40	20.97	7.13	80.97	21.97	51.17	20.27	38.13	7.40
VIII	48.83	86.50	179.42	2.15	23.48	9.73	78.82	22.72	49.08	26.30	63.55	9.62
IX	51.67	85.33	143.60	2.33	24.47	6.83	87.53	19.90	59.83	31.83	47.17	8.30
X	48.33	85.67	171.17	2.63	20.97	8.43	76.53	28.03	46.90	25.17	55.93	11.00
XI	47.55	88.50	178.40	2.00	22.40	7.60	75.60	22.60	48.20	24.50	41.60	9.20

genotypes each in cluster IV and I. Three genotypes in cluster VII, two in cluster XVIII.The remaining clusters were solitary with one genotype in each (Table 13).

4.2.3.3.1 Contribution of different characters towards divergence (Restorers)

The proportional contribution of characters towards the total D^2 statistic was different (Table 12). Days to maturity (41.42%) was the prime contributor towards divergence followed by grain yield per ear head (20.67%), peduncle length (20.00%) and flag leaf area (6.56%). Moderate contribution was made by grain yield per plant (6.67%), ear length (3.11%), plant height (0.60%), productive tiller per plant (0.66%), ear girth (0.50%) and 1000-grain weight (0.38%). Remaining characters made very little contribution. Eighty two per cent contributions to the total divergence was made by only three traits *viz.*, days to maturity, peduncle length and grain yield per ear head.

The resulting D^2 values within (intra) and between (inter) clusters are furnished in table 12. The distribution/grouping pattern of genotypes into various clusters is provided in table 13. The dendogram depicting the position of each cluster in relation to the other is presented in Fig 7.

The intra cluster distance ranged from 13.1 (cluster I) to 22.8 (cluster XVII), while the inter cluster distance was maximum (261.4) between clusters XVIII and I. Cluster I consisting four genotypes was distinctly different from all other clusters. Maximum diversity was observed between genotypes of clusters XVIII and I.

Amongst the 19 clusters, cluster III was the largest one, consisting of 16 genotypes followed by cluster II (15), V (5), I and VI (4), VII (3) and XVIII (2), the remaining clusters were solitary with one genotype in each (Table 13).

4.2.3.2.2 Cluster means

The clusters mean values (restorers) for twelve characters of each cluster are given in table 14.The genotypes in clusters IV and XVIII were earliest for flowering, while late flowering, genotypes were grouped in cluster XIV. The genotypes in cluster XIX were the earliest in maturity, while late maturing genotypes were observed in cluster VIII. Cluster XVIII had two genotypes, which were the tallest, while; cluster XIX had single genotype that was shortest. Cluster XV had longer ear length followed by clusters XIV and XIII. The shortest ear length was noticed in cluster IX. The highest mean value for ear girth was observed in case of cluster XIX; the lowest mean value for this trait was shown by cluster XIV. Highest cluster means for productive tillers per plant was noticed in cluster I, while lowest was observed in cluster XVIII. Cluster IX registered highest mean value for peduncle length, while cluster XIII showed the lowest mean value. Highest mean value for flag leaf area was observed in case of cluster XIX, while the lowest value was seen in cluster VIII. Cluster IX recorded highest mean value for ear head weight per ear, while lowest was shown by cluster I. The mean values for grain yield per ear head ranged from 21.43g in cluster XIII to 30.47 g in cluster XIX. Regarding grain yield per plant, the highest mean value was recorded by the individuals of cluster IV, followed by those in clusters XII and X. The lowest mean value was registered by cluster XIII. The mean value for 1000-grain weight for cluster I was the highest, followed by clusters XII and IX, while the lowest mean value was displayed by clusters XI and XIII.

4.3 STUDIES ON HETEROSIS AND COMBINING ABILITY

4.3.1 Influence of different CMS sources on heterosis and combining ability effects on different quantitative characters (Expt.IIIa)

The results on heterosis obtained from the Line x Tester experiments (Expt.IIIa) involving 33 crosses and their parents are presented here under.

4.3.1.1 Analysis of variance

The analysis of variance for twelve characters is presented in table 15. The entries showed highly significant differences for all the 12 characters. The parents, F_1's and interaction component (Parent vs. F_1's) showed highly significant variation for all the characters. Highly significant differences among all the characters were observed even when the standard check was included in addition to parents and hybrids.

Table 12. Average inter and intra cluster distances (D^2 values) for twelve characters in pearl millet restorer genotypes

Clusters	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	XVI	XVII	XVIII	XIX
I	13.1	228.2	248.3	248.4	240.7	257.6	226.1	248.0	223.0	253.7	240.8	209.9	236.8	240.0	237.5	245.4	261.4	221.0	235.8
II		19.3	30.3	37.6	39.3	36.5	32.9	31.0	27.7	38.7	38.3	34.3	33.0	31.0	45.5	39.4	44.4	37.0	35.1
II			20.4	27.1	34.5	26.9	40.5	26.3	38.7	26.6	34.2	50.2	41.4	30.4	47.3	36.5	37.1	51.8	36.6
IV				00.0	31.1	33.5	30.5	43.3	41.8	28.9	15.3	50.1	52.6	23.0	32.9	31.2	52.6	50.9	51.6
V					20.0	50.3	35.7	49.7	31.3	43.8	36.7	38.9	63.3	43.3	55.6	54.6	59.6	61.8	37.8
VI						00.0	47.3	25.2	51.5	29.0	37.9	62.5	30.3	31.5	43.0	26.1	28.3	46.7	51.8
VII							19.7	52.6	31.3	46.9	26.2	31.2	51.6	31.1	34.4	40.5	63.2	37.9	53.0
VIII								00.0	46.8	29.0	48.5	58.1	28.3	37.1	55.7	39.7	26.8	52.1	35.3
IX									00.0	53.6	45.3	17.3	51.7	43.7	57.5	55.2	54.0	46.6	34.3
X										00.0	32.7	61.5	44.7	26.7	42.2	32.8	47.9	57.3	46.6
XI											00.0	49.2	51.4	21.9	21.7	27.0	60.4	45.3	57.4
XII												00.0	58.7	49.0	58.9	61.5	68.6	46.8	43.7
XIII													00.0	38.0	49.2	34.1	36.1	33.9	53.8
XIV														00.0	24.9	20.5	50.8	37.4	52.6
XV															00.0	22.1	67.7	38.4	71.5
XVI																00.0	49.7	37.3	63.4
XVII																	00.0	59.2	48.4
XVIII																		22.8	65.2
XIX																			00.0

Under lined figures indicates intra cluster distance

Percent contribution of characters towards divergence

Characters	Days to 50 % flowering	Days to maturity	Plant height (cm)	Productive tillers/ plant	Ear length (cm)	Ear girth (cm)	Flag leaf area (cm^2)	Peduncle length (cm)	Ear weight (g)	Grainy yield per ear (g)	Grain yield per plant (g)	1000 grain weight (g)
% Contribution	0.11	41.42	0.60	0.66	3.61	0.50	6.56	20.00	0.00	20.67	0.67	0.38

Table 13. Grouping of 61 Pear millet restorer genotypes into different clusters by Tocher's method

Cluster No.	Total Number of genotypes in the cluster	Genotypes included in the clusters	Origin
I	4	IP-9140 IP-15857, IP-15899 IP-9286	India=1 Tanzania=2 Togo=1
II	15	IP-17979, IP-12682 IP-4779, IP-14942, IP-13645 IP-18621, IP-18625, IP-19388, IP-18742 IP-13833 IP-14778 IP-9301 IP-15681 IP-6510 IP-10811	ICRISAT=2 India=3 Namibia=4 Burkino fusa=1 Camerron=1 Togo=1 Tanzani=1 Mali=1 Sudan=1
III	16	IP-14026 IP-11211, ICMV-221, IP-15364, IP-9149, IP-16196 IP-14497, IP-14644 IP-18389, IP-19426, IP-18800 IP-10839 IP-7838, IP-8276 IP-6460 IP-5275	Zimbabwe=1 India=5 Camerron=2 Namibia=3 Sudan=1 ICRISAT=2 Mali=1 Nigeria=1
IV	1	IP-7468	Tanzania=01
V	5	IP-6417, IP-10085 IP-18355 IP-7440, IP-15879	Mali=2 India=1 Tanzania=2

Table 13. Contd…..

Cluster No.	Total Number of genotypes in the cluster	Genotypes included in the clusters	Origin
VI	4	IP-15273 IP-8429 IP-10085 IP-19243	India=1 Nigeria=1 Mali=1 Namibia=1
VII	3	IP-12901 IP-19321, IP-18657	Camerron=1 Namibia=2
VIII	1	IP-19067	Namibia=1
IX	1	IP-12768	ICRISAT=1
X	1	IP-10394	India=1
XI	1	IP-14038	Zimbabwe=1
XII	1	IP-12779	ICRISAT=1
XIII	1	IP-16197	India=1
XIV	1	IP-4695	India=1
XV	1	IP-15710	Tanzania=1
XVI	1	IP-14028	Zimbabwe=1
XVII	1	IP-4169	India=1
XVIII	2	IP-17979 IP-13840	ICRISAT=1 Burkina faso=1
XIX	1	IP-9416	Ghana=1

Table 14. Cluster means for twelve different growth parameters in 61 pearl millet restorer genotypes

Cluster	Days to 50 % flowering	Days to maturity	Plant height (cm)	Productive per tiller	Ear length (cm)	Ear girth (cm)	Flag leaf area (cm^2)	Peduncle length (cm)	Ear weight (g)	Grain yield per ear (g)	Grain yield per plant (g)	1000 grain weight (g)
I	51.33	86.83	182.24	2.58	20.98	7.51	85.36	21.10	35.02	22.18	61.72	11.28
II	51.67	87.49	177.50	2.13	23.43	7.63	79.69	21.95	54.08	28.40	66.67	9.58
III	49.36	86.36	175.45	2.22	24.44	7.39	81.97	20.88	47.91	26.53	63.09	9.53
IV	47.67	85.00	166.50	1.97	21.00	6.87	68.33	22.17	50.27	29.17	82.03	9.47
V	50.33	86.20	176.78	2.11	23.92	8.47	76.08	24.58	45.97	22.90	58.59	9.34
VI	51.00	85.25	179.56	2.36	25.23	8.08	92.13	22.60	48.89	24.66	62.72	10.13
VII	19.20	84.50	176.50	2.30	23.80	6.92	82.20	22.60	49.25	23.50	62.50	10.80
VIII	48.67	92.33	178.97	2.37	20.93	7.97	60.53	21.90	42.13	23.00	39.50	7.57
IX	49.00	89.00	175.07	2.13	17.03	6.73	98.23	26.73	68.40	30.07	71.50	10.77
X	48.33	84.67	172.27	2.03	24.93	9.07	88.70	24.17	52.83	29.80	74.50	10.00
XI	50.33	89.00	189.90	2.80	27.47	8.27	85.23	25.00	41.93	23.00	50.20	6.80
XII	52.33	85.67	170.83	1.93	23.47	6.67	98.80	24.03	62.67	26.37	75.83	11.27
XIII	51.33	89.00	171.23	2.23	29.17	8.23	67.93	19.03	53.07	21.43	37.53	6.80
XIV	55.33	89.33	166.77	2.33	30.17	6.27	76.03	19.57	50.83	22.33	40.60	7.53
XV	51.33	87.00	172.47	2.13	30.47	6.90	62.90	19.93	51.47	21.83	46.67	9.17
XVI	52.00	87.67	165.57	2.03	25.67	8.20	70.90	20.90	49.67	25.53	53.37	10.43
XVII	47.67	85.00	165.77	2.00	21.20	6.77	79.00	20.47	47.97	26.33	73.33	10.00
XVIII	50.00	87.83	195.62	1.92	24.00	8.35	86.07	24.65	41.98	22.72	53.98	8.98
XIX	49.00	83.33	174.17	1.93	21.57	10.73	114.33	19.67	51.50	30.47	61.37	7.60

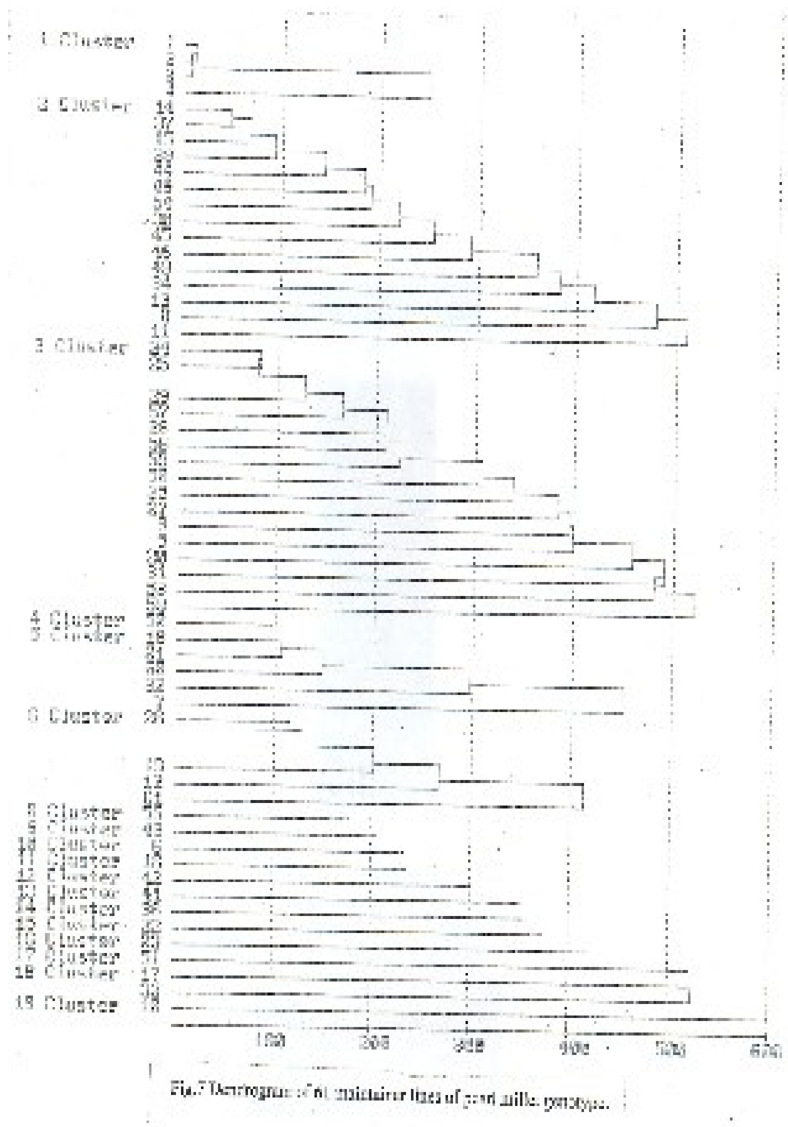

Fig.7. Dendrogram of 61 maintainer lines of pearl millet genotype.

Table 15. Analysis of variance (Mean sum of squares) in respect of 12 different characters in pearl millet (Expt. IIIa)

		Mean sum of squares											
Sources of variation	df	Days to 50% flowering	Days to maturity	Plant height (cm)	Productive tillers/ plant	Ear length (cm)	Ear girth (cm)	Flag leaf area (cm^2)	Peduncle length (cm)	Ear weight /ear (g)	Grain yield /ear head (g)	Grain yield/plant (g)	1000 grain weight (g)
Replication	2	0.91	8.87	20.03	0.22	10.14	0.06	68.46	1.55	8.57	2.74	2.69	0.49
Treatments (Parents+Hybrids)	46	9.6**	9.07**	114.9**	0.79**	42.8**	2.11**	543.79**	29.52**	267.22**	102.87**	377.94**	4.99**
Parents	13	7.56**	6.97**	57.48**	1.75**	4.71*	0.72*	389.26**	9.06**	21.14**	10.72**	139.97**	1.62**
Parents v/s Crosses	1	120.78**	81.2**	97.73**	1.98**	587.98**	12.11**	348.9**	146.19**	5144.63**	539.07**	2422.11**	6.74**
Crosses	32	6.95**	7.68**	138.77**	0.29**	41.24**	2.36**	612.65**	34.18**	214.77**	126.68**	410.73**	6.31**
Error	92	1.55	1.34	9.21	0.05	2.59	0.29	197.37	2.32	6.71	1.93	4.55	0.25

Analysis of variance comprising of parents, hybrids and check

Sources of variation	df	Days to 50% flowering	Days to maturity	Plant height (cm)	Productive tillers/ plant	Ear length (cm)	Ear girth (cm)	Flag leaf area (cm^2)	Peduncle length (cm2	Ear weight/ear (g)	Grain yield/ear (g)	Grain yield /plant (g)	1000 grain weight (g)
Replication	2	0.67	8.69	16.61	0.22	8.83	0.06	67.04	1.52	8.12	2.68	2.08	0.48
Treatments(p+h+c)	47	9.50**	8.95**	205.76**	35.58**	78.71**	7.59**	941.84**	60.25**	393.20**	139.72**	588.37**	13.03**
Error	94	1.55	1.32	8.87	0.05	2.49	0.29	40.5	2.27	6.56	1.89	3.7	0.25

Expt.IIIa : refers to line x tester experiment IIIa
* and ** : indicates significance at 5% and 1 % level respectively

4.3.1.2 Magnitude of heterosis

The mean values of the parents, hybrids and magnitude of heterosis over mid parent, better parent and check are presented for each character separately in tables 16a –16l.

4.3.1.2.1 Days to 50 per cent flowering

The mean parental values ranged from 45.33 (A_1) to 46.67 (A_4), days among the females and from 47.33 (IP-12678) to 50.33 (IP-8730) among the males. Among F_1's the lowest mean value (44.33) was recorded for A_4x IP-9140 and A_5 x IP-873, while the highest (50.00) was for A_4 x IP-10811.

Of the 11 hybrids on each source, five each on A_1 and A_4 and three on A_5 source showed significant negative mid parent (MP) heterosis for earliness. Highly significant negative heterosis over MP (-7.90) was recorded by the cross on A_4 source (A_4 x IP-873).The cross combinations involving pollen parents IP -873 and IP-804 with all the three sources showed significant and negative mid parent heterosis. The mean performance of heterosis on A_5 source was highest (-2.77) followed by A_4 and A_1 sources.

The heterotic effects of crosses for days to 50 per cent flowering over their respective mid parental values ranged from – 7.90 (A_4 x IP-873) to 4.30 (A_1 x IP-8229). Two crosses showed significant mid parent heterosis in the positive direction, while 13 crosses exhibited significant heterosis in the negative direction. The range of heterosis over better parent was from – 2.21 (A_5 x IP-873) to 10.30 (A_4 x IP-10811). Eleven crosses showed significant positive heterosis. None of hybrids recorded heterosis over check in the desired negative direction.

4.3.1.2.2 Days to maturity

The range of variation was quite lower 81.33 (A_1) to 83.33 (A_4) among the testers than among the lines where it was 83.00 (IP-7440) to 87.00 (IP-9140). The maturity period recorded for the hybrids was within the range of 80.67 (A_1x IP-9149, A_1 x IP-873) to 86.33 (A_1x IP-10811).

Among the eleven hybrids on each source, two on A_1, seven on A_4 and two hybrids on A_5 exhibited significant negative heterosis over MP for early maturity. Highly significant and negative mid parent heterosis was observed on A_4 source (A_4 x IP-8229) followed by A_5 (A_5 x IP-10811). The cross combinations involving pollen parents IP 873 and IP-804 showed significant and negative mid parent heterosis on all the three sources. The mean performance of hybrids on A_4 source was highest (-2.55) followed by A_5 (-0.61).

The magnitude of mid parent heterosis was in the range of – 4.91 per cent (A_4 x IP-8229) to 3.39 per cent (A_1 x IP-10811). Of the 33 crosses, 13 showed significant mid parent heterosis, 11 showed heterosis for earliness and the remaining two for lateness in maturity. The range of better parent heterosis varied from – 0.82 (A_1 x IP-9149, A_1 x IP-873, A_4 x IP-8229) to 6.15 per cent (A_4 x IP-8229). Twenty crosses exhibited significant heterosis over check and three crosses viz., A_1 x IP-9149, A_1 x IP-873, A_4 x IP-8229, showed maximum heterosis in negative direction.

4.3.1.2.3 Plant height

The range of variation among the lines was from 171.00 (IP-10811) to 182.43 cm (IP-7440). Though there were only three testers, the range was from 166.53 (A_4) to 172.60 cm (A_5). Between the F_1's, the lowest mean value (168.40 cm) was recorded by A_1 x IP-9140 and the highest (188.00 cm) by A_1 x IP-804.

Six, five and three hybrids each on A_4, A_1 and A_5 sources showed significant positive MP heterosis, respectively. The hybrid (A_4 x IP-7440) on A_4 source recorded positive and significantly higher heterosis followed by A_1 (A_1 x IP-804).The combinations involving pollen parent IP-16179 with A_1 and A_5 source and IP-10085 x A_1 and A_4 sources showed significant positive mid parent heterosis. The mean mid parent heterosis was highest on A_4 (3.29) followed by A_1 (1.9) and A_5 (0.89) sources.

The heterosis over mid parent ranged from – 6.83 (A_5 x IP-8229) to 9.42 per cent (A_5 x IP-9140). As many as 15 crosses showed significant mid parent heterosis in positive direction, while only four crosses exhibited significant heterosis in the negative direction. The range of better parent was from – 7.99 per cent (A_5 x IP-9149) to 6.82 per cent (A_5 x IP-9140).

Table 16a. Mean performance of parents, hybrids, check and magnitude of heterosis for days to 50% flowering (Expt.IIIa).

Crosses	Mean value				F_1 heterosis (%) over		
	Female	Male	F_1	MP	MP	BP	Check
A_1 x IP-9140	45.33	49.33	46.33	47.33	-2.11	2.21	1.46
A_1 x IP-10811	45.33	50.00	45.67	47.67	-4.19*	0.75	0.00
A_1 x IP-16197	45.33	48.67	48.67	47.00	3.55	7.37**	6.57**
A_1 x IP-12678	45.33	47.33	47.67	46.33	2.89	5.16**	4.38**
A_1 x IP-8229	45.33	48.00	48.67	46.67	4.30*	7.37**	6.57**
A_1 x IP-9149	45.33	49.33	45.33	47.33	-4.23*	0.00	-0.73
A_1 x IP-873	45.33	50.33	44.67	47.83	-6.61**	-1.46	-2.19
A_1 x IP-804	45.33	49.33	45.33	47.33	-4.23*	0.00	-0.73
A_1 x IP-577	45.33	50.00	47.33	47.67	-0.70	4.41**	3.65
A_1 x IP-7440	45.33	48.67	44.67	47.00	-4.96**	-1.46	-2.19
A_1 xIP-10085	45.33	48.33	45.33	46.83	-3.20	0.00	-0.73
Mean	45.33	49.03	46.33	47.18	-1.77	2.21	1.46
# crosses with significant desirable heterosis					4	-	-
A_4 x IP-9140	46.67	49.33	44.33	48.00	-7.65**	-2.21	-2.92
A_4 x IP-10811	46.67	50.00	50.00	48.34	3.44	10.30**	9.49**
A_4 x IP-16197	46.67	48.67	49.67	47.67	4.20*	9.57**	8.76**
A_4 x IP-12678	46.67	47.33	47.33	47.00	0.70	4.41**	3.65*
A_4 x IP-8229	46.67	48.00	47.33	47.34	-0.01	4.41**	3.65*
A_4 x IP-9149	46.67	49.33	45.00	48.00	-6.25**	-0.73	-1.46
A_4 x IP-873	46.67	50.33	44.67	48.50	-7.90**	-1.46	-2.19
A_4 x IP-804	46.67	49.33	45.67	48.00	-4.85**	0.75	0.00
A_4 x IP-577	46.67	50.00	47.00	48.34	-2.76	3.68	2.92
A_4 x IP-7440	46.67	48.67	44.67	47.67	-6.29**	-1.46	-2.19
A_1 xIP-10085	46.67	48.33	47.33	47.50	-0.36	4.41*	3.65*
Mean	46.67	49.02	46.63	47.85	-2.52	2.87	2.12
# crosses with significant desirable heterosis					5	-	-
A_5 x IP-9140	45.67	49.33	46.67	47.50	-1.75	2.96	2.19
A_5 x IP-10811	45.67	50.00	46.33	47.84	-3.15	2.21	1.46
A_5 x IP-16197	45.67	48.67	46.67	47.17	-1.06	2.96	2.19
A_5 x IP-12678	45.67	47.33	45.67	46.50	-1.78	0.75	0.00
A_5 x IP-8229	45.67	48.00	45.67	46.84	-2.49	0.75	0.00
A_5 x IP-9149	45.67	49.33	46.00	47.50	-3.16	1.48	0.73
A_5 x IP-873	45.67	50.33	44.33	48.00	-7.65**	-2.21	-2.92
A_5 x IP-804	45.67	49.33	44.67	47.50	-5.96**	-1.46	-2.19
A_5 x IP-577	45.67	50.00	45.33	47.84	-5.24**	0.00	-0.73
A_5 x IP-7440	45.67	48.67	47.67	47.17	1.06	5.16**	4.38**
A_1 xIP-10085	45.67	48.33	47.33	47.00	0.70	4.41**	3.65*
Mean	45.67	49.029	46.03	47.35	-2.77	1.54	0.86
# crosses with significant desirable heterosis					3	-	-
GHB-558 (c)			45.67				
				S.E. (diff.)	0.88	0.71	0.71
				C.D. @ 5 %	1.72	1.47	1.39
				C.D. @ 1%	2.26	1.93	1.83

MP- Mid parent
BP- Better parent
* and ** -indicate significance at 5% and 1% level respectively

Table 16b. Mean performance of parents, hybrids, check and magnitude of heterosis for days to maturity in Pearl millet (Expt.IIIa)

Crosses	Mean value				F1 heterosis (%) over		
	Female	Male	F1	MP	MP	BP	Check
A_1 x IP-9140	81.33	87.00	84.33	84.17	0.20	3.69	0.00
A_1 x IP-10811	81.33	85.67	86.33	83.50	3.39**	6.15**	2.37**
A_1 x IP-16197	81.33	85.33	84.00	83.33	0.80	3.28	-0.40
A_1 x IP-12678	81.33	85.00	84.67	83.17	1.80	4.10	0.40
A_1 x IP-8229	81.33	86.33	84.67	83.83	0.99	4.10	0.40
A_1 x IP-9149	81.33	85.00	80.67	83.17	-3.01**	-0.82**	-4.35**
A_1 x IP-873	81.33	85.33	80.67	83.33	-3.20**	-0.82**	-4.35**
A_1 x IP-804	81.33	85.00	81.67	83.17	-1.80	0.41**	-3.16**
A_1 x IP-577	81.33	85.00	82.00	83.17	-1.40	0.82**	-2.77**
A_1 x IP-7440	81.33	83.00	83.67	82.17	1.83	2.87	-0.79
A_1 xIP-10085	81.33	84.67	84.00	83.00	1.20	3.28**	-0.40
Mean	81.33	85.21	83.33	83.27	0.07	2.46	-1.21
# crosses with significant desirable heterosis					2	2	4
A_4 x IP-9140	83.33	87.00	84.33	85.17	-0.98	3.69**	0.00
A_4 x IP-10811	83.33	85.67	81.00	84.50	-4.14**	-0.41**	-3.95**
A_4 x IP-16197	83.33	85.33	81.33	84.33	-3.56**	0.00	-3.56**
A_4 x IP-12678	83.33	85.00	81.33	84.17	-3.37**	0.00	-3.56**
A_4 x IP-8229	83.33	86.33	80.67	84.83	-4.91**	-0.82*	-4.35**
A_4 x IP-9149	83.33	85.00	84.00	84.17	-0.20	3.28	-0.40
A_4 x IP-873	83.33	85.33	82.67	84.33	-1.98*	1.64*	-1.98*
A_4 x IP-804	83.33	85.00	83.33	84.17	-0.99	2.46	-1.19
A_4 x IP-577	83.33	85.00	81.00	84.17	-3.76**	-0.41	-3.95**
A_4 x IP-7440	83.33	83.00	81.00	83.17	-2.61**	-0.41	-3.95**
A_1 xIP-10085	83.33	84.67	82.67	84.00	-1.59	1.64*	-1.98*
Mean	83.33	85.21	82.12	84.27	-2.55	0.96	-2.62
# crosses with significant $+^{ve}$ heterosis					7	2	8
A_5 x IP-9140	82.67	87.00	84.33	84.83	-0.59	3.69	0.00
A_5 x IP-10811	82.67	85.67	81.00	84.17	-3.76**	-0.41	-3.95**
A_5 x IP-16197	82.67	85.33	81.67	84.00	-2.78**	0.41**	-3.16**
A_5 x IP-12678	82.67	85.00	85.67	83.83	2.19*	5.33**	1.58*
A_5 x IP-8229	82.67	86.33	84.67	84.50	0.20	4.10	0.40
A_5 x IP-9149	82.67	85.00	84.67	83.83	0.99	4.10	0.40
A_5 x IP-873	82.67	85.33	82.67	84.00	-1.59	1.64*	-1.98*
A_5 x IP-804	82.67	85.00	84.00	83.83	0.20	3.28	-0.40
A_5 x IP-577	82.67	85.00	83.00	83.83	-0.99	2.05*	-1.58*
A_5 x IP-7440	82.67	83.00	83.00	82.83	0.20	2.05*	-1.58*
A_1 xIP-10085	82.67	84.67	83.00	83.67	-0.80	2.05*	-1.58*
Mean	82.67	85.21	83.43	83.94	-0.61	2.57	-1.07
# crosses with significant desirable heterosis					2	-	6
GHB-558 (c)		84.33					
				S.E. ±	0.81	0.66	0.66
				C.D. @ 5 %	1.60	1.29	1.29
				C.D. @ 1%	2.10	1.70	1.70

MP- Mid parent, BP- Better parent , * and ** -indicate significance at 5% and 1% level respectively

Table 16c.Mean performance of parents, hybrids, check and magnitude of heterosis for plant height (cm) in Pearl millet Expt.IIIa)

Crosses	Mean value				F_1 heterosis (%) over		
	Female	Male	F_1	MP	MP	BP	Check
A_1 x IP-9140	172.43	172.00	168.40	172.22	-2.22	-4.59**	-7.47*
A_1 x IP-10811	172.43	171.00	171.57	171.72	-0.09	-2.80**	-5.73**
A_1 x IP-16197	172.43	176.17	181.47	174.30	4.11**	2.81**	-0.29
A_1 x IP-12678	172.43	181.60	171.63	177.02	-3.04*	-2.76**	-5.70
A_1 x IP-8229	172.43	176.50	178.50	174.47	2.31	1.13**	-1.92
A_1 x IP-9149	172.43	176.00	169.13	174.22	-2.92*	-4.17	-7.07**
A_1 x IP-873	172.43	176.33	183.10	174.38	5.00**	3.74	0.60**
A_1 x IP-804	172.43	178.33	188.00	175.38	7.19**	6.52	3.30**
A_1 x IP-577	172.43	178.67	183.67	175.55	4.62**	4.06	0.92**
A_1 x IP-7440	172.43	182.43	177.53	177.43	0.06	0.59**	-2.45
A_1 xIP-10085	172.43	171.67	182.17	172.05	5.88**	3.21**	0.09
Mean	172.43	176.43	177.74	174.43	1.90	0.70	-2.36
# crosses with significant desirable heterosis					5	4	3
A_4 x IP-9140	166.53	172.00	176.47	169.27	4.25**	-0.02**	-3.04
A_4 x IP-10811	166.53	171.00	184.17	168.77	9.13**	4.34	1.19**
A_4 x IP-16197	166.53	176.17	173.17	171.35	1.06	-1.89	-4.85**
A_4 x IP-12678	166.53	181.60	179.00	174.07	2.83**	1.42	-1.65**
A_4 x IP-8229	166.53	176.50	171.77	171.52	0.15	-2.68	-5.62**
A_4 x IP-9149	166.53	176.00	180.67	171.27	5.49**	2.36**	-0.73
A_4 x IP-873	166.53	176.33	170.33	171.43	-0.64	-3.49*	-6.41*
A_4 x IP-804	166.53	178.33	172.87	172.43	0.25	-2.06**	-5.02
A_4 x IP-577	166.53	178.67	171.07	172.60	-0.89	-3.08	-6.01***
A_4 x IP-7440	166.53	182.43	188.43	174.48	8.00**	6.76	3.53**
A_1 xIP-10085	166.53	171.67	180.27	169.10	6.60**	2.13*	-0.95*
Mean	166.53	176.43	177.11	171.48	3.29	0.34	-2.68
# crosses with significant desirable heterosis					6	2	2
A_5 x IP-9140	172.60	172.00	188.53	172.30	9.42**	6.82**	3.59
A_5 x IP-10811	172.60	171.00	173.93	171.80	1.24	-1.45	-4.43**
A_5 x IP-16197	172.60	176.17	190.10	174.38	9.01**	7.71	4.45**
A_5 x IP-12678	172.60	181.60	168.50	177.10	-4.86**	-4.53	-7.42**
A_5 x IP-8229	172.60	176.50	174.20	174.55	-0.20	-1.30**	-4.29**
A_5 x IP-9149	172.60	176.00	162.40	174.30	-6.83**	-7.99**	-10.77**
A_5 x IP-873	172.60	176.33	178.90	174.47	2.54*	1.36**	-1.70
A_5 x IP-804	172.60	178.33	178.83	175.47	1.92	1.32*	-1.74
A_5 x IP-577	172.60	178.67	178.40	175.63	1.58	1.08**	-1.98*
A_5 x IP-7440	172.60	182.43	170.17	177.52	-4.14**	-3.59*	-6.50**
A_1 xIP-10085	172.60	171.67	172.30	172.13	0.10	-2.38*	-5.33**
Mean	172.60	176.43	176.02	174.51	0.89	-0.26	-3.28
# crosses with significant desirable heterosis					3	4	1
GHB-558 (c)			182.00				
			S.E.±		2.14	1.75	1.71
			C.D. @ 5 %		4.19	3.43	3.35
			C.D. @ 1%		5.51	4.50	4.40

MP- Mid parent

BP- Better parent

* and ** -indicate significance at 5% and 1% level respectively

The maximum heterosis over standard check was manifested by the cross A_5 x IP-16197 (4.45 %).

4.3.1.2.4 Productive tillers per plant

Variation for this character among the testers ranged from 2.67 to 2.80, while among the lines it ranged from 2.13 to 2.80. The hybrids also exhibited similar range of variation (2.07 to 3.40).

Of the 11 hybrids on each source, one on A_1, four on A_4 and nine on A_5 source showed significant and positive mid parent heterosis.Highly significant positive heterosis was observed on A_5 (A_5x IP-577) followed by A_4 source (A_4 xIP-7440).The parental combinations viz., A_4/A_5 x IP-10085 and A_1/A_4 x IP-577 showed significant positive mid heterosis. The mean heterosis of hybrids on A_5 (18.5) source was highest followed by A_4 (5.99) and A_1(-1.78).

The range of positive mid parent heterosis was from 12.05 (A_4 x IP-804) to 41.67 per cent (A_5 x IP-577). Thirteen hybrids showed significant positive heterosis over their mid parent values. As regards better parent heterosis, fourteen hybrids exhibited significant heterosis in positive direction. The highest heterosis was manifested by the cross A_5 x IP-577 (27.5%). Ten crosses registered significant positive heterosis over standard check.

4.3.1.2.5 Ear length

From the table 20e it can be seen that the mean values of females ranged from 20.60 to 21.93 cm. Among the males, the range was from 20.27 (IP-9149) to 24.60 cm (IP-8229). The ability of F_1's to produce lengthiest ear head was from 20.17 (A_5 x IP-873) to 31.5 cm (A_4 x IP-12678).

Among the 11 hybrids on each source, six on A_1, 9 on A_4 and 8 on A_5 exhibited significant and positive mid parent heterosis. Highly significant positive mid parent heterosis observed on A_5 source (A_5 x IP-10085) followed by A_1 (A_1 x IP-10085).The combinations involving pollen parents viz., IP-10085, IP-12678, IP-804 showed significant and positive mid parent heterosis on all the three sources. The mean mid parent heterosis of hybrid on A_4 (25.54) was highest followed by A_5 (14.92) and A_1 (14.06) sources.

As many as 23 hybrids exhibited significant mid parent heterosis in the positive direction and the range was from –7.65 to 45.54 per cent. The maximum heterosis over better parent was recorded by A_4 X IP-12678 (36.71 per cent). Highly significant and positive heterosis values over check were recorded by A_4 x IP-12678 (29.95%), A_5 x IP-7440 (24.86%) and A_4 x IP-8229 (24.18%).

4.3.1.2.6 Ear girth

The three testers A_4, A_5 and A_1 recorded the mean ear girth of 8.70, 8.93 and 8.95 cm respectively. The mean values among lines fell in between 8.10 cm to 9.85 cm. Comparison of heterosis among the hybrids revealed a greater range of variation (8.0 to 11.0 cm).

Out of 33 hybrids on three different sources, eight on A_1, five on A_4 and two on A_5 showed significant positive mid parent heterosis.Highly significant positive heterosis was observed on A_5 source (A_5 x IP-12678) followed by A_4 (A_4 x IP-12678). The crosses involving pollen parents IP- 9140 and IP- 10811 showed significant positive mid parent heterosis on A_1 and A_4 sources. The mean mid parent heterosis of hybrids on A_1 source was highest (12.83) followed by A_4 (8.07) and A_5 (2.12).

Twenty-one crosses exhibited significant heterosis over mid parent values. The range was from –12.09 (A_5 x IP-10085) to 23.59 per cent (A_5 x IP-12678). Nineteen crosses recorded significant heterosis over better parent. The range was from –6.51 (A_4 x IP-10085) to 26.44 per cent (A_1 x IP-873). Eighteen hybrids showed significant heterosis over check, fourteen of them carried positive values. The highest positive heterosis was recorded by the cross A_1 x IP-873 (20.88%).

Table 16d. Mean performance of parents, hybrids, check and magnitude of heterosis ofr productive tillers/plant in pearl millet (Expt.IIIa)

Crosses	Mean value				F_1 heterosis (%) over		
	Female	Male	F_1	MP	MP	BP	Check
A_1 x IP-9140	2.80	2.53	2.73	2.67	2.50	2.50	-2.38
A_1 x IP-10811	2.80	2.60	2.53	2.70	-6.17	-5.00	-9.52*
A_1 x IP-16197	2.80	2.63	2.67	2.72	-1.84	0.00	-4.76
A_1 x IP-12678	2.80	2.70	2.80	2.75	1.82	5.00	0.00
A_1 x IP-8229	2.80	2.57	2.80	2.68	4.35	5.00	0.00
A_1 x IP-9149	2.80	2.10	2.73	2.45	11.56	2.50	-2.38
A_1 x IP-873	2.80	2.60	2.20	2.70	-18.52**	-17.50**	-21.43**
A_1 x IP-804	2.80	2.80	2.47	2.80	-11.90*	-7.50	-11.90**
A_1 x IP-577	2.80	2.13	2.83	2.47	14.86*	6.25	1.19
A_1 x IP-7440	2.80	2.60	2.33	2.70	-13.58*	-12.50**	-16.67**
A_1 xIP-10085	2.80	2.13	2.40	2.47	-2.70	-10.00*	-14.29**
Mean	2.80	2.49	2.59	2.65	-1.78	-2.84	-4.56
# crosses with significant desirable heterosis					-	-	-
A_4 x IP-9140	2.73	2.53	2.83	2.63	7.59	6.25	1.19
A_4 x IP-10811	2.73	2.60	2.93	2.67	10.00	10.00**	4.76
A_4 x IP-16197	2.73	2.63	2.67	2.68	-0.62	0.00	-4.76
A_4 x IP-12678	2.73	2.70	2.53	2.72	-6.75	-5.00	-9.52**
A_4 x IP-8229	2.73	2.57	2.07	2.65	-22.01**	-22.50**	-26.19**
A_4 x IP-9149	2.73	2.10	2.33	2.42	-3.45	-12.50**	-16.67**
A_4 x IP-873	2.73	2.60	3.03	2.67	13.75*	13.75**	8.33*
A_4 x IP-804	2.73	2.80	3.10	2.77	12.05*	16.25***	10.71**
A_4 x IP-577	2.73	2.13	2.73	2.43	12.33	2.50	-2.38
A_4 x IP-7440	2.73	2.60	3.27	2.67	22.50**	22.50**	16.67**
A_1 xIP-10085	2.73	2.13	2.93	2.43	20.55**	10.00*	4.76
Mean	2.73	2.49	2.77	2.61	5.99	3.75	-1.19
# crosses with significant desirable heterosis					4	5	3
A_5 x IP-9140	2.67	2.53	3.07	2.60	17.95**	15.00**	9.52*
A_5 x IP-10811	2.67	2.60	3.00	2.63	13.92*	12.50**	7.14
A_5 x IP-16197	2.67	2.63	2.93	2.65	10.69	10.00*	4.76
A_5 x IP-12678	2.67	2.70	3.03	2.68	13.04*	13.75**	8.33*
A_5 x IP-8229	2.67	2.57	3.07	2.62	17.20**	15.00**	9.52*
A_5 x IP-9149	2.67	2.10	3.07	2.38	28.67**	15.00**	9.52*
A_5 x IP-873	2.67	2.60	3.07	2.63	16.46**	15.00**	9.52*
A_5 x IP-804	2.67	2.80	3.27	2.73	19.51**	22.50**	16.67**
A_5 x IP-577	2.67	2.13	3.40	2.40	41.67**	27.50**	21.43**
A_5 x IP-7440	2.67	2.60	2.80	2.63	6.33	5.00	0.00
A_1 xIP-10085	2.67	2.13	2.83	2.40	18.06**	6.25	1.19
Mean	2.67	2.49	3.05	2.58	18.50	14.31	8.84
# crosses with significant desirable heterosis					9	9	7
GHB-558 (c)			2.57				
				S.E. ±	0.15	0.12	0.12
				C.D. @ 5 %	0.29	0.23	0.23
				C.D. @ 1%	0.38	0.30	0.30

MP- Mid parent, BP- Better parent

Table 16e. Mean performance of parents, hybrids, check and magnitude of heterosis for ear length (cm) in pearl millet (Expt.IIIa)

Crosses	Mean value				F_1 heterosis (%) over		
	Female	Male	F_1	MP	MP	BP	Check
A_1 x IP-9140	21.13	22.33	20.53	21.73	-5.52	-10.98**	-15.38**
A_1 x IP-10811	21.13	22.50	26.53	21.82	21.62**	15.03**	9.34*
A_1 x IP-16197	21.13	22.13	25.23	21.63	16.64**	9.39*	3.98
A_1 x IP-12678	21.13	23.07	29.57	22.10	33.79**	28.18**	21.84**
A_1 x IP-8229	21.13	24.60	20.87	22.87	-8.75	-9.54*	-14.01**
A_1 x IP-9149	21.13	20.27	22.73	20.70	9.82	-1.45	-6.32
A_1 x IP-873	21.13	21.80	21.70	21.47	1.09	-5.92	-10.58**
A_1 x IP-804	21.13	22.67	24.40	21.90	11.42*	5.78	0.55
A_1 x IP-577	21.13	23.33	20.53	22.23	-7.65	-10.98**	-15.38**
A_1 x IP-7440	21.13	22.73	30.10	21.93	37.23**	30.49**	24.04**
A_1 xIP-10085	21.13	20.53	30.20	20.83	44.96**	30.92**	24.45**
Mean	21.13	22.36	24.76	21.75	14.06	6.83	2.04
# crosses with significant desirable heterosis					6	5	4
A_4 x IP-9140	20.80	22.33	28.93	21.57	34.16**	25.43**	19.23**
A_4 x IP-10811	20.80	22.50	24.20	21.65	11.78*	4.91	-0.27
A_4 x IP-16197	20.80	22.13	28.83	21.47	34.32**	25.00**	18.82**
A_4 x IP-12678	20.80	23.07	31.53	21.93	43.77**	36.71**	29.95**
A_4 x IP-8229	20.80	24.60	30.13	22.70	32.75**	30.64**	24.18**
A_4 x IP-9149	20.80	20.27	27.87	20.53	35.71**	20.81**	14.84**
A_4 x IP-873	20.80	21.80	26.53	21.30	24.57**	15.03**	9.34*
A_4 x IP-804	20.80	22.67	29.63	21.73	36.35**	28.47**	22.12**
A_4 x IP-577	20.80	23.33	20.67	22.07	-6.34	-10.40**	-14.84**
A_4 x IP-7440	20.80	22.73	23.83	21.77	9.49	3.32	-1.79
A_1 xIP-10085	20.80	20.53	26.27	20.67	27.10**	13.87**	8.24*
Mean	20.80	22.36	27.13	21.58	25.79	24.00	11.40
# crosses with significant desirable heterosis					9	8	8
A_5 x IP-9140	20.60	22.33	29.23	21.47	36.18**	26.73**	20.47**
A_5 x IP-10811	20.60	22.50	20.93	21.55	-2.86	-9.25*	-13.74**
A_5 x IP-16197	20.60	22.13	21.53	21.37	0.78	-6.65	-11.26*
A_5 x IP-12678	20.60	23.07	29.87	21.83	36.79**	29.48**	23.08**
A_5 x IP-8229	20.60	24.60	28.47	22.60	25.96**	23.41**	17.31**
A_5 x IP-9149	20.60	20.27	25.10	20.43	22.84**	8.82*	3.43
A_5 x IP-873	20.60	21.80	20.17	21.20	-4.87	-12.57**	-16.90**
A_5 x IP-804	20.60	22.67	26.87	21.63	24.19**	16.47**	10.71**
A_5 x IP-577	20.60	23.33	29.20	21.97	32.93**	26.59**	20.33**
A_5 x IP-7440	20.60	22.73	30.30	21.67	39.85**	31.36**	24.86**
A_1 xIP-10085	20.60	20.53	29.93	20.57	45.54**	29.77**	23.35**
Mean	20.60	22.36	26.51	21.48	14.92	14.90	9.21
# crosses with significant desirable heterosis					8	8	7
GHB-558 (c)		24.17					
				S.E.±	1.13	0.92	0.91
				C.D.@ 5%	2.21	1.8	1.78
				C.D. @ %	2.91	2.36	2.34

MP- Mid parent

BP- Better parent

* and ** -indicate significance at 5% and 1% level respectively

Table 16f. Mean performance of parents, hybrids, check and magnitude of heterosis for ear girth (cm) in pearl millet (Expt.IIIa)

Crosses	Mean value				F_1 heterosis (%) over		
	Female	Male	F_1	MP	MP	BP	Check
A_1 x IP-9140	8.93	8.90	10.40	8.92	16.64**	19.54**	14.29**
A_1 x IP-10811	8.93	9.80	10.50	9.37	12.10**	20.69**	15.38**
A_1 x IP-16197	8.93	8.93	10.80	8.93	20.90**	24.14**	18.68**
A_1 x IP-12678	8.93	8.17	9.50	8.55	11.11*	9.20**	4.40
A_1 x IP-8229	8.93	9.23	9.27	9.08	2.02	6.51	1.83
A_1 x IP-9149	8.93	9.07	10.57	9.00	17.41**	21.46**	16.12**
A_1 x IP-873	8.93	9.83	11.00	9.38	17.23**	26.44**	20.88**
A_1 x IP-804	8.93	8.53	9.83	8.73	12.60**	13.03**	8.06*
A_1 x IP-577	8.93	8.80	9.07	8.87	2.26	4.21	-0.37
A_1 x IP-7440	8.93	8.20	9.57	8.57	11.67**	9.96**	5.13
A_1 xIP-10085	8.93	9.27	10.67	9.10	17.22**	22.61**	17.22**
Mean	8.93	8.98	10.11	8.95	12.83	16.16	9.50
# crosses with significant desirable heterosis					9	9	7
A_4 x IP-9140	8.70	8.90	10.73	8.80	21.97**	23.37**	17.95**
A_4 x IP-10811	8.70	9.80	10.53	9.25	13.87**	21.07**	15.75**
A_4 x IP-16197	8.70	8.93	9.00	8.82	2.08	3.45	-1.10
A_4 x IP-12678	8.70	8.17	10.30	8.43	22.13**	18.39**	13.19**
A_4 x IP-8229	8.70	9.23	10.17	8.97	13.38**	16.86**	11.72**
A_4 x IP-9149	8.70	9.07	10.73	8.88	20.83**	23.37**	17.95**
A_4 x IP-873	8.70	9.83	8.30	9.27	-10.43*	-4.60	-8.79**
A_4 x IP-804	8.70	8.53	8.80	8.62	2.13	1.15	-3.30
A_4 x IP-577	8.70	8.80	9.50	8.75	8.57*	9.20**	4.40
A_4 x IP-7440	8.70	8.20	8.77	8.45	3.75	0.77	-3.66
A_1 xIP-10085	8.70	9.27	8.13	8.98	-9.46*	-6.51	-10.62**
Mean	8.70	8.98	9.54	8.84	8.07	9.77	4.46
# crosses with significant desirable heterosis					6	6	5
A_5 x IP-9140	8.93	8.90	8.53	8.92	-4.30	-1.92	-6.23
A_5 x IP-10811	8.93	9.80	9.07	9.37	-3.20	4.21	-0.37
A_5 x IP-16197	8.93	8.93	9.23	8.93	3.36	6.13	1.47
A_5 x IP-12678	8.93	8.17	10.57	8.55	23.59**	21.46**	16.12**
A_5 x IP-8229	8.93	9.23	8.93	9.08	-1.65	2.68	-1.83
A_5 x IP-9149	8.93	9.07	8.50	9.00	-5.56	-2.30	-6.59*
A_5 x IP-873	8.93	9.83	8.73	9.38	-6.93	0.38	-4.03
A_5 x IP-804	8.93	8.53	9.17	8.73	4.96	5.36	0.73
A_5 x IP-577	8.93	8.80	10.17	8.87	14.66**	16.86*	11.72**
A_5 x IP-7440	8.93	8.20	9.47	8.57	10.51*	8.81*	4.03
A_1 xIP-10085	8.93	9.27	8.00	9.10	-12.09**	-8.05*	-12.09*
Mean	8.93	8.98	9.12	8.95	2.12	4.87	0.20
# crosses with significant desirable heterosis					3	3	2
GHB-558 (c)		8.83					
				S.E. ±	0.38	0.31	0.31
				C.D. @ 5 %	0.74	0.60	0.60
				C.D. 1%	0.98	0.79	0.79

MP- Mid parent, BP- Better parent , * and ** -indicate significance at 5% and 1% level respectively

4.3.1.2.7 Flag leaf area

The range of values of three females was from 54.97 to 75.07 cm^2. Among the males, three had the highest flag leaf area of 97.20 cm^2 and five possessed the lowest flag leaf area of 80.53 cm^2. The mean value of hybrids was in the range of 40.80 to 111.90 cm^2.

None of the hybrids except two on A_5 source exhibited significant positive mid parent heterosis. Highly significant positive mid parent heterosis was observed on A_5 (A_5 x IP-10811). The crosses involving pollen parents IP-10811 and IP-873 showed significant heterosis on A_5 source. The mean heterosis of hybrids on A_4 source was highest (6.07) followed by A_1 (5.72) and A_5 (0.15).

The percentage of heterosis over mid parent ranged from –45.06 (A_5 x IP-10811) to 41.92 per cent (A_5 x IP-873) and was significant in four hybrids and only two hybrids exhibited significant positive heterosis. Sixteen crosses showed significant negative heterosis and the range was from –58.02 to 15.12 per cent. The crosses A_5 x IP-873 (56.28%), A_1 x IP-7440 (37.10%) A_5 x IP-9149 (37.06%) recorded highly significant positive heterosis over standard check.

4.3.1.2.8 Peduncle length

Peduncle length of females ranged from 20.77 (A_5) to 21.53 cm (A_1). The range of variation among males was from 16.57 (IP-873) to 23.27cm (IP-7440). Hybrids were in the range of 17.27 (A_1 x IP-10085) to 30.27cm (A_5 x IP-804)

Four hybrids each on A_1 and A_4 sources and seven on A_5 recorded significant positive mid parent heterosis. Highest mid parent heterosis was noticed on A_5 (A_5 x IP-804) followed by A_4 (A_4 x IP-873). The hybrids involving pollen parents IP-16197, IP-12678 showed significant positive heterosis on all the three sources. The mean heterosis of hybrids on A_5 was highest (18.73) followed by A_4(10.3) and A_1(2.16) sources.

The range of mid parent heterosis varied from –18.30 per cent (A_1 x IP-10085) to 43.90 per cent (A_5 x IP-804). Fifteen hybrids showed significant positive heterosis.

The range of better parent heterosis was from – 21.04 (A_1 x IP-10085) to 38.41 per cent (A_5 x IP-804). Among the 25 hybrids that showed significant heterosis over standard check, seven hybrids recorded positive values, while 18 deviated in negative direction. The maximum peduncle length over check was observed in the hybrid A_5 x IP-804.

4.3.1.2.9 Ear weight

Narrow range of variation was observed among the testers (33.50 to 34.87 g). In case of lines, the entry IP-804 had the least (34.17 g), while the line IP-10811 had the maximum (44.23 g) ear head weight. Among the hybrids, A_1 x IP-9140 (31.17 g) and A_4 x IP-16197 (62.90 g) recorded minimum and maximum ear head weight respectively.

Among the 11 hybrids on each source, nine on A_1, eleven on A_4 and ten on A_5 source exhibited significant positive mid parent heterosis. Highly significant positive heterosis was recorded on A_4 source (A_4 x IP-873) followed by A_5 (A_5 x IP-804). The mean heterosis of hybrids on A_4 was highest (48.61) followed by A_5 (40.55) and A_1 (30.15).

Per cent heterosis over mid parent values in case of hybrids varied from –11.67 (A_1 x IP-9140) to 81.68 per cent (A_4 x IP-873). Thirty hybrids showed significant positive mid parent heterosis. Significant positive better parent heterosis was observed in thirty crosses and the range was from –15.84 (A_1 x IP-9140) to 69.94 per cent (A_4 x IP-16197). Although twenty-eight crosses exhibited significant heterosis over check, seventeen crosses registered significant positive values. Maximum significant positive heterosis was recorded by the cross A_5 x IP-16197 (32.31 %).

4.3.1.2.10 Grain yield per ear

The mean values of lines ranged from 20.43 (IP-9149) to 26.77g (IP-9140). Three testers possessed mean values of 21.07 (A_1), 21.07 (A_4) and 20.33 (A_5). The performance of F_1's with respect to the grain yield per ear head ranged from 18.0 (A_5 x IP-8229) to 39.77 g (A_4 x IP-16197).

Table 16g. Mean performance of parents, hybrids, check and magnitude of heterosis for flag leaf area (cm^2) in Pearl millet (Expt.IIIa)

Crosses	Mean value				F_1 heterosis (%) over		
	Female	Male	F_1	MP	MP	BP	Check
A_1 x IP-9140	75.07	86.20	88.77	80.63	10.09	-8.68	23.98**
A_1 x IP-10811	75.07	81.33	89.23	78.20	14.11	-8.20	24.63**
A_1 x IP-16197	75.07	97.20	71.80	86.13	-16.64	-26.13**	0.28
A_1 x IP-12678	75.07	91.37	75.93	83.22	-8.75	-21.88**	6.05
A_1 x IP-8229	75.07	80.53	87.27	77.80	12.17	-10.22	21.88**
A_1 x IP-9149	75.07	87.17	83.20	81.12	2.57	-14.40	16.20**
A_1 x IP-873	75.07	90.50	92.13	82.78	11.29	-5.21	28.68**
A_1 x IP-804	75.07	96.00	88.47	85.53	3.43	-8.98	23.56**
A_1 x IP-577	75.07	88.17	88.13	81.62	7.98	-9.33	23.09**
A_1 x IP-7440	75.07	83.00	98.17	79.03	24.21	0.99	37.10**
A_1 xIP-10085	75.07	88.50	83.80	81.78	2.47	-13.79	17.04*
Mean	75.07	88.18	86.08	81.62	5.72	11.42	20.22
# crosses with significant desirable heterosis					-	-	9
A_4 x IP-9140	54.97	86.20	69.53	70.58	-1.49	-28.46**	-2.89
A_4 x IP-10811	54.97	81.33	71.77	68.15	5.31	-26.17**	0.23
A_4 x IP-16197	54.97	97.20	81.20	76.08	6.73	-16.46*	13.41
A_4 x IP-12678	54.97	91.37	69.00	73.17	-5.69	-29.01**	-3.63
A_4 x IP-8229	54.97	80.53	79.51	67.75	17.36	-18.20*	11.05*
A_4 x IP-9149	54.97	87.17	83.13	71.07	16.98	-14.47	16.11**
A_4 x IP-873	54.97	90.50	78.40	72.73	7.79	-19.34*	9.50
A_4 x IP-804	54.97	96.00	67.23	75.48	-10.93	-30.83**	-6.10
A_4 x IP-577	54.97	88.17	90.23	71.57	26.08	-7.17	26.02**
A_4 x IP-7440	54.97	83.00	87.53	68.98	26.89	-9.95	22.25**
A_1 xIP-10085	54.97	88.50	55.80	71.73	-22.21	-42.59**	-22.07**
Mean	54.97	88.18	75.76	71.57	6.07	-22.05	10.15
# crosses with significant desirable heterosis					-	-	4
A_5 x IP-9140	67.20	86.20	52.00	76.70	-32.20*	-46.50**	-27.37**
A_5 x IP-10811	67.20	81.33	40.80	74.27	-45.06**	-58.02**	-43.02**
A_5 x IP-16197	67.20	97.20	70.47	82.20	-14.27	-27.50**	-1.58**
A_5 x IP-12678	67.20	91.37	71.83	79.28	-9.40	-26.10**	0.33
A_5 x IP-8229	67.20	80.53	87.87	73.87	18.95	-9.60	22.72**
A_5 x IP-9149	67.20	87.17	98.13	77.18	27.14*	0.96	37.06**
A_5 x IP-873	67.20	90.50	111.90	78.85	41.92**	15.12	56.28**
A_5 x IP-804	67.20	96.00	92.53	81.60	13.40	-4.80	29.24**
A_5 x IP-577	67.20	88.17	87.50	77.68	12.64	-9.98	22.21**
A_5 x IP-7440	67.20	83.00	63.47	75.10	-15.49	-34.71**	-11.36*
A_1 xIP-10085	67.20	88.50	81.00	77.85	4.05	-16.67*	13.13*
Mean	67.20	88.18	77.95	77.69	0.15	-17.39	8.87
# crosses with significant desirable heterosis					2	-	6
GHB-558 (c)			74.80				
				S.E. ±	9.93	8.11	3.67
				C.D.@5%	19.47	15.89	7.19
				C.D.@ 1%	25.58	20.89	9.45

MP- Mid parent, BP- Better parent , * and ** -indicate significance at 5% and 1% level respectively

Table16h. Mean performance of parents, hybrids, check and magnitude of heterosis for peduncle length (cm) in pearl millet (Expt.IIIa)

Crosses	Mean value				F_1 heterosis (%) over		
	Female	Male	F_1	MP	MP	BP	Check
A_1 x IP-9140	21.53	21.87	22.77	21.70	4.92	4.12	-6.69
A_1 x IP-10811	21.53	22.97	20.70	22.25	-6.97	-5.34	-15.16**
A_1 x IP-16197	21.53	20.27	23.87	20.90	14.19**	9.15*	-2.19
A_1 x IP-12678	21.53	20.33	25.70	20.93	22.77*	17.53**	5.33
A_1 x IP-8229	21.53	21.70	19.80	21.62	-8.40	-9.45*	-18.85**
A_1 x IP-9149	21.53	18.13	22.10	19.83	11.43*	1.07	-9.43**
A_1 x IP-873	21.53	16.57	21.00	19.05	10.24	-3.96	-13.93**
A_1 x IP-804	21.53	21.30	23.63	21.42	10.35*	8.08*	-3.14
A_1 x IP-577	21.53	21.23	19.60	21.38	-8.34	-10.37**	-19.67**
A_1 x IP-7440	21.53	23.27	20.60	22.40	-8.04	-5.79**	-15.57**
A_1 xIP-10085	21.53	20.73	17.27	21.13	-18.30**	-21.04**	-29.23**
Mean	21.53	20.76	21.55	21.15	2.16	-1.45	-11.68
# crosses with significant desirable heterosis					4	3	-
A_4 x IP-9140	21.07	21.87	21.23	21.47	-1.09	-2.90	-12.98**
A_4 x IP-10811	21.07	22.97	22.93	22.02	4.16	4.88	-6.01
A_4 x IP-16197	21.07	20.27	23.60	20.67	14.19**	7.93*	-3.28
A_4 x IP-12678	21.07	20.33	23.07	20.70	11.43*	5.49	-5.46
A_4 x IP-8229	21.07	21.70	22.03	21.38	3.04	0.76	-9.70**
A_4 x IP-9149	21.07	18.13	21.30	19.60	8.67	-2.59	-12.70**
A_4 x IP-873	21.07	16.57	26.80	18.82	42.43**	22.56**	9.84**
A_4 x IP-804	21.07	21.30	20.33	21.18	-4.01	-7.01	-16.67**
A_4 x IP-577	21.07	21.23	22.13	21.15	4.65	1.22	-9.29**
A_4 x IP-7440	21.07	23.27	28.73	22.17	29.62**	31.40	17.76**
A_1 xIP-10085	21.07	20.73	21.07	20.90	0.80	-3.66	-13.66**
Mean	21.07	20.76	23.02	20.91	10.35	5.28	-4.65
# crosses with significant desirable heterosis					4	2	1
A_5 x IP-9140	20.77	21.87	19.23	21.32	-9.7	-12.04**	-21.17**
A_5 x IP-10811	20.77	22.97	29.97	21.87	37.04**	37.04**	22.81**
A_5 x IP-16197	20.77	20.27	27.13	20.52	32.25**	24.09**	11.20**
A_5 x IP-12678	20.77	20.33	29.40	20.55	43.07**	34.45**	20.49**
A_5 x IP-8229	20.77	21.70	21.00	21.23	-1.10	-3.96	-13.93**
A_5 x IP-9149	20.77	18.13	22.03	19.45	13.28*	0.76	-9.70**
A_5 x IP-873	20.77	16.57	22.33	18.67	19.64**	2.13	-8.47**
A_5 x IP-804	20.77	21.30	30.27	21.03	43.90**	38.41**	24.04**
A_5 x IP-577	20.77	21.23	28.33	21.00	34.92**	29.57**	16.12**
A_5 x IP-7440	20.77	23.27	20.13	22.02	-8.55	-7.93*	-17.49**
A_1 xIP-10085	20.77	20.73	21.03	20.75	1.37	-3.81	-13.80**
Mean	20.77	20.76	24.62	20.76	18.73	12.61	10.08
# crosses with significant desirable heterosis					7	5	3
GHB-558 (c)			23.77				
				S.E. ±	1.07	0.87	0.86
				C.D. @ 5 %	2.10	1.70	1.68
				C.D. @ 1%	2.75	2.24	2.21

MP- Mid parent

BP- Better parent

* and ** -indicate significance at 5% and 1% level respectively

Table 16i. Mean performance of parents, hybrids, check and magnitude of heterosis for ear weight /ear (g) in Pearl millet (Expt.IIIa)

Crosses	Mean value				F_1 heterosis (%) over		
	Female	Male	F_1	MP	MP	BP	Check
A_1 x IP-9140	33.90	36.67	31.17	35.28	-11.67*	-15.84**	-34.48**
A_1 x IP-10811	33.90	44.23	41.60	39.07	6.48	12.33**	-12.54**
A_1 x IP-16197	33.90	37.03	40.47	35.47	14.10**	9.27**	-14.93**
A_1 x IP-12678	33.90	36.80	51.83	35.35	46.63**	39.96**	8.97**
A_1 x IP-8229	33.90	35.37	52.80	34.63	52.45**	42.57**	11.00**
A_1 x IP-9149	33.90	36.90	48.43	35.40	36.82**	30.78**	1.82
A_1 x IP-873	33.90	35.27	39.63	34.58	14.60**	7.02	-16.68**
A_1 x IP-804	33.90	34.17	41.47	34.03	21.84**	11.97**	-12.82**
A_1 x IP-577	33.90	36.37	52.33	35.13	48.96**	41.31**	10.02**
A_1 x IP-7440	33.90	38.17	59.83	36.03	66.05**	61.57**	25.79**
A_1 xIP-10085	33.90	38.17	48.77	36.03	35.34**	31.68**	2.52
Mean	33.90	37.20	46.21	35.55	30.15	24.78	-2.84
# crosses with significant desirable heterosis					9	9	4
A_4 x IP-9140	33.50	36.67	60.17	35.08	71.50**	62.47**	26.49**
A_4 x IP-10811	33.50	44.23	57.80	38.87	48.71**	56.08**	21.51**
A_4 x IP-16197	33.50	37.03	62.93	35.27	78.45**	69.94**	32.31**
A_4 x IP-12678	33.50	36.80	42.53	35.15	21.01**	14.85**	-10.58**
A_4 x IP-8229	33.50	35.37	51.53	34.43	49.66**	39.15**	8.34**
A_4 x IP-9149	33.50	36.90	52.07	35.20	47.92**	40.59**	9.46**
A_4 x IP-873	33.50	35.27	62.47	34.38	81.68**	68.68**	31.32**
A_4 x IP-804	33.50	34.17	42.73	33.83	26.31**	15.39**	-10.16**
A_4 x IP-577	33.50	36.37	54.00	34.93	54.58**	45.81**	13.52**
A_4 x IP-7440	33.50	38.17	40.63	35.83	13.40**	9.72*	-14.58**
A_1 xIP-10085	33.50	38.17	50.70	35.83	41.49**	36.90**	6.59
Mean	33.50	37.20	52.51	35.35	48.61	41.78	10.38
# crosses with significant desirable heterosis					11	11	7
A_5 x IP-9140	34.87	36.67	41.07	35.77	14.82**	10.89**	-13.67**
A_5 x IP-10811	34.87	44.23	47.77	39.55	20.78**	28.98**	0.42
A_5 x IP-16197	34.87	37.03	56.27	35.95	56.51**	51.94**	18.29**
A_5 x IP-12678	34.87	36.80	47.60	35.83	32.84**	28.53**	0.07
A_5 x IP-8229	34.87	35.37	36.73	35.12	4.60	-0.81	-22.78**
A_5 x IP-9149	34.87	36.90	40.07	35.88	11.66*	8.19*	-15.77**
A_5 x IP-873	34.87	35.27	51.67	35.07	47.34**	39.51**	8.62**
A_5 x IP-804	34.87	34.17	61.07	34.52	76.92**	64.90*	28.38**
A_5 x IP-577	34.87	36.37	60.07	35.62	68.65**	62.20**	26.28**
A_5 x IP-7440	34.87	38.17	52.20	36.52	42.95**	40.95**	9.74**
A_1 xIP-10085	34.87	38.17	61.70	36.52	68.96**	66.61**	29.71**
Mean	34.87	37.20	50.57	36.03	40.55	36.58	11.04
# crosses with significant desirable heterosis					10	10	6
GHB-558 (c)	50.30						
				S.E. ±	1.83	1.49	1.47
				C.D. @ 5 %	3.58	2.92	2.88
				C.D. @ 1%	4.71	3.83	3.78

MP- Mid parent
BP- Better parent
* and ** -indicate significance at 5% and 1% level respectively

Table 16j. Mean performance of parents ,hybrids, check and magnitude of heterosis for grain yield /ear (g) in pearl millet (Expt.IIIa)

Crosses	Mean value				F_1 heterosis (%) over		
	Female	Male	F_1	MP	MP	BP	Check
A_1 x IP-9140	21.07	26.77	19.70	23.92	-17.63**	-17.34**	-28.45**
A_1 x IP-10811	21.07	20.67	27.60	20.87	32.27**	15.80**	0.24
A_1 x IP-16197	21.07	21.67	26.80	21.37	25.43**	12.45**	-2.66
A_1 x IP-12678	21.07	20.53	19.97	20.80	-4.01	-16.22**	-27.48**
A_1 x IP-8229	21.07	20.80	25.27	20.93	20.70**	6.01	-8.23**
A_1 x IP-9149	21.07	20.43	22.00	20.75	6.02	-7.69*	-20.10**
A_1 x IP-873	21.07	20.80	31.03	20.93	48.25**	30.21**	12.71**
A_1 x IP-804	21.07	22.43	21.80	21.75	0.23	-8.53*	-20.82**
A_1 x IP-577	21.07	24.17	33.53	22.62	48.27**	40.70**	21.79**
A_1 x IP-7440	21.07	23.27	38.03	22.17	71.58**	59.58**	38.14**
A_1 xIP-10085	21.07	23.83	23.77	22.45	5.86	-0.28	-13.68**
Mean	21.07	22.31	26.32	21.69	21.54	10.42	-4.41
# crosses with significant desirable heterosis					6	5	3
A_4 x IP-9140	21.07	26.77	40.23	23.92	68.22**	68.81**	46.13**
A_4 x IP-10811	21.07	20.67	30.30	20.87	45.21**	27.13**	10.05**
A_4 x IP-16197	21.07	21.67	39.77	21.37	86.12**	66.85**	44.43**
A_4 x IP-12678	21.07	20.53	19.83	20.80	-4.65	-16.78**	-27.97**
A_4 x IP-8229	21.07	20.80	26.17	20.93	25.00**	9.79**	-4.96
A_4 x IP-9149	21.07	20.43	28.83	20.75	38.96**	20.98**	4.72
A_4 x IP-873	21.07	20.80	35.50	20.93	69.59**	48.95**	28.93**
A_4 x IP-804	21.07	22.43	20.20	21.75	-7.13	-15.24**	-26.63**
A_4 x IP-577	21.07	24.17	29.63	22.62	31.02**	24.34**	7.63**
A_4 x IP-7440	21.07	23.27	18.13	22.17	-18.20**	-23.92**	-34.14**
A_1 xIP-10085	21.07	23.83	20.37	22.45	-9.28*	-14.55**	-26.03**
Mean	21.07	22.31	28.09	21.69	29.53	17.85	8.22
# crosses with significant desirable heterosis					7	7	5
A_5 x IP-9140	20.33	26.77	19.73	23.55	-16.21**	-17.20**	-28.33**
A_5 x IP-10811	20.33	20.67	18.10	20.50	-11.71*	-24.06**	-34.26**
A_5 x IP-16197	20.33	21.67	29.37	21.00	39.84**	23.22**	6.66*
A_5 x IP-12678	20.33	20.53	29.17	20.43	42.74**	22.38**	5.93*
A_5 x IP-8229	20.33	20.80	18.00	20.57	-12.48**	-24.48**	-34.62**
A_5 x IP-9149	20.33	20.43	21.80	20.38	6.95	-8.53*	-20.82**
A_5 x IP-873	20.33	20.80	20.47	20.57	-0.49	-14.13**	-25.67**
A_5 x IP-804	20.33	22.43	25.27	21.38	18.16**	6.01	-8.23**
A_5 x IP-577	20.33	24.17	30.47	22.25	36.93**	27.83**	10.65**
A_5 x IP-7440	20.33	23.27	22.57	21.80	3.52	-5.31	-18.04**
A_1 xIP-10085	20.33	23.83	33.30	22.08	50.79**	39.72**	20.94**
Mean	20.33	22.31	24.39	21.32	14.37	2.31	-11.43
# crosses with significant desirable heterosis					5	4	4
GHB-558 (c)		26.8					
				S.E.±	0.98	0.80	0.79
				C.D. @ 5 %	1.89	1.56	1.54
				C.D. @1%	2.52	2.06	2.03

MP- Mid parent

BP- Better parent

* and ** -indicate significance at 5% and 1% level respectively

Among the hybrids, six on A_1, seven on A_4 and five on A_5 source recorded significant positive mid parent heterosis. Highly significant positive heterosis was noticed on A_4 source (A_4 x IP-16197). The crosses involving the pollen parents viz., IP-16197 and IP-577 showed significant positive heterosis on all the three sources. The mean heterosis of hybrids on A_4 source was highest (29.53) followed by A_1 (21.54) and A_5 (14.37).

The extent of mid parent heterosis ranged from – 8.20 per cent (A_4 x IP-7440) to 86.12 per cent (A_4 x IP-16197). Out of 24 F_1's, which exhibited significant heterosis for grain yield per ear, 18 deviated in positive directions and remaining in negative direction.

Heterosis over better parent ranged from –24.48 (A_5 x IP-8229) to 68.81 per cent (A_4 x IP-9140). Out of 29 crosses, 16 crosses showed significant positive heterosis and the remaining were negative. Nearly 29 crosses exhibited significant heterosis over standard check; of these, 12 deviated in positive direction. The maximum heterosis (46.13%) over check was recorded by the cross A_4 x IP-9140.

4.3.1.2.11 Grain yield per plant

Among the parents, lines generally tended to be higher yielder than the testers and showed a wider range of variation [41.50 (IP-9149) to 62.90 g (IP-577)]. The three testers, A_1, A_4 and A_5 cytoplasm yielded 55.00, 43.8 and 52.67 g respectively. The hybrids exhibited greater range of variation [43.67 (A_4 x IP-7440) to 82.97 g (A_4 x IP-9140)] than lines.

Of the 11 hybrids on each source seven each on A_1 and A_5 and eight on A_4 exhibited significant positive mid parent heterosis for grain yield /plant. Highly significant heterosis was recorded on A_4 source (A_4 x IP-873) followed by A_5 (A_5 x IP-10085).The crosses with pollen parents IP-16197, IP-9149 and IP-577 showed significant heterosis on all the three sources. The mean heterosis of hybrids on A4 was highest (30.70) followed A_1 (14.13) and A5 (11.81).

Of the 29 crosses that showed significant mid parent heterosis, as many as 22 deviated in positive direction. The extent of positive mid parent heterosis was from 5.82 (A_4 x IP-8229) to 70.58 per cent (A_4 x IP-16197). A total of 19 crosses exhibited significant positive heterosis over better parent. Maximum better parent heterosis was recorded by A_4 x IP-16197 (42.15%). Twenty-six crosses showed significant heterosis over check, of which 12 crosses exhibited positive significant heterosis. Maximum heterosis over check was recorded by the cross A_4 x IP-9140 (34.98%).

4.3.1.2.12 1000-grain weight

Within testers the extent of 1000-grain weight ranged from 10.13 to 11.20 g. Among the lines, the range was from 10.00 (IP-16197) to 12.23 g (IP-10085). The range of variation in F_1's was appreciable [9.07 (A_1 x IP-577) to 14.47 g ($A_{4\ x}$ IP-9140)].

Of the 11 hybrids on each source three on A_1, five on A_4 and four on A_5 sources exhibited significant positive mid parent heterosis. Highly significant heterosis was observed on A_4 source (A_4 x IP-9140). The crosses involving pollen parent IP-10811 exhibited significant heterosis on all the three sources. The mean heterosis of the hybrids on A_4 (7.06) was highest followed by A_1 (6.76) and A_5 (3.43).

Mid parent heterosis among crosses ranged from –17.84 (A_4 x IP-16197) to 33.12 per cent (A_1 x IP-10811). Twenty-two crosses showed significant mid parent heterosis, with 14 of them exhibiting heterosis in the positive direction. As regards to better parent heterosis, 11 hybrids exhibited significant heterosis in positive direction. The highest better parent heterosis was manifested by A_4 x IP-9140 (24.00 %). On the other hand 22 hybrids recorded significant positive heterosis over check. The maximum positive heterosis over check was recorded by A_4 x IP-9140 (41.83%).

4.3.1.3 Combining ability analysis

4.3.1.3.1 Analysis of variance

Analysis of variance of combining ability in respect of 12 characters is presented in Table 17. Mean squares due to hybrids were significant for all the characters. The interaction component (between lines and testers) was also significant for all the characters. Mean sum of squares due to lines and testers were significant for all the characters.

Table 16k. Mean performance of parents, hybrids, check and magnitude of heterosis for grain yield per plant (g) in pearl millet (Expt.IIIa)

Crosses	Mean value				F_1 heterosis (%) over		
	Female	Male	F_1	MP	MP	BP	Check
A_1 x IP-9140	55.00	59.83	50.57	57.42	-11.93**	-11.80**	-17.73**
A_1 x IP-10811	55.00	43.53	71.53	49.27	45.20**	24.77**	16.38**
A_1 x IP-16197	55.00	53.00	70.67	54.00	30.86**	23.26**	14.97**
A_1 x IP-12678	55.00	60.33	44.17	57.67	-23.41**	-22.97**	-28.15**
A_1 x IP-8229	55.00	59.83	55.93	57.42	-2.58	-2.44	-9.00**
A_1 x IP-9149	55.00	41.50	60.70	48.25	25.80**	5.87**	-1.25
A_1 x IP-873	55.00	42.53	70.63	48.77	44.84**	23.20**	14.91**
A_1 x IP-804	55.00	49.07	50.50	52.03	-2.95	-11.92**	-17.84**
A_1 x IP-577	55.00	62.70	68.93	58.85	17.13**	20.23**	12.15**
A_1 x IP-7440	55.00	62.30	73.10	58.65	24.64**	27.50**	18.93**
A_1 xIP-10085	55.00	57.33	60.53	56.17	7.77**	5.58	-1.52
Mean	55.00	53.81	61.57	54.41	14.13	11.85	0.28
# crosses with significant desirable heterosis					7	6	5
A_4 x IP-9140	43.80	59.83	82.97	51.82	60.12**	44.71**	34.98**
A_4 x IP-10811	43.80	43.53	68.70	43.67	57.33**	19.83**	11.77**
A_4 x IP-16197	43.80	53.00	81.50	48.40	68.39**	42.15**	32.59**
A_4 x IP-12678	43.80	60.33	43.37	52.07	-16.71**	-24.36**	-29.45**
A_4 x IP-8229	43.80	59.83	54.83	51.82	5.82*	-4.36*	-10.79**
A_4 x IP-9149	43.80	41.50	61.93	42.65	45.21**	8.02**	0.76
A_4 x IP-873	43.80	42.53	73.63	43.17	70.58**	28.43**	19.79**
A_4 x IP-804	43.80	49.07	61.10	46.43	31.59**	6.57**	-0.60
$_4$ x IP-577	43.80	62.70	71.93	53.25	35.09**	25.47**	17.03**
A_4 x IP-7440	43.80	62.30	43.67	53.05	-17.69**	-23.84**	-28.96**
A_1 xIP-10085	43.80	57.33	49.53	50.57	-2.04	-13.60**	-19.41**
Mean	43.80	53.81	63.01	48.81	30.70	9.91	2.51
# crosses with significant desirable heterosis					8	7	6
A_5 x IP-9140	52.67	59.83	51.07	56.25	-9.21**	-10.93**	-16.92**
A_5 x IP-10811	52.67	43.53	45.37	48.10	-5.68	-20.87**	-26.19**
A_5 x IP-16197	52.67	53.00	67.60	52.83	27.95**	17.91**	9.98**
A_5 x IP-12678	52.67	60.33	62.57	56.50	10.74**	9.13**	1.79
A_5 x IP-8229	52.67	59.83	46.63	56.25	-17.10**	-18.66**	-24.13**
A_5 x IP-9149	52.67	41.50	53.87	47.08	14.41**	-6.05*	-12.36**
A_5 x IP-873	52.67	42.53	60.97	47.60	28.08**	6.34**	-0.81
A_5 x IP-804	52.67	49.07	63.47	50.87	24.77**	10.70**	3.25
A_5 x IP-577	52.67	62.70	71.53	57.68	24.01**	24.77**	16.38**
A_5 x IP-7440	52.67	62.30	48.50	57.48	-15.63**	-15.41**	-21.10**
A_1 xIP-10085	52.67	57.33	81.17	55.00	47.58**	41.57**	32.05**
Mean	52.67	53.81	59.34	53.24	11.81	3.50	-3.46
# crosses with significant desirable heterosis					7	6	3
GHB-558 (c)			58.77				
				S.E. ±	1.50	1.23	1.11
				C.D. @ 5 %	2.94	2.41	2.17
				C.D. @ 1%	3.86	3.16	2.85

MP- Mid parent

BP- Better parent

*and ** -indicate significance at 5% and 1% level respectively

Table 16l. Mean performance of parents, hybrids, check and magnitude of heterosis for 1000-grain weight (g) in pearl millet (Expt.IIIa)

Crosses	Mean value				F_1 heterosis (%) over		
	Female	Male	F_1	MP	MP	BP	Check
A_1 x IP-9140	10.13	10.93	11.80	10.53	12.03**	1.14	15.69**
A_1 x IP-10811	10.13	10.80	13.93	10.47	33.12**	19.43**	36.60**
A_1 x IP-16197	10.13	10.00	12.70	10.07	26.16**	8.86**	24.51**
A_1 x IP-12678	10.13	12.13	10.93	11.13	-1.80	-6.29	7.19**
A_1 x IP-8229	10.13	10.67	12.13	10.40	16.67**	4.00	18.95**
A_1 x IP-9149	10.13	11.93	10.80	11.03	-2.11	-7.43**	5.88*
A_1 x IP-873	10.13	11.33	10.00	10.73	-6.83*	-14.29*	-1.96
A_1 x IP-804	10.13	10.07	10.67	10.10	5.61	-8.57**	4.58
A_1 x IP-577	10.13	11.67	9.07	10.90	-16.82**	-22.29**	-11.11**
A_1 x IP-7440	10.13	11.27	11.90	10.70	11.21**	2.00	16.67**
A_1 xIP-10085	10.13	12.23	10.87	11.18	-2.83	-6.86**	6.54*
Mean	10.13	11.18	11.35	10.66	6.76	-2.75	11.23
# crosses with significant desirable heterosis					5	2	8
A_4 x IP-9140	10.87	10.93	14.47	10.90	32.72*	24.00**	41.83**
A_4 x IP-10811	10.87	10.80	13.90	10.83	28.31**	19.14**	36.27**
A_4 x IP-16197	10.87	10.00	12.23	10.43	17.25**	4.86*	19.93**
A_4 x IP-12678	10.87	12.13	10.93	11.50	-4.93	-6.29**	7.19**
A_4 x IP-8229	10.87	10.67	10.00	10.77	-7.12*	-14.29**	-1.96
A_4 x IP-9149	10.87	11.93	9.37	11.40	-17.84**	-19.71**	-8.17**
A_4 x IP-873	10.87	11.33	10.40	11.10	-6.31*	-10.86**	1.96
A_4 x IP-804	10.87	10.07	12.50	10.47	19.43**	7.14**	22.55**
A_4 x IP-577	10.87	11.67	14.00	11.27	24.26**	20.00**	37.25**
A_4 x IP-7440	10.87	11.27	11.33	11.07	2.41	-2.86	11.11**
A_1 xIP-10085	10.87	12.23	10.33	11.55	-10.53**	-11.43**	1.31
Mean	10.87	11.18	11.77	11.03	7.06	-5.94	15.38
# crosses with significant desirable heterosis					5	5	7
A_5 x IP-9140	11.20	10.93	13.97	11.07	26.20**	19.71**	36.93**
A_5 x IP-10811	11.20	10.80	13.07	11.00	18.79**	12.00**	28.10**
A_5 x IP-16197	11.20	10.00	12.30	10.60	16.04*	5.43*	20.59**
A_5 x IP-12678	11.20	12.13	11.07	11.67	-5.14	-5.14*	8.50**
A_5 x IP-8229	11.20	10.67	10.27	10.93	-6.10	-12.00**	0.65
A_5 x IP-9149	11.20	11.93	11.30	11.57	-2.31	-3.14	10.78**
A_5 x IP-873	11.20	11.33	12.80	11.27	13.61**	9.71**	25.49**
A_5 x IP-804	11.20	10.07	10.13	10.63	-4.70	-13.14**	-0.65
A_5 x IP-577	11.20	11.67	10.73	11.43	-6.12*	-8.00**	5.23
A_5 x IP-7440	11.20	11.27	11.47	11.23	2.08	-1.71	12.42**
A_1 xIP-10085	11.20	12.23	10.00	11.72	-14.65**	-14.29**	-1.96
Mean	11.20	11.18	11.56	11.19	3.43	-5.22	13.28
# crosses with significant desirable heterosis					4	4	7
GHB-558 (c)		10.26					
				S.E. ±	0.35	0.28	0.28
				C.D. @ 5 %	0.68	0.54	0.54
				C.D. @ 1%	0.90	0.72	0.72

MP- Mid parent

BP- Better parent

* and ** -indicate significance at 5% and 1% level respectively

Table 17 Analysis of variance for combining ability in respect of 12 different characters in pearl millet (Expt.IIIa)

Sources of variation	df	Mean sum of squares											
		Days to 50% flowering	Days to maturity	Plant height (cm)	Productive tillers/ plant	Ear length (cm)	Ear Girth (cm)	Flag leaf area (cm^2)	Peduncle length (cm)	Ear weight /ear (g)	Grain yield / ear (g)	Grain yield/ Plant (g)	1000 grain weight (g)
Replication	2	6.41	33.39	55.57	0.36	10.94	2.22	12.95	26.05	5.03	3.24	65.7	5.01
Hybrids	32	6.96**	7.68**	138.77**	0.30**	41.24**	2.36**	612.66**	34.18**	214.78**	126.69**	410.56**	0.98**
Lines	10	10.98**	4.87*	85.52**	0.09**	48.79**	1.27**	696.5*	34.30**	107.62**	94.68**	49.56**	11.16**
Testers	2	3.03**	17.46*	24.92**	1.76**	49.69**	8.01**	975.91**	78.09**	342.77**	113.2**	113.16**	1.49**
LxT	20	5.34**	8.11**	176.78**	0.25**	36.63**	2.34**	534.41**	29.73**	255.55**	144.04**	399.08**	4.38**
Error	92	1.55	1.34	9.21	0.05	2.59	0.29	197.37	2.32	6.7	1.93	4.55	0.25

	Estimates of variance											
	Days to 50% flowering	Days to maturity	Plant height (cm)	Productive tillers/ plant	Ear length (cm)	Ear girth (cm)	Flag leaf area (cm^2)	Peduncle length (cm)	Ear weight /ear (g)	Grain yield /ear (g)	Grain yield/ plant (g)	1000 Grain weight (g)
CA	0.28	0.42	2.79	1.28	1.28	0.08	35.76	1.74	9.15	4.82	11.42	0.28
SCA	1.02	1.32	49.33	11.41	11.41	0.55	75.13	11.65	50.44	41.49	145.88	1.55
GCA/SCA	0.27	0.31	0.05	0.11	0.11	0.14	0.47	0.14	0.18	0.10	0.08	0.18
Variance of testers	1.22	1.22	-0.08	-0.05	-0.05	0.01	4.72	1.56	0.81	1.98	2.10	0.00
Variance of lines	0.02	0.96	13.20	6.17	6.17	0.36	14.95	2.38	39.75	15.29	45.62	1.07
Contribution												
Tester	2.06	6.36	0.35	0.12	0.12	1.87	2.01	9.86	0.97	3.33	1.12	2.38
Lines.	56.06	50.37	28.83	44.04	44.04	46.83	10.77	21.75	53.02	34.30	31.15	49.03
LxT	41.44	43.25	70.80	55.83	55.83	51.29	27.21	68.37	45.99	62.35	67.28	48.58

Expt.IIIa – refers to Line x Tester experiment IIIa

* and ** - indicates significance at 5% and 1 % level respectively

Estimates of GCA and SCA variance are presented in table 17. In general, magnitude of SCA variance was greater than GCA variance. The ratio of GCA to SCA variances was less than unity in all the cases.

Lines contributed more than testers for all the characters. Contribution of line x tester interaction was of higher magnitude for plant height, peduncle length, and grain yield per plant, grain yield per ear, ear length, ear girth and 1000-grain weight.

4.3.1.3.2 Combing ability effects

Estimates of general combining ability (gca) and specific combing ability (sca) for all the characters are presented in table 18 and 19 respectively.

4.3.1.3.2.1 Days to 50 per cent flowering

None of the testers with three different cytoplasmic sources (A_1, A_4 & A_5) showed significant gca effect. Among the lines, highly significant and negative effect was shown by IP-873 (-1.78), while IP-16197 (2.00) exhibited significant positive effect.

Two hybrids on A_1 cytoplasm showed significant sca effect. Hybrids from pollen parents IP-16197 and IP-8229 were highly significant and positive, while from IP-10811, IP-9149, IP-873, IP-804, IP-7440 and IP-10085 were negative but not significant. Two hybrids based on A_4 exhibited significant positive sca effects and none of the hybrids showed significant sca effect on A_5 cytoplasm.

4.3.1.3.2.2 Days to maturity

The tester with A_4 source of cytoplasm showed negative gca effect, while A_1 and A_5 sources revealed positive effect but none of these showed significant gca effect. Among the lines IP-10811, IP-16197, IP-873, IP-577 and IP-7440 exhibited negative gca effect, whereas IP-9140 exhibited significant positive effect.

Four crosses on A_1, two on A_4 and six on A_5 source showed significant negative sca effects for days to maturity. The crosses A_1 x IP-9149 (-4.04), A_1 x IP-873 (-4.04), A_4 x IP-10811 (-3.71), A_5 x IP-8229 (-4.04) and A_5 x IP- 10811 (-3.71) recorded the highest negative sca effects.

4.3.1.3.2.3 Plant height

Amongst the testers with three different cytoplasmic sources, none of the sources exhibited significant gca effects. Among the male parents, significant gca effect ranged from –6.23 (IP9149) to 4.62 per cent (IP-16197). The lines IP-16197 and IP-804 recorded highest gca values in positive direction and were found to be good general combiners.

Sixteen out of thirty three crosses showed significant sca effects. Two crosses each on A_1, A_4 and A_5 sources exhibited significant positive sca effects. The cross, A_5 x IP-16197 had the highest positive sca effect (11.52). Of all the crosses that exhibited negative sca effects, the cross A_5 x IP-9149 attained the highest value (-16.18) and hence was considered the poorest specific combiner.

4.3.1.3.2.4 Productive tillers per plant

Out of three cytoplasmic diverse male sterile sources, A_1 showed significant negative gca effect (-0.21) and A_4 showed negative gca effect (-0.04), while A_5 registered significant positive gca effect (0.25). None of the male parents registered significant gca effect.

Only nine cross combinations showed significantly positive sca effects for this character and out of which seven crosses were on A_4 and two crosses on A_5 source. The cross A_5 x IP-577 registered the highest value (0.73).

4.3.1.3.2.5 Ear girth

The tester with A_1 source exhibited significant positive gca effect. Out of 11 pollen parents, only one parent viz., IP-12678 (4.19) showed significant positive gca effect. Fifteen crosses exhibited significant negative gca effects and were considered the poorest general combiners. None of the cross combinations registered significant positive sca effects on any of the three sources.

Table 18. Estimates of general combining ability effects (gca) for 12 different characters in pearl millet (Expt.IIIa)

Characters	Days to flowering	Days to maturity	Plant height (cm)	Productive tillers per plant	Ear length (cm)	Ear girth (cm)	Flag leaf area (cm^2)	Peduncle length (cm)	Ear weight per ear (g)	Grain yield per ear (g)	Grain yield per plant (g)	1000 grain weight (g)
Testers												
A_1	0.00	0.37	0.78	-0.21*	-1.37	0.52*	6.15*	-1.52*	-3.55**	0.05	0.26	0.21
A_4	-0.30	0.47	-0.93	0.04*	0.38	-0.47	-1.98	1.56*	2.75*	1.82**	1.71	0.00
A_5	0.30	-0.84	0.15	-0.25	1.00	-0.05	-4.17	-0.04	0.80	-1.88**	-1.97*	-0.21
S.E (gi)	0.21	0.19	0.52	0.03	0.27	0.09	1.10	0.26	0.44	0.23	0.33	0.08
S.E.(gi-gi)	0.30	0.28	0.73	0.05	0.38	13.00	1.56	0.37	0.63	0.33	0.47	0.12
Lines												
IP-9140	-0.56	1.37*	0.84	0.08	0.10	0.30	-9.83**	-1.99**	-5.63**	0.29	0.23	1.86**
IP-10811	1.00	-0.18	-0.40	0.02	-2.25**	0.44	-2.67**	1.47*	-0.71	-0.93	0.56	2.08**
IP-16197	2.00**	-0.63	4.62**	-0.05	-0.93	0.09	-5.44	1.80**	3.46**	5.71**	11.95**	0.86**
IP-12678	0.56	0.93	-3.91**	-0.01	4.19*	0.53*	-7.68*	2.99**	-2.44*	-3.28**	-11.28**	-0.58*
IP-8229	0.89	0.37	-2.14	-0.16	0.36	-0.14	4.95	-2.12**	-2.74*	-3.12**	-8.84**	-0.76**
IP-9149	-0.89	0.15	-6.23**	-0.09	-0.90	0.34	8.22**	-1.25	-2.91*	-2.05**	-2.48*	-1.07**
IP-873	-1.78**	-0.96	0.49	-0.04	-3.33**	-0.25	14.21**	0.31	1.50	2.74**	7.10**	-0.49*
IP-804	-1.11	0.04	2.94*	0.14	0.83	-0.32	2.81	1.68*	-1.34	-3.84**	-2.95**	-0.46
IP-577	0.22	-0.96	0.75	0.19	-2.67**	-0.01	8.69**	0.29	5.71**	4.95**	9.49**	-0.29
IP-7440	-0.67	-0.40	1.75	0.00	1.94*	-0.32	3.12	0.09	1.13	-0.02	-6.22**	0.01
IP-10085	0.33	0.26	1.29	-0.08	2.67**	-0.66	-6.40*	-3.28**	3.96**	-0.45	2.44*	-1.16**
S.E.(gi)	0.35	0.33	0.86	0.06	0.45	0.15	1.83	0.43	0.73	0.39	0.56	0.14
S.E(gi-gj)	0.26	0.24	0.63	0.04	0.33	0.11	1.35	0.32	0.54	0.29	0.41	0.1
C.D @ 5%	1.166	1.08	2.84	0.2	1.5	0.5	6.02	1.42	2.42	1.29	1.99	0.47
C.D @ 1%	1.54	1.43	3.76	0.27	2.00	0.67	7.98	1.85	3.21	1.72	2.69	0.62

Expt.IIIa : refers to line x tester –experiment IIIa

Table 19. Estimates of specific combining ability effects for 12 different characters in pearl millet (Expt.IIIa)

Characters	Days to flowering	Days to maturity	Plant height (cm)	Productive tillers per plant	Ear length (cm)	Ear girth (cm)	Flag leaf area (cm^2)	Peduncle length (cm)	Grain weight per ear (g)	Grain yield per ear (g)	Grain yield per plant (g)	1000 grain weight (g)
Crosses						sca effects						
A_1xIP-9140	0.56	-0.37	-10.18**	0.07	-4.33**	0.00	12.52**	3.21*	-9.42**	-6.91**	-11.23**	0.84**
A_1xIP-16197	2.89**	-0.71	2.88	0.00	0.37	0.40	-4.45	4.31**	-0.12	0.19	8.87**	-1.39**
A_1xIP-12678	1.89	-0.04	-6.95**	0.13	4.70**	-0.90*	-0.32	6.14**	11.25**	-6.64**	-17.63**	-2.69**
A_1xIP-8229	2.89**	-0.04	-0.08	0.13	-4.00**	-1.14	11.02*	0.24	12.22**	-1.34	-5.86**	-3.62**
A_1xIP-9149	-0.44	-4.04**	-9.45**	0.07	-2.13	0.16	6.95	2.54*	7.85**	-4.61**	-1.10	-4.26**
A_1xIP-873	-1.11	-4.04**	4.52	-0.47*	-3.16*	0.60	15.88**	1.44	-0.95	4.42	8.84**	-3.22**
A_1xIP-804	-0.44	-3.04**	9.42**	-0.20	-0.46	-0.57	12.22*	4.07**	0.88	-4.81**	-11.30**	-1.12**
A_1xIP-577	1.56	-2.71**	5.08**	0.17	-4.33**	-1.34	11.88*	0.04	11.75**	6.92**	7.14**	0.38**
A_1xIP-7440	-1.11	-1.04	-1.05	-0.33	5.24**	-0.84	21.92**	1.04	19.25**	11.42**	11.31**	-2.29**
A_1xIP-10085	-0.44	-0.71	3.58	-0.27	5.34**	0.26	7.55	-2.30	8.18**	-2.84*	-1.26	-3.29**
A_4xIP-9140	0.89	-0.37**	9.95**	0.40*	4.37**	-1.87**	-24.25**	-0.33	19.58**	13.62**	21.17**	0.34*
A_4xIP-10811	0.56	-3.71**	-4.65	0.33	-3.93**	-1.34*	-35.45**	10.41**	17.22**	3.69**	6.91**	-0.56**
A_4xIP-16197	0.89	-3.04	11.52**	0.27	-3.33**	-1.17*	-5.78	7.57**	22.35**	13.16**	19.71**	-1.32**
A_4xIP-12678	-0.11	0.96	-10.08	0.37*	3.60**	0.16	-4.42	9.84**	1.95	-6.78**	-18.43**	-2.56**
A_4xIP-8229	-0.11	-0.04	-4.38	0.40*	5.00**	-1.47*	11.62*	1.44	10.95**	-0.44	-6.96**	-3.36**
A_4xIP-9149	0.22	-0.04	-16.18**	0.40*	0.24	-1.90**	21.88**	2.47*	11.48**	2.22	0.14	-2.32**
A_4xIP-873	-1.44	-2.04	0.32	0.40*	-4.67**	-1.67**	35.65**	2.77*	24.88**	8.89**	11.84**	-0.82**
A_4xIP-804	-1.11	-0.71	0.25	0.60**	2.00	-1.24*	16.28**	10.71**	7.15	-6.41**	-0.70	-3.49**
A_4xIP-*577*	-0.44	-1.71	-0.18	0.73**	4.34**	-0.24	11.25*	8.77**	13.42**	3.02**	10.14**	-2.89**
A_4xIP-7440	1.89	-1.71	-8.42**	0.13	5.44**	-0.94*	-12.78*	0.57	0.05	-8.48**	-18.13**	-2.16**
A_4xIP-10085	1.56	-1.71	-6.28*	0.17	5.07**	-2.40**	4.75	1.47	10.12**	-6.24**	-12.26**	-3.62**
A_5xIP-9140	-1.44	-0.37	-2.12	0.17	4.07**	0.33	-6.72	1.67	0.48	-6.88**	-10.73**	-1.82**
A_5xIP-10811	4.22	-3.71**	5.58*	0.27	-0.66	0.13	-4.48	3.37**	7.18**	-8.51**	-16.43**	0.31*
A_5xIP-16197	3.89	-3.37**	-5.42	0.00	3.97**	-1.40*	4.95	4.04**	15.68**	2.76*	5.81**	-0.92**
A_5xIP-12678	1.56	-3.37**	0.42	-0.13	6.67**	-0.10	-7.25	3.51**	7.02**	2.56*	0.77	-2.69**
A_5xIP-8229	1.56	-4.04**	-6.82**	-0.60**	5.27**	-0.24	3.26	2.47*	-3.85	-8.61**	-15.16**	-1.49**
A_5xIP-9149	-0.78	-0.71*	2.08	-0.33	3.00*	0.33	6.88	1.74	-0.52	-4.81**	-7.93**	-2.82**
A_5xIP-873	-1.11	-2.04*	-8.25**	0.37*	1.67	-2.10	2.15	7.24**	11.08**	-6.14**	-0.83	-3.62**
A_5xIP-804	-0.11	-1.37	-5.72*	0.43	4.77**	-1.60*	-9.02	0.77	20.48**	-1.34	1.67	-2.96**
A_5xIP-577	1.22	-3.71	-7.52	0.07	-4.20**	-0.90*	13.98**	2.57*	19.48**	3.86**	9.74**	-4.56**
A_5xIP-7440	-1.11	-3.71	9.85**	0.60**	-1.03	-1.64*	11.28*	9.17**	11.62**	-4.04**	-13.30**	-1.72**
A_5xIP-10085	1.56	-2.04	1.68	0.27	1.40	-2.27**	-20.45**	1.51	21.12**	6.69**	19.37**	-2.76**
S.E. ±	0.77	0.72	1.72	0.12	0.91	0.30	3.67	0.86	1.47	0.79	1.12	0.28
S.E (sij-skl)	1.01	0.93	2.44	0.17	1.28	0.43	5.19	1.23	2.09	1.12	1.58	0.40

Expt.IIIa: refers to line tester –experiment IIIa

* and ** : indicate significance at 5% and 1 % level respectively

4.3.1.3.2.6 Ear length

Of the three female parents, none showed significant gca effect for ear length. Estimation of gca effects were significant for six pollen parents of which the line IP-12678 had the highest positive gca effect (4.19) and was found to be the superior general combiner followed by IP-10085 and IP7440.

Out of 33 hybrids, 15 hybrids exhibited significant positive sca effects for ear length. Of the fifteen three crosses on A_1, six each on A_4 and A_5 sources exhibited significant positive sca effects.

4.3.1.3.2.7 Flag leaf area

Among the three testers with different cytoplasmic sources, A_1 was the best general combiner with highest significant positive gca effect (6.15). Among the pollen parents IP-9149, IP-873 and IP-577 showed significant positive gca effects.

Estimates of sca effects were significant and positive for 14 crosses, of which seven were on A_1, five on A_4 and two on A_5 sources. The crosses A_5 x IP-9149 and A_5 x IP-10811 were the best and the poorest specific combiners respectively.

4.3.1.3.2.8 Peduncle length

Of the three testers A_4 source alone registered significant and positive gca effect(1.56) . Among the lines IP-10811, IP-16197, IP-12678 and IP-804 contributed positive significant gca effects.

As regards sca effect, 19 crosses exhibited significant positive effect and of which five crosses were on A_1 and seven each on A_4 and A_5 sources. The cross A_5 x IP-804 was found to be best specific combiner.

4.3.1.3.2.9 Ear weight per ear

An estimate of gca effects was positively significant for tester A_4 source. Seven of the eleven pollen parents showed significant gca effects. Three parents registered significant and positive gca effects.

Estimate of sca effects were significant for 23 crosses, of which 22 were positive and the only other was negative. Six crosses on A_1 and eight each on A_4 and A_5 sources showed significant positive sca effects. The crosses A_5 x IP-873 and A_1 x IP-9140 were the best and the poorest specific combiners respectively.

4.3.1.3.2.10 Grain yield per ear

Only one tester with A_4 source of cytoplasm exhibited positive and significant gca effect (1.82). Three male lines *viz.,* IP-16197 (5.71), IP-873(2.74) and IP-577 (4.95) showed significant positive gca effect. On the other hand, four lines deviated in the negative direction.

Twenty-six crosses manifested significant sca effects. Eleven crosses (two on $A_{1,}$ five on A_4 and four on A_5 sources) showed positive and 15 crosses showed negative values. The hybrids A_5 x IP-9140, A_5 x IP-16197 and A_1 x IP-7440 registered significant high positive sca values.

4.3.1.3.2.11 Grain yield per plant

None of the three female parents with diverse cytoplasmic sources showed significant gca effects. Out of 11 pollen parents, nine showed significant gca effect of which, four parents exhibited significant positive gca effect, while five lines showed significant negative gca effects.

Out of 33 hybrids, 26 hybrids exhibited significant sca effects for grain yield per plant. Five crosses on A_1, eight on A_4 and three on A_5 sources exhibited significant positive sca effects. Amongst superior specific combiners A_5 x IP-9140 had highest significant positive sca effect followed by A_5 x IP-16197, A_4 x IP-10085, A_5 x IP-873, A_5 x IP-577 and A_1 x IP-10811.

4.3.1.3.2.12 1000-grain weight

Estimates of gca effects were non-significant for all the three testers with different cytoplasmic sources. Eight out of eleven pollen parents showed significant gca effects. Three parents *viz*., IP-9140, IP-10811 and IP-16197 expressed significant positive gca effects. The line IP-10085 exhibited poor general combining ability.

Estimates of sca effects were significant for all the crosses; of which five were positive (three on A_1, one each on A_4 and A_5 sources) and 28 were negative. The crosses A_1 x IP-9140 and A_4 x IP-577 were the best and the poorest specific combiners respectively.

4.3.2 Heterosis and combining ability studies on A_1 source for commercial exploitation (Expt.IIIb)

4.3.2.1 Analysis of Variance

Analysis of variance for the 12 characters studied is presented in table 20. The mean squares due to entries were significant for all the characters except days to maturity. Parents, crosses and interaction component (parents vs. hybrids) showed significant differences for all the characters except days to maturity. Mean sum of squares inclusive of check in addition to parents and hybrids were significant for all the characters.

4.3.2.2 Magnitude of heterosis

The mean values of parents, hybrids and magnitude of heterosis over mid parent, better parent and check are presented for each character separately in tables 21a –21l.

4.3.2.2.1 Days to 50 per cent flowering

Among the testers, minimum of 50.00 (ICMA 88004) and maximum of 52.33 (ICMA 842) days were required for days to 50 per cent flowering. In case of lines, IPC-828 was the earliest (48.00 days), while IPC-1361 was the last to (61.00 days) flower. Among the crosses, the range was from 42.00 in JMSA 101 x IPC-1394 to 58.00 days in ICMA 88004 x IPC-1394.

Degree of heterosis exhibited by F_1's over their mid parent values were within the range of –24.29 (JMSA 101 x IPC-1361) to 9.90 (ICMA 88004 x IPC-827-1). Thirty-two hybrids showed significant heterosis of which two crosses exhibited significant positive and remaining exhibited significant negative. The range of heterosis over better parent was from -12.50 (JMSA 101 x IPC-1394) to 20.83 per cent (ICMA 88004 x IPC-1394). Twelve crosses showed significant positive heterosis. Twenty-four crosses revealed significant negative heterosis over check. Out of which the cross JMSA101 x IPC-1394 was the earliest (-17.11%).

4.3.2.2.2 Days to maturity

Range of variation observed among the testers was from 84.00 to 86.67 days to mature. Among the lines, IPC-804 (84.00 days) and IPC-1503 (88.0 days) were respectively the earliest and the last to mature. The maturity period recorded for the hybrids was in the range of 83.33 (ICMA 94555 x IPC-1104) to 87.67 days (JMSA 101 x IPC-804).

The magnitude of heterosis over mid parent was small and the range being –2.14 (ICMA 88004 x IPC-338) to 4.37 (JMSA 101 x IPC-804) per cent.

4.3.2.2.3 Plant height

The mean value for plant height among testers was in the range of 133.50 (ICMA 88004) to 141.20 cm (JMSA 101). Among the males, IPC-804 involved in the study was generally tall, the range being 151.27 (IPC-804) to 169.60 cm (IPC-873). Between the F_1's the lowest mean value (121.60 cm) was recorded by ICMA 94555 x IPC-1503 and the highest (178.57 cm) by JMSA 101 x IPC-804.

The range of per cent heterosis of the hybrids over their respective mid parent values varied from –19.47 (ICMA 94555 x IPC-1503) to 22.11 cm (JMSA 101 x IPC-804). Out of 31 crosses that showed significant mid parent heterosis, 23 were in positive direction. Significant better parent heterosis was observed in 37 crosses, of which JMSA 101 x IPC-1503 showed highest positive heterosis (12.09%). With respect to heterosis over check, the cross JMSA 101 x IPC-1503 registered the highest positive value. In addition, nearly 13 hybrids were also found to be significantly taller than the check.

Table 20. Analysis of variance (Mean sum of squares) in respect of 12 different characters in pearl millet (Expt.IIIb)

Sources of variation	df	Characters											
		Days to 50% flowering	Days to maturity	Plant height (cm)	Prod. tillers /plant	Ear length (cm)	Ear girth (cm)	Flag leaf area (cm^2)	Peduncle length (cm)	Ear weight/ ear (g)	Grain yield /ear (g)	Grain yield/ Plant (g)	1000 grain weight (g)
		Mean sum of squares											
Replication	2	6.41	3.39	55.57	0.36	10.94	2.22	12.95	26.05	5.03	3.24	65.7	5.01
Treatments (p+h)	63	15.20**	23.16	546.45**	0.35**	13.87*	3.15**	469.48**	34.08**	208.52**	85**	24.11**	6.72**
Parents	15	38.47**	4.27	449.91**	0.09	4.18	1.23**	339.67**	11.65**	37.23**	39.94**	64.1**	9.49**
Crosses	47	30.11**	42.58	588.86**	0.41**	15.75**	3.51**	520.84**	36.9**	160.73**	92.96**	737.86**	5.33**
Parent v/s. crosses	1	52.40	23.76	0.62	1.88	70.63	14.88	2.87	238.31	5024.44	386.45	3677	30.2
Error	126	8.66	6.58	10.62	0.06	2.14	0.17	12.09	2.24	3.89	3.85	6.14	1.87

Analysis of variance comprising of parents, hybrids and check

Sources of variation	df	Days to 50% flowering	Days to maturity	Plant height (cm)	Prod. tillers /plant	Ear length (cm)	Ear head girth (cm)	Flag leaf area (cm^2)	Peduncle length (cm)	Ear head weight/ ear (g)	Grain yield /ear head (g)	Grain yield/ plant (g)	1000 seed weight (g)
Replication	2	7.06	13.07	9.55	0.37	10.88	2.1	13.21	21.93	4.97	2.67	41.01	2.73
Treatments (p+h+c)	64	14.96**	3.6**	459.06**	0.35**	13.66**	3.1**	416.58**	33.99**	206.29**	83.76**	605.13**	4.49**
Error	128	7.02	2.19	9.12	0.06	2.13	0.17	12.05	2.2	4.32	3.43	6.35	0.28

Expt.IIIb: refers to line x tester experiment IIIb p: parents h: hybrids c: check

* and ** : indicates significance at 5% and 1 % level respectively

Table 21a. Mean performance of parent s, hybrids, check and magnitude of heterosis for days to flowering in pearl millet (Expt.IIIb)

Crosses	Mean value				F_1 heterosis (%)value		
	Female	Male	F_1	MP	MP	BP	Check
ICMA94555 x IPC-577	50.67	57.67	47.00	54.17	-13.24**	-2.08	-7.24*
ICMA94555 x IPC-804	50.67	54.00	53.00	52.34	1.27	10.42**	4.61
ICMA94555 x IPC-873	50.67	55.00	46.33	52.84	-12.31**	-3.48	-8.55**
ICMA94555 x IPC-827-1	50.67	54.33	45.33	52.50	-13.66**	-5.56	-10.53**
ICMA94555 x IPC-1518	50.67	57.00	46.33	53.84	-13.94**	-3.48	-8.55**
ICMA94555 x IPC-1104	50.67	55.67	46.00	53.17	-13.49**	-4.17	-9.21**
ICMA94555 x IPC-217	50.67	57.33	49.67	54.00	-8.02*	3.48	-1.97
ICMA94555 x IPC-338	50.67	57.00	48.00	53.84	-10.84**	0.00	-5.25
ICMA94555 x IPC-1361	50.67	61.00	46.33	55.84	-17.02**	-3.48	-8.55**
ICMA94555 x IPC-1394	50.67	57.67	45.67	54.17	-15.69**	-4.85	-9.87**
ICMA94555 x IPC-1503	50.67	58.00	47.33	54.34	-12.89**	-1.40	-6.58*
ICMA94555 x IPC-828	50.67	48.00	50.67	49.34	2.71	5.56	0.00
JMSA101 x IPC-577	50.67	57.67	52.67	54.17	-2.77	9.73**	3.95
JMSA101 x IPC-804	50.67	54.00	53.67	52.34	2.55	11.81**	5.92*
JMSA101 x IPC-873	50.67	55.00	53.00	52.84	0.31	10.42**	4.61
JMSA101 x IPC-827-1	50.67	54.33	49.00	52.50	-6.67	2.08	-3.29
JMSA101x IPC-1518	50.67	57.00	46.00	53.84	-14.55	-4.17	-9.21*
JMSA101 x IPC-1104	50.67	55.67	46.87	53.17	-11.85**	-2.35	-7.49**
JMSA101x IPC-217	50.67	57.33	43.20	54.00	-20.00**	-10.00**	-14.74**
JMSA101x IPC-338	50.67	57.00	45.50	53.84	-15.48**	-5.21	-10.20**
JMSA101x IPC-1361	50.67	61.00	42.27	55.84	-24.29**	-14.94**	-16.57**
JMSA101x IPC-1394	50.67	57.67	42.00	54.17	-22.47**	-12.50**	-17.11**
JMSA101 x IPC-1503	50.67	58.00	45.30	54.34	-16.57**	-5.63	-10.59**
JMSA101 x IPC-828	50.67	48.00	45.33	49.34	-8.12	-5.56	-10.53**
ICMA842 x IPC-577	52.33	57.67	51.00	55.00	-7.27	6.25	0.66
ICMA842 x IPC-804	52.33	54.00	49.67	53.17	-6.57	3.48	-1.97
ICMA842 x IPC-873	52.33	55.00	49.00	53.67	-8.69*	2.08	-3.29
ICMA842 x IPC-827-1	52.33	54.33	51.33	53.33	-3.75	6.94	1.32
ICMA842 x IPC-1518	52.33	57.00	50.00	54.67	-8.53*	4.17	-1.32
ICMA842 x IPC-1104	52.33	55.67	48.33	54.00	-10.50**	0.69	-4.61
ICMA842 x IPC-217	52.33	57.33	51.67	54.83	-5.76	7.65*	1.97
ICMA842 x IPC-338	52.33	57.00	52.33	54.67	-4.27	9.02**	3.29
ICMA842 x IPC-1361	52.33	61.00	48.67	56.67	-14.11**	1.40	-3.95
ICMA842 x IPC-1394	52.33	57.67	45.33	55.00	-17.58**	-5.56	-10.53*
ICMA842 x IPC-1503	52.33	58.00	45.00	55.17	-18.43**	-6.25	-11.18**
ICMA842 x IPC-828	52.33	48.00	45.67	50.17	-8.96*	-4.85	-9.87**
ICMA88004 x IPC-577	50.00	57.67	46.67	53.84	-13.31**	-2.77	-7.89**
ICMA88004 x IPC-804	50.00	54.00	46.67	52.00	-10.25**	-2.77	-7.89**
ICMA88004 x IPC-873	50.00	55.00	48.00	52.50	-8.57*	0.00	-5.26
ICMA88004 x IPC-827-1	50.00	54.33	57.33	52.17	9.90*	19.44**	13.16**
ICMA88004 x IPC-1518	50.00	57.00	52.67	53.50	-1.55	9.73**	3.95
ICMA88004 x IPC-1104	50.00	55.67	55.67	52.84	5.37	15.98**	9.87**
ICMA88004 x IPC-217	50.00	57.33	47.67	53.67	-11.1**7	-0.69	-5.92
ICMA88004 x IPC-338	50.00	57.00	47.67	53.50	-10.90**	-0.69	-5.92
ICMA88004 x IPC-1361	50.00	61.00	47.00	55.50	-15.32**	-2.08	-7.24*
ICMA88004 x IPC-1394	50.00	57.67	58.00	53.84	7.74*	20.83**	14.47**
ICMA88004 x IPC-1503	50.00	58.00	54.67	54.00	1.24	13.90**	7.89**
ICMA88004 x IPC-828	50.00	48.00	55.00	49.00	12.24**	14.58**	8.55**
GHB-558 (c)		50.67					
				S.E.±	2.08	1.69	1.52
				C.D. @ 5%	4.07	3.35	2.97
				C.D.@ 1%	5.35	4.35	3.91

MP- Mid parent
BP- Better parent
* and ** -indicate significance at 5% and 1% level respectively

4.3.2.2.4 Productive tillers per plant

The range of variation among the testers was from 2.37 (JMSA 101) to 2.50 (ICMA 94555). Among the lines, the range was from 2.27 (IPC-873) to 2.80 (IPC-1518 and IPC-1104). The range of variation in F_1's was from 1.67 (ICMA 842 x IPC-1503) to 3.00 (ICMA 94555 x IPC-577).

Significant mid parent heterosis was observed in 19 crosses, of which two deviated in positive direction. As regards better parent heterosis, nine hybrids showed significantly positive heterosis and a maximum of 22.50 per cent was recorded by ICMA 94555 x IPC-577. With respect to heterosis over standard check, eight crosses exhibited significant positive heterosis, and the maximum was recorded by the cross ICMA 94555 x IPC-577 (30.43 %).

4.3.2.2.5 Ear length

The differences noticed among the female lines under the study were from 20.27 to 23.00 cm. Among the males, IPC-1503 showed the lowest (19.90 cm) and IPC-217 the highest (24.03 cm) mean value for ear length. Among the hybrids, ICMA 88004 x IPC-217 and ICMA 88004 x IPC-1518 were observed to have minimum (19.63 cm) and maximum (27.40 cm) length respectively.

The heterosis per cent over mid parent value varied from –16.52 (ICMA 88004 x IPC-217) to 30.30 per cent (JMSA 101 x IPC-1503). The F_1's deviation was positive and significant in 20 crosses. The per cent heterosis over better parent ranged from –14.86 (ICMA 88004 x IPC-217) to 17.48 per cent (ICMA 88004 x IPC-1518). As many as 20 crosses exhibited significant positive deviation from the better parent. With respect to heterosis over check (GHB-558), nearly 15 hybrids showed significant positive heterosis and the maximum (19.13%) was recorded by ICMA 88004 x IPC-217.

4.3.2.2.6 Ear girth

The range of variation for ear girth among testers was from 5.03 (ICMA 88004) to 5.90 cm (ICMA 842) and among the lines, it was from 5.10 (IPC-577) to 6.9 cm (IPC-338). The range of variation between F_1's was from 4.67 (JMSA 101 x IPC-1394) to 8.37 cm (ICMA 842 x IPC-217).

The range of positive mid parent heterosis was from 5.98 (ICMA 842 x IPC-804) to 45.57 per cent (ICMA 842x IPC-1104). Thirty hybrids showed significant heterosis over their mid parental value. It was observed that heterosis over their better parent was positive and significantly superior in nineteen hybrids. Heterosis observed by these crosses ranged from 5.83 (JMSA 101 x IPC-1361) to 25.22 (ICMA 842 x IPC-217) per cent. Regarding heterosis over check, seventeen cross combination showed positive significant heterosis. A maximum heterosis of 32.80 per cent over the check was manifested by the cross ICMA 842 x IPC-217.

4.3.2.2.7 Flag leaf area (cm^2)

The range of variation among the testers was from 74.13 (JMSA 101) to 98.90 cm^2 (ICMA 94555). Among the lines, the range was from 61.60 (IPC-1394) to 97.87 cm^2 (IPC-577). The range of variation in F_1's was from 55.70 (ICMA 88004 x IPC-577) to 104.90 cm^2 (JMSA 101 x IPC-1518).

Significant mid parent heterosis was observed in 40 crosses, of which 18 deviated in positive direction. As regards better parent heterosis, twenty-five hybrids showed significant positive heterosis and a maximum of 48.79% was recorded by JMSA 101 x IPC-1361. With respect to heterosis over standard check, twenty-six crosses exhibited significant positive heterosis and the maximum was recorded by the cross JMSA 101 x IPC-217 (48.79%).

4.3.2.2.8 Peduncle length

The testers varied with a range of 28.57 (ICMA 842) to 30.53 cm (ICMA 94555). Among the lines, IPC-873 showed lowest (23.77 cm) and IPC-338 the highest (30.43 cm), while the F_1's showed an appreciable range from 19.27 (ICMA 94555 x IPC-1361) to 30.70 cm (ICMA 842 x IPC 217).

Heterosis over mid parent ranged from –34.68 (ICMA 94555 x IPC-1361) to 10.77 (ICMA 842 x IPC-1104) per cent. Five and thirty crosses showed significantly positive and negative mid parent heterosis respectively. The range of better parent heterosis was from –

Table 21b. Mean performance of parents, hybrids, check and magnitude of heterosis for days to maturity in pearl millet (Expt.IIIb)

Croses	Mean value				F_1 heterosis (%) over		
	Female	Male	F_1	MP	MP	BP	Check
ICMA94555 x IPC-577	85.00	85.33	84.00	85.17	-1.37	-1.19	0.40
ICMA94555 x IPC-804	85.00	84.00	85.00	84.50	0.59	0.00	1.59
ICMA94555 x IPC-873	85.00	84.33	85.67	84.67	1.19	0.80	2.39*
ICMA94555 x IPC-827-1	85.00	85.67	85.00	85.34	-0.39	0.00	1.59
ICMA94555 x IPC-1518	85.00	86.33	85.33	85.67	-0.39	0.39	1.99*
ICMA94555 x IPC-1104	85.00	86.33	83.33	85.67	-2.73	-1.99	-0.40
ICMA94555 x IPC-217	85.00	85.67	84.67	85.34	-0.78	-0.39	1.20
ICMA94555 x IPC-338	85.00	84.33	84.33	84.67	-0.40	-0.80	0.80
ICMA94555 x IPC-1361	85.00	84.33	86.33	84.67	1.97	1.58	3.19**
ICMA94555 x IPC-1394	85.00	86.67	87.00	85.84	1.36	2.38	3.98**
ICMA94555 x IPC-1503	85.00	88.00	85.67	86.50	-0.96	0.80	2.39*
ICMA94555 x IPC-828	84.00	85.67	86.00	85.34	0.78	1.19	2.79**
JMSA101 x IPC-577	84.00	85.33	85.33	84.67	0.79	0.39	1.99*
JMSA101 x IPC-804	84.00	84.00	87.67	84.00	4.37*	3.18	4.78**
JMSA101 x IPC-873	84.00	84.33	85.67	84.17	1.79	0.80	2.39*
JMSA101 x IPC-827-1	84.00	85.67	85.33	84.84	0.58	0.39	1.99*
JMSA101x IPC-1518	84.00	86.33	85.67	85.17	0.59	0.80	2.39*
JMSA101 x IPC-1104	84.00	86.33	83.67	85.17	-1.76	-1.58	0.00
JMSA101x IPC-217	84.00	85.67	84.67	84.84	-0.19	-0.39	1.20
JMSA101x IPC-338	84.00	84.33	84.33	84.17	0.20	-0.80	0.80
JMSA101x IPC-1361	84.00	84.33	83.67	84.17	-0.59	-1.58	0.00
JMSA101x IPC-1394	84.00	86.67	85.00	85.34	-0.39	0.00	1.59
JMSA101 x IPC-1503	84.00	88.00	85.67	86.00	-0.38	0.80	2.39**
JMSA101 x IPC-828	84.00	85.67	86.66	84.84	2.15	-1.98	3.58
ICMA842 x IPC-577	84.00	85.33	87.00	84.67	2.76	2.38	3.98**
ICMA842 x IPC-804	84.00	84.00	84.33	84.00	0.39	-0.80	0.80
ICMA842 x IPC-873	84.00	84.33	83.67	84.17	-0.59	-1.58	0.00
ICMA842 x IPC-827-1	84.00	85.67	84.67	84.84	-0.19	-0.39	1.20
ICMA842 x IPC-1518	84.00	86.33	85.67	85.17	0.59	0.80	2.39*
ICMA842 x IPC-1104	84.00	86.33	84.67	85.17	-0.58	-0.39	1.20
ICMA842 x IPC-217	84.00	85.67	84.33	84.84	-0.60	-0.80	0.80
ICMA842 x IPC-338	84.00	84.33	84.33	84.17	0.20	-0.80	0.80
ICMA842 x IPC-1361	84.00	84.33	84.00	84.17	-0.20	-1.19	0.40
ICMA842 x IPC-1394	84.00	86.67	85.33	85.34	-0.01	0.39	1.99*
ICMA842 x IPC-1503	84.00	88.00	84.33	86.00	-1.94	-0.80	0.80
ICMA842 x IPC-828	84.00	85.67	86.00	84.835	1.37	1.19	2.79**
ICMA88004 x IPC-577	86.67	85.33	84.33	86	-1.94	-0.80	0.80
ICMA88004 x IPC-804	86.67	84.00	87.67	85.335	2.74	3.18	4.78**
ICMA88004 x IPC-873	86.67	84.33	86.00	85.5	0.58	1.19	2.79**
ICMA88004 x IPC-827-1	86.67	85.67	85.33	86.17	-0.97	0.39	1.99*
ICMA88004 x IPC-1518	86.67	86.33	84.67	86.5	-2.12	-0.39	1.20
ICMA88004 x IPC-1104	86.67	86.33	86.33	86.5	-0.20	1.58	3.19**
ICMA88004 x IPC-217	86.67	85.67	84.67	86.17	-1.74	-0.39	1.20
ICMA88004 x IPC-338	86.67	84.33	83.67	85.5	-2.14	-1.58	0.00
ICMA88004 x IPC-1361	86.67	84.33	84.00	85.5	-1.75	-1.19	0.40
ICMA88004 x IPC-1394	86.67	86.67	86.33	86.67	-0.39	1.58	3.19**
ICMA88004 x IPC-1503	86.67	88.00	85.00	87.335	-2.67	0.00	1.59
ICMA88004 x IPC-828	86.67	85.67	84.67	86.17	-1.74	-0.39	1.20
GHB-558 (c)		83.67					
				S.E.±	1.81	1.40	0.85
				C.D. @ 5%	3.54	2.70	1.66
				C.D.@ 1%	4.66	3.66	2.18

MP- Mid parent, BP- Better parent , * and ** -indicate significance at 5% and 1% level respectively

Table 21c. Mean performance of parent s, hybrids, check and magnitude of heterosis for plant height (cm) in pearl millet (Expt.IIIb)

Crosses	Mean value				F1 heterosis (%) over		
	Female	Male	F_1	MP	MP	BP	Check
ICMA94555 x IPC-577	138.47	153.93	173.67	146.20	18.79**	7.47**	6.20**
ICMA94555 x IPC-804	138.47	151.27	173.80	144.87	19.97**	7.55**	6.28**
ICMA94555 x IPC-873	138.47	169.60	158.37	154.04	2.81	-1.55	-3.16**
ICMA94555 x IPC-827-1	138.47	157.80	168.33	148.14	13.63**	4.32**	2.94**
ICMA94555 x IPC-1518	138.47	162.17	160.43	150.32	6.73**	-0.34	-1.90
ICMA94555 x IPC-1104	138.47	168.27	168.93	153.37	10.15***	4.68**	3.30**
ICMA94555 x IPC-217	138.47	168.00	172.73	153.24	12.72**	6.92	5.63**
ICMA94555 x IPC-338	138.47	168.63	140.97	153.55	-8.19**	-11.81**	-13.80**
ICMA94555 x IPC-1361	138.47	161.00	160.17	149.74	6.97**	-0.49	-2.06
ICMA94555 x IPC-1394	138.47	163.33	142.03	150.90	-5.88**	-11.19**	-13.15**
ICMA94555 x IPC-1503	138.47	163.33	121.60	150.90	-19.42**	-23.23**	-25.64**
ICMA94555 x IPC-828	138.47	162.33	128.07	150.40	-14.85**	-19.42**	-21.69**
JMSA101 x IPC-577	141.20	153.93	167.73	147.57	13.67**	3.97**	2.57*
JMSA101 x IPC-804	141.20	151.27	178.57	146.24	22.11**	10.36**	9.19**
JMSA101 x IPC-873	141.20	169.60	148.50	155.40	-4.44**	-7.37**	-9.19**
JMSA101 x IPC-827-1	141.20	157.80	145.30	149.50	-2.81	-9.26**	-11.15**
JMSA101x IPC-1518	141.20	162.17	150.10	151.69	-1.04	-6.43**	-8.21**
JMSA101 x IPC-1104	141.20	168.27	172.57	154.74	11.53**	6.82**	5.52**
JMSA101x IPC-217	141.20	168.00	150.27	154.60	-2.80	-6.33**	-8.11**
JMSA101x IPC-338	141.20	168.63	151.33	154.92	-2.31	-5.70**	-7.46**
JMSA101x IPC-1361	141.20	161.00	148.57	151.10	-1.67	-7.33**	-9.15**
JMSA101x IPC-1394	141.20	163.33	170.20	152.27	11.78**	5.42**	4.08**
JMSA101 x IPC-1503	141.20	163.33	181.50	152.27	19.20*	12.09**	10.99**
JMSA101 x IPC-828	141.20	162.33	158.22	151.77	-4.21**	-1.64	3.22*
ICMA842 x IPC-577	136.60	153.93	160.20	145.77	9.90**	-0.47	-2.04
ICMA842 x IPC-804	136.60	151.27	170.57	144.44	18.09**	5.64**	4.30**
ICMA842 x IPC-873	136.60	169.60	152.00	153.60	-1.04	-5.31**	-7.05**
ICMA842 x IPC-827-1	136.60	157.80	145.90	147.70	-1.22	-8.90**	-10.78**
ICMA842 x IPC-1518	136.60	162.17	145.27	149.89	-3.08*	-9.27**	-11.17**
ICMA842 x IPC-1104	136.60	168.27	160.70	152.94	5.08**	-0.18	-1.73
ICMA842 x IPC-217	136.60	168.00	164.73	152.80	7.81**	2.20	0.73
ICMA842 x IPC-338	136.60	168.63	163.50	153.12	6.78**	1.47*	-0.02
ICMA842 x IPC-1361	136.60	161.00	165.37	149.30	10.76**	2.58	1.12
ICMA842 x IPC-1394	136.60	163.33	148.03	150.47	-1.62	-7.65*	-9.48**
ICMA842 x IPC-1503	136.60	163.33	147.03	150.47	-2.28	-8.24**	-10.09**
ICMA842 x IPC-828	136.60	162.33	148.60	149.97	-0.91	-7.31**	-9.13*
ICMA88004 x IPC-577	133.50	153.93	151.20	143.72	5.21	-5.78**	-7.54**
ICMA88004 x IPC-804	133.50	151.27	144.77	142.39	1.68	-9.57**	-11.48**
ICMA88004 x IPC-873	133.50	169.60	153.83	151.55	1.50	-4.23**	-5.93**
ICMA88004 x IPC-827-1	133.50	157.80	149.03	145.65	2.32	-7.06**	-8.87**
ICMA88004 x IPC-1518	133.50	162.17	143.87	147.84	-2.68	-10.10***	-12.03**
ICMA88004 x IPC-1104	133.50	168.27	148.27	150.89	-1.73	-7.51**	-9.34**
ICMA88004 x IPC-217	133.50	168.00	161.47	150.75	7.11**	0.28**	-1.26
ICMA88004 x IPC-338	133.50	168.63	167.03	151.07	10.57*	3.56	2.14
ICMA88004 x IPC-1361	133.50	161.00	158.90	147.25	7.91**	-1.24**	-2.83
ICMA88004 x IPC-1394	133.50	163.33	159.60	148.42	7.54**	-0.83	-2.41*
ICMA88004 x IPC-1503	133.50	163.33	166.00	148.42	11.85**	2.95**	1.51**
ICMA88004 x IPC-828	133.50	162.33	170.47	147.92	15.25**	5.58**	4.24*
GHB-558 (c)		163.53					
				S.E.±	2.30	1.88	1.74
				C.D. @ 5%	4.50	3.68	3.40
				C.D.@ 1%	5.52	4.84	4.48

MP- Mid parent
BP- Better parent
* and ** -indicate significance at 5% and 1% level respectively

Table 21d. Mean performance of parents, hybrids, check and magnitude of heterosis for productive tillers per plant in pearl millet (Expt.IIIb).

Crosses	Mean value				F_1 heterosis (%) over		
	Female	Male	F_1	MP	MP	BP	Check
ICMA94555 x IPC-577	2.50	2.33	3.00	2.42	24.22**	22.50**	30.43**
ICMA94555 x IPC-804	2.50	2.33	2.47	2.42	2.28	3.57	7.25
ICMA94555 x IPC-873	2.50	2.27	2.70	2.39	13.21	11.79*	17.39*
ICMA94555 x IPC-827-1	2.50	2.50	2.83	2.50	13.20*	16.43*	23.19**
ICMA94555 x IPC-1518	2.50	2.80	2.70	2.65	1.89	11.798	17.39*
ICMA94555 x IPC-1104	2.50	2.80	2.67	2.65	0.75	10.71*	15.94
ICMA94555 x IPC-217	2.50	2.70	2.30	2.60	-11.54	-2.50	0.00
ICMA94555 x IPC-338	2.50	2.43	2.23	2.47	-9.53	-5.00	-2.90
ICMA94555 x IPC-1361	2.50	2.47	2.80	2.49	12.68	15.36**	21.74*
ICMA94555 x IPC-1394	2.50	2.67	2.47	2.59	-4.45	3.57	7.25
ICMA94555 x IPC-1503	2.50	2.60	2.80	2.55	9.80	15.36**	21.74*
ICMA94555 x IPC-828	2.50	2.70	2.33	2.60	-10.38	-1.43	1.45
JMSA101 x IPC-577	2.37	2.33	2.43	2.35	3.40	2.14	5.80
JMSA101 x IPC-804	2.37	2.33	2.63	2.35	11.91	9.29	14.49
JMSA101 x IPC-873	2.37	2.27	2.43	2.32	4.74	2.14	5.80
JMSA101 x IPC-827-1	2.37	2.50	2.30	2.44	-5.54	-2.50	0.00
JMSA101x IPC-1518	2.37	2.80	2.47	2.59	-4.45	3.57	7.25**
JMSA101 x IPC-1104	2.37	2.80	2.90	2.59	12.19	18.93**	26.09
JMSA101x IPC-217	2.37	2.70	2.80	2.54	10.45	15.36**	21.74*
JMSA101x IPC-338	2.37	2.43	2.80	2.40	16.67	15.36*	21.74
JMSA101x IPC-1361	2.37	2.47	2.70	2.42	11.57	11.79	17.39
JMSA101x IPC-1394	2.37	2.67	2.60	2.52	3.17	8.21	13.04
JMSA101 x IPC-1503	2.37	2.60	2.37	2.49	-4.63	0.00	2.90
JMSA101 x IPC-828	2.37	2.70	2.30	2.54	-9.27	-2.50	0.00
ICMA842 x IPC-577	2.37	2.33	2.07	2.40	-13.75	-10.71	-10.14
ICMA842 x IPC-804	2.37	2.33	1.87	2.40	-22.08	-17.86**	-18.84*
ICMA842 x IPC-873	2.37	2.27	1.87	2.37	-21.10*	-17.86**	-18.84*
ICMA842 x IPC-827-1	2.37	2.50	1.97	2.49	-20.72**	-14.29**	-14.49
ICMA842 x IPC-1518	2.37	2.80	2.00	2.64	-24.10**	-13.21**	-13.04
ICMA842 x IPC-1104	2.37	2.80	1.67	2.64	-36.62**	-25.00**	-27.54**
ICMA842 x IPC-217	2.37	2.70	2.10	2.59	-18.76**	-9.64**	-8.70
ICMA842 x IPC-338	2.37	2.43	1.97	2.45	-19.59**	-14.29**	-14.49
ICMA842 x IPC-1361	2.37	2.47	1.73	2.47	-29.96**	-22.86**	-24.64**
ICMA842 x IPC-1394	2.37	2.67	1.70	2.57	-33.85**	-23.93**	-26.09**
ICMA842 x IPC-1503	2.37	2.60	1.67	2.54	-34.12**	-25.00**	-27.54**
ICMA842 x IPC-828	2.37	2.70	1.97	2.59	-23.79**	-14.29**	-14.49
ICMA88004 x IPC-577	2.40	2.33	1.83	2.37	-22.62**	-19.29**	-20.29*
ICMA88004 x IPC-804	2.40	2.33	1.87	2.37	-20.93**	-17.86**	-18.84*
ICMA88004 x IPC-873	2.40	2.27	2.17	2.34	-7.07	-7.14	-5.80
ICMA88004 x IPC-827-1	2.40	2.50	2.33	2.45	-4.90	-1.43	1.45
ICMA88004 x IPC-1518	2.40	2.80	2.50	2.60	-3.85	4.64	8.70
ICMA88004 x IPC-1104	2.40	2.80	2.33	2.60	-10.38	-1.43	1.45
ICMA88004 x IPC-217	2.40	2.70	2.33	2.55	-8.63	-1.43	1.45
ICMA88004 x IPC-338	2.40	2.43	2.30	2.42	-4.76	-2.50	0.00
ICMA88004 x IPC-1361	2.40	2.47	1.80	2.44	-26.08**	-20.36**	-21.74*
ICMA88004 x IPC-1394	2.40	2.67	1.90	2.54	-25.05**	-16.79*	-17.39*
ICMA88004 x IPC-1503	2.40	2.60	1.97	2.50	-21.20**	-14.29*	-14.49
ICMA88004 x IPC-828	2.40	2.70	2.10	2.55	-17.65**	-9.64	-8.70
GHB-558 (c)			2.30				
				S.E.±	0.17	0.14	0.14
				C.D. @ 5%	0.33	0.27	0.27
				C.D.@ 1%	0.44	0.36	0.27

MP- Mid parent
BP- Better parent
* and ** -indicate significance at 5% and 1% level respectively

Table 21f. Mean performance of parents, hybrids, check and magnitude of heterosis for ear girth (cm) in pearl millet (Expt.IIIb)

crosses	Mean value				F_1 heterosis (%) over		
	Female	Male	F_1	MP	MP	BP	Check
ICMA94555 x IPC-577	5.57	5.10	6.77	5.34	26.90**	2.03	7.41
ICMA94555 x IPC-804	5.57	5.80	6.63	5.69	16.62**	0.00	5.29
ICMA94555 x IPC-873	5.57	5.37	7.23	5.47	32.18**	8.70**	14.81**
ICMA94555 x IPC-827-1	5.57	5.57	8.00	5.57	43.63**	19.86**	26.98**
ICMA94555 x IPC-1518	5.57	6.63	7.43	6.10	21.80**	11.59**	17.99**
ICMA94555 x IPC-1104	5.57	5.60	7.67	5.59	37.33**	15.07**	21.69**
ICMA94555 x IPC-217	5.57	5.73	8.03	5.65	42.12**	20.29**	27.51**
ICMA94555 x IPC-338	5.57	6.90	7.10	6.24	13.87**	6.81*	12.70*
ICMA94555 x IPC-1361	5.57	6.50	6.83	6.04	13.17**	2.90	8.47
ICMA94555 x IPC-1394	5.57	6.50	6.50	6.04	7.71	-1.88	3.17
ICMA94555 x IPC-1503	5.57	6.70	6.77	6.14	10.35*	2.03	7.41
ICMA94555 x IPC-828	5.57	6.57	6.90	6.07	13.67**	3.91	9.52
JMSA101 x IPC-577	5.17	5.10	7.20	5.14	40.21**	8.26*	14.29
JMSA101 x IPC-804	5.17	5.80	7.27	5.49	32.54**	9.28**	15.34**
JMSA101 x IPC-873	5.17	5.37	7.40	5.27	40.42**	11.16**	17.46**
JMSA101 x IPC-827-1	5.17	5.57	7.50	5.37	39.66**	12.61**	19.05**
JMSA101x IPC-1518	5.17	6.63	5.03	5.90	-14.75**	-23.19**	-20.11**
JMSA101 x IPC-1104	5.17	5.60	4.87	5.39	-9.56	-25.51**	-22.75**
JMSA101x IPC-217	5.17	5.73	5.03	5.45	-7.71	-23.19**	-20.11**
JMSA101x IPC-338	5.17	6.90	5.97	6.04	-1.08	-9.57**	-5.29
JMSA101x IPC-1361	5.17	6.50	7.03	5.84	20.48**	5.80**	11.64
JMSA101x IPC-1394	5.17	6.50	4.67	5.84	-19.97**	-28.41**	-25.93*
JMSA101 x IPC-1503	5.17	6.70	4.77	5.94	-19.63**	-26.96**	-24.34**
JMSA101 x IPC-828	5.17	6.57	5.07	5.87	-13.63**	-22.61**	-19.58**
ICMA842 x IPC-577	5.90	5.10	5.37	5.50	-2.36	-18.26**	-14.81**
ICMA842 x IPC-804	5.90	5.80	6.20	5.85	5.98	-6.23**	-1.59
ICMA842 x IPC-873	5.90	5.37	7.23	5.64	28.31**	8.70**	14.81**
ICMA842 x IPC-827-1	5.90	5.57	7.47	5.74	30.25**	12.17**	18.52**
ICMA842 x IPC-1518	5.90	6.63	7.40	6.27	18.12**	11.16**	17.46**
ICMA842 x IPC-1104	5.90	5.60	8.37	5.75	45.57**	25.22**	32.80**
ICMA842 x IPC-217	5.90	5.73	8.37	5.82	43.94**	25.22**	32.80**
ICMA842 x IPC-338	5.90	6.90	8.10	6.40	26.56**	21.30**	28.57**
ICMA842 x IPC-1361	5.90	6.50	8.13	6.20	31.13**	21.74**	29.10**
ICMA842 x IPC-1394	5.90	6.50	5.03	6.20	-18.87**	-23.19**	-20.11**
ICMA842 x IPC-1503	5.90	6.70	5.00	6.30	-20.63**	-23.62**	-20.63**
ICMA842 x IPC-828	5.90	6.57	5.50	6.24	-11.79**	-16.38**	-12.70*
ICMA88004 x IPC-577	5.03	5.10	5.70	5.07	12.54*	-13.48**	-9.52
ICMA88004 x IPC-804	5.03	5.80	6.40	5.42	18.19**	-3.33	1.59
ICMA88004 x IPC-873	5.03	5.37	6.40	5.20	23.08**	-3.33	1.59
ICMA88004 x IPC-827-1	5.03	5.57	6.43	5.30	21.32**	-2.90	2.12
ICMA88004 x IPC-1518	5.03	6.63	6.83	5.83	17.15**	2.90	8.47
ICMA88004 x IPC-1104	5.03	5.60	7.20	5.32	35.47**	8.26*	14.29**
ICMA88004 x IPC-217	5.03	5.73	7.57	5.38	40.71**	13.62**	20.11**
ICMA88004 x IPC-338	5.03	6.90	5.37	5.97	-9.97*	-18.26**	-14.81**
ICMA88004 x IPC-1361	5.03	6.50	5.37	5.77	-6.85	-18.26**	-14.81**
ICMA88004 x IPC-1394	5.03	6.50	5.20	5.77	-9.80*	-20.72**	-17.46**
ICMA88004 x IPC-1503	5.03	6.70	5.83	5.87	-0.60	-11.59**	-7.41
ICMA88004 x IPC-828	5.03	6.57	6.20	5.80	6.90	-6.23	-1.59
GHB-558 (c)		6.30					
				S. E.±	0.29	0.23	0.23
				C.D. @ 5%	0.56	0.45	0.45
				C.D.@ 1%	0.74	0.59	0.59

MP- Mid parent
BP- Better parent
* and ** -indicate significance at 5% and 1% level respectively

Table 21e. Mean performance of parent, hybrid , check and magnitude of heterosis for ear length (cm) in pearl millet (Expt.IIIb)

Crosses	Mean value				F_1 heterosis(%) over		
	Female	Male	F_1	MP	MP	BP	Check
ICMA94555 x IPC-577	22.07	22.93	22.83	22.50	1.47	-1.54**	-0.72
ICMA94555 x IPC-804	22.07	23.20	25.53	22.64	12.79**	9.70**	11.01**
ICMA94555 x IPC-873	22.07	22.70	24.87	22.39	11.10**	6.95*	8.12*
ICMA94555 x IPC-827-1	22.07	21.37	20.47	21.72	-5.76	-11.36**	-11.01**
ICMA94555 x IPC-1518	22.07	20.47	20.87	21.27	-1.88	-9.70**	-9.28*
ICMA94555 x IPC-1104	22.07	22.33	21.93	22.20	-1.22	-5.29*	-4.64
ICMA94555 x IPC-217	22.07	24.03	25.57	23.05	10.93*	9.86**	11.16**
ICMA94555 x IPC-338	22.07	22.13	20.47	22.10	-7.38	-11.36**	-11.01**
ICMA94555 x IPC-1361	22.07	23.20	22.57	22.64	-0.29	-2.62*	-1.88
ICMA94555 x IPC-1394	22.07	22.27	21.57	22.17	-2.71	-6.78	-6.23
ICMA94555 x IPC-1503	22.07	19.90	20.40	20.99	-2.79	-11.65**	-11.30**
ICMA94555 x IPC-828	22.07	20.90	21.23	21.49	-1.19	-8.20**	-7.68
JMSA101 x IPC-577	20.27	22.93	21.87	21.60	1.25	-5.53	-4.93**
JMSA101 x IPC-804	20.27	23.20	26.53	21.74	22.06**	13.86**	15.36**
JMSA101 x IPC-873	20.27	22.70	25.40	21.49	18.22**	9.16*	10.43
JMSA101 x IPC-827-1	20.27	21.37	26.27	20.82	26.18**	12.78**	14.20**
JMSA101x IPC-1518	20.27	20.47	24.20	20.37	18.80**	4.16	5.22
JMSA101 x IPC-1104	20.27	22.33	27.20	21.30	27.70**	16.65**	18.26**
JMSA101x IPC-217	20.27	24.03	23.23	22.15	4.88	0.12	1.01
JMSA101x IPC-338	20.27	22.13	25.67	21.20	21.08**	10.28**	11.59
JMSA101x IPC-1361	20.27	23.20	22.30	21.74	2.60	-3.75	-3.04
JMSA101x IPC-1394	20.27	22.27	22.67	21.27	6.58	-2.21	-1.45
JMSA101 x IPC-1503	20.27	19.90	26.17	20.09	30.30**	12.36**	13.77**
JMSA101 x IPC-828	20.27	20.90	26.47	20.59	28.59**	13.61**	15.07**
ICMA842 x IPC-577	21.90	22.93	23.77	22.42	6.05	2.37	3.33
ICMA842 x IPC-804	21.90	23.20	24.53	22.55	8.78	5.53	6.67
ICMA842 x IPC-873	21.90	22.70	25.43	22.30	14.04**	9.28**	10.58**
ICMA842 x IPC-827-1	21.90	21.37	22.47	21.64	3.86	-3.04*	-2.32
ICMA842 x IPC-1518	21.90	20.47	22.20	21.19	4.79	-4.16	-3.48
ICMA842 x IPC-1104	21.90	22.33	20.07	22.12	-9.25*	-13.03**	-12.75**
ICMA842 x IPC-217	21.90	24.03	20.97	22.97	-8.69	-9.28**	-8.84*
ICMA842 x IPC-338	21.90	22.13	23.53	22.02	6.88	1.37*	2.32
ICMA842 x IPC-1361	21.90	23.20	25.13	22.55	11.44*	8.03**	9.28*
ICMA842 x IPC-1394	21.90	22.27	24.30	22.09	10.03*	4.58**	5.65
ICMA842 x IPC-1503	21.90	19.90	27.07	20.90	29.52**	16.10**	17.68**
ICMA842 x IPC-828	21.90	20.90	20.80	21.40	-2.80	-9.99**	-9.57**
ICMA88004 x IPC-577	23.00	22.93	22.17	22.97	-3.46	-4.29**	-3.62
ICMA88004 x IPC-804	23.00	23.20	21.30	23.10	-7.79	-7.91*	-7.39*
ICMA88004 x IPC-873	23.00	22.70	22.00	22.85	-3.72	-4.99	-4.35
ICMA88004 x IPC-827-1	23.00	21.37	26.70	22.19	20.35**	14.57**	16.09**
ICMA88004 x IPC-1518	23.00	20.47	27.40	21.74	26.06**	17.48**	19.13**
ICMA88004 x IPC-1104	23.00	22.33	26.53	22.67	17.05**	13.86**	15.36**
ICMA88004 x IPC-217	23.00	24.03	19.63	23.52	-16.52**	-14.86**	-14.64**
ICMA88004 x IPC-338	23.00	22.13	21.47	22.57	-4.85	-7.20*	-6.67
ICMA88004 x IPC-1361	23.00	23.20	20.10	23.10	-12.99**	-12.90*	-12.61**
ICMA88004 x IPC-1394	23.00	22.27	22.13	22.64	-2.23	-4.45	-3.77
ICMA88004 x IPC-1503	23.00	19.90	23.83	21.45	11.10**	2.62*	3.62
ICMA88004 x IPC-828	23.00	20.90	25.43	21.95	15.858*	9.28**	10.58**
GHB-558 (c)		23.00					
				S.E.±	1.03	0.84	0.84
				C.D. @ 5%	2.01	1.64	1.64
				C.D.@ 1%	2.65	2.16	2.16

MP- Mid parent
BP- Better parent
* and ** -indicate significance at 5% and 1% level respectively

Table 21g. Mean performance of parents, hybrids, check and magnitude of heterosis for flag leaf area (cm^2) in pearl millet (Expt.IIIb).

Crosses	Mean value				F_1 heterosis (%) over		
	Female	Male	F_1	MP	MP	BP	Check
ICMA94555 x IPC-577	98.90	97.87	81.20	98.39	-17.47**	-17.90	13.41**
ICMA94555 x IPC-804	98.90	87.47	74.67	93.19	-19.87**	-24.50	4.28
ICMA94555 x IPC-873	98.90	81.90	91.20	90.40	0.88	-7.79	27.37**
ICMA94555 x IPC-827-1	98.90	87.47	87.13	93.19	-6.50*	-11.90	21.69**
ICMA94555 x IPC-1518	98.90	77.80	86.10	88.35	-2.55	-12.94	20.25**
ICMA94555 x IPC-1104	98.90	83.50	98.77	91.20	8.30**	-0.13	37.94**
ICMA94555 x IPC-217	98.90	72.70	103.87	85.80	21.06**	5.03	45.07**
ICMA94555 x IPC-338	98.90	78.67	85.33	88.79	-3.89	-13.72	19.18**
ICMA94555 x IPC-1361	98.90	61.60	90.33	80.25	12.56**	-8.67	26.16**
ICMA94555 x IPC-1394	98.90	61.67	69.57	80.29	-13.35**	-29.66	-2.84
ICMA94555 x IPC-1503	98.90	87.80	71.27	93.35	-23.65**	-27.94	-0.47
ICMA94555 x IPC-828	98.90	86.27	66.63	92.59	-28.03**	-32.63	-6.94
JMSA101 x IPC-577	74.13	97.87	62.53	86.00	-27.29**	-36.77	-12.66**
JMSA101 x IPC-804	74.13	87.47	53.87	80.80	-33.33**	-45.53	-24.77**
JMSA101 x IPC-873	74.13	81.90	73.00	78.02	-6.43*	-26.19	1.96
JMSA101 x IPC-827-1	74.13	87.47	89.50	80.80	10.77**	-9.50	25.00**
JMSA101x IPC-1518	74.13	77.80	104.90	75.97	38.09**	6.07	46.51**
JMSA101 x IPC-1104	74.13	83.50	95.23	78.82	20.83**	-3.71	33.01**
JMSA101x IPC-217	74.13	72.70	89.40	73.42	21.77**	-9.61	24.86**
JMSA101x IPC-338	74.13	78.67	95.30	76.40	24.74**	-3.64	33.10**
JMSA101x IPC-1361	74.13	61.60	106.53	67.87	56.97**	7.71	48.79**
JMSA101x IPC-1394	74.13	61.67	70.13	67.90	3.28	-29.09	-2.05
JMSA101 x IPC-1503	74.13	87.80	74.73	80.97	-7.70*	-24.44	4.38
JMSA101 x IPC-828	74.13	86.27	83.03	80.20	3.53	-16.05	15.97**
ICMA842 x IPC-577	79.80	97.87	85.53	88.84	-3.72	-13.52	19.46**
ICMA842 x IPC-804	79.80	87.47	91.80	83.64	9.76**	-7.18	28.21**
ICMA842 x IPC-873	79.80	81.90	73.63	80.85	-8.93**	-25.55	2.84
ICMA842 x IPC-827-1	79.80	87.47	74.70	83.64	-10.68**	-24.47	4.33
ICMA842 x IPC-1518	79.80	77.80	92.73	78.80	17.68**	-6.24	29.52**
ICMA842 x IPC-1104	79.80	83.50	97.97	81.65	19.99**	-0.94	36.82**
ICMA842 x IPC-217	79.80	72.70	95.87	76.25	25.73**	-3.06	33.89**
ICMA842 x IPC-338	79.80	78.67	96.53	79.24	21.83**	-2.40	34.82**
ICMA842 x IPC-1361	79.80	61.60	84.50	70.70	19.52**	-14.56	18.02**
ICMA842 x IPC-1394	79.80	61.67	80.37	70.74	13.62**	-18.74	12.24**
ICMA842 x IPC-1503	79.80	87.80	67.80	83.80	-19.09**	-31.45	-5.31
ICMA842 x IPC-828	79.80	86.27	70.87	83.04	-14.65**	-28.34	-1.02
ICMA88004 x IPC-577	88.17	97.87	55.70	93.02	-40.12**	-43.68	-22.21**
ICMA88004 x IPC-804	88.17	87.47	61.43	87.82	-30.05**	-37.89	-14.20**
ICMA88004 x IPC-873	88.17	81.90	70.50	85.04	-17.09**	-28.72	-1.54
ICMA88004 x IPC-827-1	88.17	87.47	74.83	87.82	-14.79**	-24.34	4.52
ICMA88004 x IPC-1518	88.17	77.80	85.43	82.99	2.95	-13.62	19.32**
ICMA88004 x IPC-1104	88.17	83.50	91.20	85.84	6.25*	-7.79	27.37**
ICMA88004 x IPC-217	88.17	72.70	95.47	80.44	18.69**	-3.47	33.33**
ICMA88004 x IPC-338	88.17	78.67	74.83	83.42	-10.30*	-24.34	4.52
ICMA88004 x IPC-1361	88.17	61.60	71.63	74.89	-4.35	-27.57	0.05
ICMA88004 x IPC-1394	88.17	61.67	69.63	74.92	-7.06*	-29.60	-2.75
ICMA88004 x IPC-1503	88.17	87.80	66.17	87.99	-24.79**	-33.09	-7.59
ICMA88004 x IPC-828	88.17	86.27	70.17	87.22	-19.55**	-29.05	-2.00
GHB-558 (c)		71.60					
				S.E.±	2.45	2.10	2.00
				C.D. @ 5%	4.81	5.49	5.54
				C.D.@ 1%	6.33	7.20	7.29

MP- Mid parent
BP- Better parent
* and ** -indicate significance at 5% and 1% level respectively

Table 21h. Mean performance of parent s,hybrid, check and magnitude of heterosis for peduncle length (cm)in pearl millet (Expt.IIIb)

Crosses	Mean value				F_1 heterosis(%) over		
	Female	Male	F_1	MP	MP	BP	Check
ICMA94555 x IPC-577	30.53	26.13	29.97	28.33	5.79	-1.83	12.94**
ICMA94555 x IPC-804	30.53	29.27	26.53	29.90	-11.27**	-13.10	0.00
ICMA94555 x IPC-873	30.53	23.77	22.13	27.15	-18.49**	-27.51**	-16.58**
ICMA94555 x IPC-827-1	30.53	26.20	20.87	28.37	-26.42**	-31.64**	-21.36**
ICMA94555 x IPC-1518	30.53	29.73	21.03	30.13	-30.20**	-31.12**	-20.73**
ICMA94555 x IPC-1104	30.53	25.83	22.60	28.18	-19.80**	-25.97**	-14.82**
ICMA94555 x IPC-217	30.53	27.00	23.43	28.77	-18.55**	-23.26**	-11.68**
ICMA94555 x IPC-338	30.53	30.43	20.20	30.48	-33.73**	-33.84**	-23.87**
ICMA94555 x IPC-1361	30.53	28.47	19.27	29.50	-34.68**	-36.88**	-27.39**
ICMA94555 x IPC-1394	30.53	27.80	24.67	29.17	-15.41**	-19.19**	-7.04
ICMA94555 x IPC-1503	30.53	27.73	22.43	29.13	-23.00**	-26.53**	-15.45**
ICMA94555 x IPC-828	30.53	24.80	25.50	27.67	-7.83*	-16.48**	-3.89
JMSA101 x IPC-577	28.77	26.13	21.13	27.45	-23.02**	-30.79**	-20.35**
JMSA101 x IPC-804	28.77	29.27	23.40	29.02	-19.37**	-23.35**	-11.81**
JMSA101 x IPC-873	28.77	23.77	23.13	26.27	-11.95**	-24.24**	-12.81**
JMSA101 x IPC-827-1	28.77	26.20	24.90	27.49	-9.41**	-18.44**	-6.16
JMSA101x IPC-1518	28.77	29.73	24.83	29.25	-15.11**	-18.67**	-6.41
JMSA101 x IPC-1104	28.77	25.83	29.27	27.30	7.22	-4.13	10.30*
JMSA101x IPC-217	28.77	27.00	30.57	27.89	9.63*	0.13	15.20**
JMSA101x IPC-338	28.77	30.43	29.30	29.60	-1.01	-4.03	10.43*
JMSA101x IPC-1361	28.77	28.47	24.17	28.62	-15.55**	-20.83**	-8.92*
JMSA101x IPC-1394	28.77	27.80	29.97	28.29	5.96	-1.83	12.94**
JMSA101 x IPC-1503	28.77	27.73	22.10	28.25	-21.77**	-27.61**	-16.71**
JMSA101 x IPC-828	28.77	24.80	23.07	26.79	-13.87**	-24.43**	-13.07**
ICMA842 x IPC-577	28.57	26.13	25.00	27.35	-8.59*	-18.11**	-5.78
ICMA842 x IPC-804	28.57	29.27	30.20	28.92	4.43	-1.08	13.82**
ICMA842 x IPC-873	28.57	23.77	28.63	26.17	9.40*	-6.22	7.91
ICMA842 x IPC-827-1	28.57	26.20	29.17	27.39	6.52	-4.45	9.92
ICMA842 x IPC-1518	28.57	29.73	27.13	29.15	-6.93	-11.14**	2.26
ICMA842 x IPC-1104	28.57	25.83	30.13	27.20	10.77**	-1.31	13.57**
ICMA842 x IPC-217	28.57	27.00	30.70	27.79	10.49**	0.56	15.70
ICMA842 x IPC-338	28.57	30.43	20.70	29.50	-29.83**	-32.20**	-21.98**
ICMA842 x IPC-1361	28.57	28.47	31.20	28.52	9.40*	2.19	17.59**
ICMA842 x IPC-1394	28.57	27.80	23.43	28.19	-16.87**	-23.26**	-11.68**
ICMA842 x IPC-1503	28.57	27.73	26.17	28.15	-7.03	-14.28**	-1.38**
ICMA842 x IPC-828	28.57	24.80	22.33	26.69	-16.32**	-26.86**	-15.83**
ICMA88004 x IPC-577	28.77	26.13	20.87	27.45	-23.97**	-31.64**	-21.36**
ICMA88004 x IPC-804	28.77	29.27	22.53	29.02	-22.36**	-26.20**	-15.08**
ICMA88004 x IPC-873	28.77	23.77	21.27	26.27	-19.03**	-30.33**	-19.85**
ICMA88004 x IPC-827-1	28.77	26.20	22.93	27.49	-16.57**	-24.89**	-13.57**
ICMA88004 x IPC-1518	28.77	29.73	27.50	29.25	-5.98	-9.92*	3.64
ICMA88004 x IPC-1104	28.77	25.83	22.60	27.30	-17.22**	-25.97**	-14.82**
ICMA88004 x IPC-217	28.77	27.00	21.07	27.89	-24.44**	-30.99**	-20.60**
ICMA88004 x IPC-338	28.77	30.43	28.67	29.60	-3.14	-6.09	8.04**
ICMA88004 x IPC-1361	28.77	28.47	30.30	28.62	5.87	-0.75	14.20**
ICMA88004 x IPC-1394	28.77	27.80	28.83	28.29	1.93	-5.57	8.67
ICMA88004 x IPC-1503	28.77	27.73	25.33	28.25	-10.34**	-17.03**	-4.52
ICMA88004 x IPC-828	28.77	24.80	28.40	26.79	6.03	-6.98	7.04
GHB-558 ©		26.53					
				S.E.±	1.05	0.86	0.85
				C.D. @ 5%	2.05	1.68	1.66
				C.D.@ 1%	2.70	2.21	2.18

MP- Mid parent

BP- Better parent

*and ** -indicate significance at 5% and 1% level respectively

36.88 (ICMA 94555 x IPC-1361) to 0.56 per cent (ICMA 842 x IPC-217). None of the cross combinations showed significant heterobeltiosis. On the other hand, ten hybrids exhibited significant positive heterosis over check. A maximum heterosis of 17.59 per cent over standard check was registered by the cross ICMA 842 x IPC-1361.

4.3.2.2.9 Ear weight per ear

Among the females, the range of variation was from 28.50 to 33.27g and amongst males; it was from 29.13 (IPC-338) to 40.30 g (IPC-827-1). The F_1's ranged from 30.47 (JMSA 101x IPC-873) to 65.40 g (ICMA 842 x IPC827-10).

All the crosses except (JMSA101 x IPC-873) showed positive significant positive mid parent heterosis and the range was from – 8.58 (JMSA101 x IPC-873) to 100.71 per cent (ICMA x IPC-1361). Positive and significant superiority of F_1's over their corresponding better parents were observed in twenty eight hybrids, of which the maximum (64.76%) was manifested by the cross ICMA 842 x IPC-827-1. With respect to heterosis over standard check, nineteen crosses showed significant positive heterosis to an extent of 42.07 per cent.

4.3.2.2.10 Grain yield per ear

There was considerable variation amongst the females, males and hybrids and their range was from 20.13 (ICMA 842) to 30.60 g (ICMA 94555), 19.80 (IPC-338) to 31.67 g (IPC-827-1) and 19.63g (ICMA 94555 x IPC-1503) to 40.33g (ICMA 94555 x IPC-217), respectively.

Twenty-five out of forty eight F_1's showed significant positive heterosis over mid parental value and the range of heterosis was from –33.68 (ICMA 94555 x IPC-1503) to 102.70 (ICMA 842 x IPC-1361) per cent. It was observed that heterosis over better parent was positive and significantly superior in seven cross combinations. Heterosis exhibited by these crosses ranged from –38.02 (ICMA 94555 x IPC-1503) to 27.34 (ICMA 94555 x IPC-217) per cent. With respect to heterosis over the check, eleven crosses manifested significant positive heterosis. A maximum of 38.93 per cent of standard heterosis was displayed by the cross ICMA 842 x IPC-1361.

4.3.2.2.11 Grain yield per plant

The tester varied with a range of 51.57 (ICMA 88004) to 61.47 g (ICMA 842). Among the lines, IPC-873 showed the lowest (51.43 g) and IPC-577 the highest (62.27 g) mean values for grain yield per plant. The F_1's showed an appreciable range of variation from 42.67 (ICMA 842 x IPC-873) to 102.57 g (ICMA 842 x IPC-1361).

Heterosis over mid parent ranged from – 24.41 (JMSA 101 x IPC-873) to 80.58 per cent (ICMA 842 x IPC-1361). Thirty-one and fourteen crosses showed significantly positive and negative mid parent heterosis respectively. The range of better parent heterosis was from –14.98 (ICMA 842 x IPC-873) to 81.21 per cent (ICMA 842 x IPC-1361). Of the 38 hybrids that showed significant heterosis over better parent, only five deviated in negative while as many as 33 deviated in the positive direction. Regarding heterosis over standard check, seventeen crosses recorded significant positive heterosis. A higher heterosis of 58.61 per cent was manifested by cross ICMA 842 x IPC-1361.

4.3.2.2.12 1000-grain weight

Among the testers, ICMA 842 and ICMA 88004 showed the lowest (11.20 g), while JMSA 101 showed the highest (12.00 g) test weight. Among the lines, IPC-873 and IPC-338 had the lowest (9.93 g) and the highest (12.0 g) mean values respectively. The range of variation in F_1's was from 9.47 (ICMA 842 x IPC-338) to 14.63 g (JMSA 101 x IPC-217).

Mid parent heterosis among the crosses ranged from –18.36 (ICMA 842 x IPC-338) to 33.68 (ICMA 88004 x IPC-577). Of the 48 crosses, seven crosses showed significant positive heterosis. As regards the percentage of better parent heterosis, four crosses showed significant heterosis, and their range was from –20.00 (ICMA 842 xIPC-338) to 23.00 (JMSA 101 x IPC-217) per cent. Twenty-one crosses exhibited significant positive heterosis over standard check. The maximum standard heterosis of 35.49 per cent was registered by the cross JMSA 101 x IPC-217.

Table 21i. Mean performance of parents, hybrids , check and magnitude of heterosis for ear weight (g) per ear in pearl millet (Expt.IIIb).

Crosses	Mean value				F_1 heterosis (%) over		
	Female	Male	F_1	MP	MP	BP	Check
ICMA94555 x IPC-577	33.27	38.40	38.60	35.84	7.72**	-1.74	-16.15**
ICMA94555 x IPC-804	33.27	33.93	43.47	33.60	29.38**	10.35**	-5.58*
ICMA94555 x IPC-873	33.27	35.33	51.87	34.30	51.22**	31.19	12.67**
ICMA94555 x IPC-827-1	33.27	40.30	45.57	36.79	23.88**	15.56	-1.01
ICMA94555 x IPC-1518	33.27	39.30	40.23	36.29	10.87**	2.31	-12.60**
ICMA94555 x IPC-1104	33.27	38.03	38.63	35.65	8.36*	-1.66	-16.08**
ICMA94555 x IPC-217	33.27	35.37	49.87	34.32	45.31**	26.23**	8.33**
ICMA94555 x IPC-338	33.27	29.13	40.33	31.20	29.26**	2.56	-12.38**
ICMA94555 x IPC-1361	33.27	33.80	38.60	33.54	15.10**	-1.74	-16.15**
ICMA94555 x IPC-1394	33.27	31.53	40.20	32.40	24.07**	2.23	-12.67**
ICMA94555 x IPC-1503	33.27	38.27	39.20	35.77	9.59*	-0.25	-14.84**
ICMA94555 x IPC-828	33.27	35.23	38.57	34.25	12.61**	-1.81	-16.22**
JMSA101 x IPC-577	31.33	38.40	49.60	34.87	42.26**	25.56**	7.75**
JMSA101 x IPC-804	31.33	33.93	38.50	32.63	17.99**	-1.99	-16.36**
JMSA101 x IPC-873	31.33	35.33	30.47	33.33	-8.58*	-21.91**	-33.82**
JMSA101 x IPC-827-1	31.33	40.30	41.37	35.82	15.51**	5.14	-10.14**
JMSA101x IPC-1518	31.33	39.30	49.27	35.32	39.52**	24.74**	7.02
JMSA101 x IPC-1104	31.33	38.03	53.60	34.68	54.56**	35.48**	16.44**
JMSA101x IPC-217	31.33	35.37	62.63	33.35	87.80**	57.89**	36.06**
JMSA101x IPC-338	31.33	29.13	40.50	30.23	33.97**	2.98	-12.02**
JMSA101x IPC-1361	31.33	33.80	49.97	32.57	53.45**	26.48**	8.54*
JMSA101x IPC-1394	31.33	31.53	38.90	31.43	23.77**	-0.99	-15.50**
JMSA101 x IPC-1503	31.33	38.27	42.07	34.80	20.89**	6.87**	-8.62**
JMSA101 x IPC-828	31.33	35.23	53.47	33.28	60.67**	35.16**	16.15**
ICMA842 x IPC-577	31.20	38.40	55.10	34.80	58.33**	39.21**	19.70**
ICMA842 x IPC-804	31.20	33.93	45.00	32.57	38.19**	14.14**	-2.24**
ICMA842 x IPC-873	31.20	35.33	51.20	33.27	53.92**	29.53**	11.22
ICMA842 x IPC-827-1	31.20	40.30	65.40	35.75	82.94**	64.76**	42.07**
ICMA842 x IPC-1518	31.20	39.30	53.23	35.25	51.01**	34.57**	15.64**
ICMA842 x IPC-1104	31.20	38.03	46.50	34.62	34.33**	17.87**	1.01**
ICMA842 x IPC-217	31.20	35.37	41.20	33.29	23.78**	4.71	-10.50
ICMA842 x IPC-338	31.20	29.13	41.67	30.17	38.14**	5.88	-9.49**
ICMA842 x IPC-1361	31.20	33.80	65.23	32.50	100.71**	64.34**	41.71**
ICMA842 x IPC-1394	31.20	31.53	42.03	31.37	34.00**	6.77	-8.69**
ICMA842 x IPC-1503	31.20	38.27	45.87	34.74	32.06**	16.30**	-0.36**
ICMA842 x IPC-828	31.20	35.23	44.60	33.22	34.28**	13.15**	-3.11
ICMA88004 x IPC-577	28.50	38.40	53.80	33.45	60.84**	35.98**	16.87**
ICMA88004 x IPC-804	28.50	33.93	52.10	31.22	66.91**	31.76**	13.18**
ICMA88004 x IPC-873	28.50	35.33	42.53	31.92	33.26**	8.01**	-7.60*
ICMA88004 x IPC-827-1	28.50	40.30	53.10	34.40	54.36**	34.24**	15.35**
ICMA88004 x IPC-1518	28.50	39.30	48.20	33.90	42.18**	22.08**	4.71
ICMA88004 x IPC-1104	28.50	38.03	47.33	33.27	42.28**	19.93**	2.82
ICMA88004 x IPC-217	28.50	35.37	44.13	31.94	38.19**	11.99**	-4.13
ICMA88004 x IPC-338	28.50	29.13	42.27	28.82	46.69**	7.37	-8.18**
ICMA88004 x IPC-1361	28.50	33.80	42.10	31.15	35.15**	6.95	-8.54**
ICMA88004 x IPC-1394	28.50	31.53	52.10	30.02	73.58**	31.76**	13.18**
ICMA88004 x IPC-1503	28.50	38.27	49.47	33.39	48.18**	25.24**	7.46**
ICMA88004 x IPC-828	28.50	35.23	50.77	31.87	59.33**	28.46**	10.28**
GHB-558 (c)		46.03					
				S.E.±	1.39	1.13	1.20
				C.D. @ 5%	2.72	2.21	2.35
				C.D.@ 1%	3.58	2.91	3.09

MP- Mid parent
BP- Better parent
* and ** -indicate significance at 5% and 1% level respectively

Table 21j. Mean performance of parents, hybrids, check and magnitude of heterosis for grain yield per ear (g) in pearl millet (Expt.IIIb)

Crosses	Mean value				F_1 heterosis (%) over		
	Female	Male	F_1	MP	MP	BP	Check
ICMA94555 x IPC-577	30.60	27.83	28.60	29.22	-2.11	-9.69	-2.05
ICMA94555 x IPC-804	30.60	23.60	30.27	27.10	11.70*	-4.42	3.65
ICMA94555 x IPC-873	30.60	30.00	36.63	30.30	20.89**	15.66**	25.46**
ICMA94555 x IPC-827-1	30.60	31.67	31.03	31.14	-0.34	-2.02	6.28
ICMA94555 x IPC-1518	30.60	26.13	29.80	28.37	5.06	-5.90	2.05
ICMA94555 x IPC-1104	30.60	26.53	29.40	28.57	2.92	-7.17	0.68
ICMA94555 x IPC-217	30.60	26.20	40.33	28.40	42.01**	27.34**	38.13**
ICMA94555 x IPC-338	30.60	19.80	36.70	25.20	45.63**	15.88**	25.68**
ICMA94555 x IPC-1361	30.60	19.90	26.70	25.25	5.74	-15.69**	-8.56
ICMA94555 x IPC-1394	30.60	27.30	20.53	28.95	-29.08**	-35.18**	-29.68**
ICMA94555 x IPC-1503	30.60	28.60	19.63	29.60	-33.68**	-38.02**	-32.76**
ICMA94555 x IPC-828	30.60	30.67	24.63	30.64	-19.60**	-22.23**	-15.64**
JMSA101 x IPC-577	24.57	27.83	27.53	26.20	5.08	-13.07**	-5.71
JMSA101 x IPC-804	24.57	23.60	28.37	24.09	17.79**	-10.42*	-2.85
JMSA101 x IPC-873	24.57	30.00	21.13	27.29	-22.56**	-33.28**	-27.63**
JMSA101 x IPC-827-1	24.57	31.67	25.33	28.12	-9.92*	-20.02**	-13.24**
JMSA101x IPC-1518	24.57	26.13	35.50	25.35	40.04**	12.09*	21.58**
JMSA101 x IPC-1104	24.57	26.53	36.33	25.55	42.19**	14.71**	24.43**
JMSA101x IPC-217	24.57	26.20	40.03	25.39	57.69**	26.40**	37.10**
JMSA101x IPC-338	24.57	19.80	32.40	22.19	46.04**	2.31	10.96**
JMSA101x IPC-1361	24.57	19.90	34.93	22.24	57.09**	10.29*	19.63**
JMSA101x IPC-1394	24.57	27.30	31.50	25.94	21.46**	-0.54*	7.88
JMSA101 x IPC-1503	24.57	28.60	28.30	26.59	6.45	-10.64**	-3.08
JMSA101 x IPC-828	24.57	30.67	32.20	27.62	16.58**	1.67	10.27
ICMA842 x IPC-577	20.13	27.83	28.33	23.98	18.14**	-10.55**	-2.97
ICMA842 x IPC-804	20.13	23.60	20.77	21.87	-5.01	-34.42**	-28.88**
ICMA842 x IPC-873	20.13	30.00	23.03	25.07	-8.12	-27.28**	-21.12**
ICMA842 x IPC-827-1	20.13	31.67	29.73	25.90	14.79**	-6.13	1.83
ICMA842 x IPC-1518	20.13	26.13	27.07	23.13	17.03**	-14.52**	-7.31
ICMA842 x IPC-1104	20.13	26.53	23.67	23.33	1.46	-25.26**	-18.95**
ICMA842 x IPC-217	20.13	26.20	20.73	23.17	-10.51	-34.54**	-29.00**
ICMA842 x IPC-338	20.13	19.80	24.37	19.97	22.06**	-23.05**	-16.55**
ICMA842 x IPC-1361	20.13	19.90	40.57	20.02	102.70**	28.10**	38.93**
ICMA842 x IPC-1394	20.13	27.30	30.43	23.72	28.32**	-3.92	4.22
ICMA842 x IPC-1503	20.13	28.60	31.87	24.37	30.80**	0.63	9.13
ICMA842 x IPC-828	20.13	30.67	33.50	25.40	31.89**	5.78	14.73**
ICMA88004 x IPC-577	21.83	27.83	34.77	24.83	40.03**	9.79	19.06**
ICMA88004 x IPC-804	21.83	23.60	29.87	22.72	31.50**	-5.68	2.28
ICMA88004 x IPC-873	21.83	30.00	30.83	25.92	18.97**	-2.65	5.59
ICMA88004 x IPC-827-1	21.83	31.67	30.37	26.75	13.53**	-4.10	4.00
ICMA88004 x IPC-1518	21.83	26.13	24.73	23.98	3.13	-21.91**	-15.30**
ICMA88004 x IPC-1104	21.83	26.53	26.27	24.18	8.64	-17.05**	-10.05**
ICMA88004 x IPC-217	21.83	26.20	22.40	24.02	-6.72	-29.27**	-23.29**
ICMA88004 x IPC-338	21.83	19.80	20.47	20.82	-1.66	-35.36**	-29.91**
ICMA88004 x IPC-1361	21.83	19.90	20.87	20.87	0.02	-34.10**	-28.54**
ICMA88004 x IPC-1394	21.83	27.30	26.27	24.57	6.94**	-17.05**	-10.05
ICMA88004 x IPC-1503	21.83	28.60	29.67	25.22	17.67	-6.32	1.60
ICMA88004 x IPC-828	21.83	30.67	26.53	26.25	1.07	-16.23**	-9.13
GHB-558 (c)			29.20				
				S.E.±	1.38	1.13	1.06
				C.D. @ 5%	2.70	2.21	2.07
				C.D.@ 1%	3.55	2.91	2.73

MP- Mid parent
BP- Better parent
* and ** -indicate significance at 5% and 1% level respectively.

Table 21k. Mean performance of parents, hybrids, check and magnitude of heterosis for grain yield per plant (g) in pearl millet (Expt.IIIb).

Crosses	Mean value				F1 heterosis(%) over		
	Female	Male	F_1	MP	MP	BP	Check
ICMA94555 x IPC-577	57.13	62.27	73.20	29.22	22.61**	34.05**	13.20**
ICMA94555 x IPC-804	57.13	52.00	74.33	27.10	36.22**	35.86**	14.95**
ICMA94555 x IPC-873	57.13	51.43	77.80	30.30	43.33**	41.43**	20.31**
ICMA94555 x IPC-827-1	57.13	58.33	79.23	31.14	37.24**	43.73**	22.53**
ICMA94555 x IPC-1518	57.13	55.20	80.80	28.37	43.86**	46.25**	24.95**
ICMA94555 x IPC-1104	57.13	52.63	65.20	28.57	18.80**	21.20**	0.82
ICMA94555 x IPC-217	57.13	59.73	100.70	28.40	72.34**	78.21**	55.72**
ICMA94555 x IPC-338	57.13	53.23	83.50	25.20	51.32**	50.59**	29.12**
ICMA94555 x IPC-1361	57.13	52.13	59.30	25.25	8.55**	11.72**	-8.30**
ICMA94555 x IPC-1394	57.13	59.77	53.33	28.95	-8.76**	2.14	-17.53**
ICMA94555 x IPC-1503	57.13	58.73	52.10	29.60	-10.06**	0.16	-19.43**
ICMA94555 x IPC-828	57.13	58.60	65.53	30.64	13.25**	21.73**	1.34
JMSA101 x IPC-577	52.00	62.27	61.80	26.20	8.16**	15.74**	-4.43*
JMSA101 x IPC-804	52.00	52.00	72.80	24.09	40.00**	33.40**	12.58**
JMSA101 x IPC-873	52.00	51.43	51.40	27.29	-0.61	-0.96	-20.52**
JMSA101 x IPC-827-1	52.00	58.33	61.67	28.12	11.79**	15.53**	-4.64*
JMSA101x IPC-1518	52.00	55.20	82.33	25.35	53.60**	48.71**	27.32**
JMSA101 x IPC-1104	52.00	52.63	90.33	25.55	72.67**	61.55**	39.69**
JMSA101x IPC-217	52.00	59.73	98.53	25.39	76.37**	74.72**	52.37**
JMSA101x IPC-338	52.00	53.23	73.80	22.19	40.26**	35.01**	14.12**
JMSA101x IPC-1361	52.00	52.13	77.33	22.24	48.53**	40.68**	19.59**
JMSA101x IPC-1394	52.00	59.77	66.47	25.94	18.94**	23.24**	2.78
JMSA101 x IPC-1503	52.00	58.73	60.20	26.59	8.73**	13.17**	-6.91**
JMSA101 x IPC-828	52.00	58.60	66.07	27.62	19.48**	22.60**	2.16
ICMA842 x IPC-577	61.47	62.27	51.70	23.98	-16.44**	-0.48	-20.05**
ICMA842 x IPC-804	61.47	52.00	48.10	21.87	-15.22**	-6.26	-25.62**
ICMA842 x IPC-873	61.47	51.43	42.67	25.07	-24.41**	-14.98**	-34.02**
ICMA842 x IPC-827-1	61.47	58.33	51.13	25.90	-14.64**	-1.40	-20.93**
ICMA842 x IPC-1518	61.47	55.20	52.27	23.13	-10.40**	0.43	-19.18**
ICMA842 x IPC-1104	61.47	52.63	60.80	23.33	6.57**	14.13**	-5.98**
ICMA842 x IPC-217	61.47	59.73	50.77	23.17	-16.22**	-1.98	-21.49**
ICMA842 x IPC-338	61.47	53.23	44.87	19.97	-21.76**	-11.45**	-30.62**
ICMA842 x IPC-1361	61.47	52.13	102.57	20.02	80.58**	81.21**	58.61**
ICMA842 x IPC-1394	61.47	59.77	75.73	23.72	24.93**	38.11**	17.11**
ICMA842 x IPC-1503	61.47	58.73	66.13	24.37	10.03**	22.69**	2.27
ICMA842 x IPC-828	61.47	58.60	74.53	25.40	24.14**	36.18**	15.26**
ICMA88004 x IPC-577	51.57	62.27	99.53	24.83	74.86**	76.33**	53.92**
ICMA88004 x IPC-804	51.57	52.00	59.47	22.72	14.84**	12.00**	-8.04**
ICMA88004 x IPC-873	51.57	51.43	60.23	25.92	16.95**	13.22**	-6.86**
ICMA88004 x IPC-827-1	51.57	58.33	63.27	26.75	15.14**	18.10**	-2.16
ICMA88004 x IPC-1518	51.57	55.20	47.43	23.98	-11.15**	-7.34**	-26.65**
ICMA88004 x IPC-1104	51.57	52.63	58.47	24.18	12.23**	10.39**	-9.59**
ICMA88004 x IPC-217	51.57	59.73	49.93	24.02	-10.28**	-3.32	-22.78**
ICMA88004 x IPC-338	51.57	53.23	47.80	20.82	-8.78**	-6.74*	-26.08**
ICMA88004 x IPC-1361	51.57	52.13	47.10	20.87	-9.16**	-7.87*	-27.16**
ICMA88004 x IPC-1394	51.57	59.77	50.00	24.57	-10.19**	-3.21	-22.68**
ICMA88004 x IPC-1503	51.57	58.73	62.93	25.22	14.11**	17.55**	-2.68
ICMA88004 x IPC-828	51.57	58.60	59.33	26.25	7.71*	11.77**	-8.25**
GHB-558 (c)			64.67				
				S.E.±	1.75	1.43	1.45
				C.D. @ 5%	3.43	2.80	2.84
				C.D.@ 1%	4.50	3.68	3.73

MP- Mid parent
BP- Better parent
* and ** -indicate significance at 5% and 1% level respectively

4.3.2.2 Combining ability analysis

4.3.2.2.1 Analysis of variance

Analysis of variance for combining ability for the twelve characters studied is summarized in table 22. Mean sum of squares due to testers were highly significant for ear girth, flag leaf area, ear weight, grain yield per ear head and grain yield per plant. In case of lines, eight characters showed highly significant differences *viz*., days to 50 per cent flowering, ear girth, ear length, flag leaf area, peduncle length, ear head weight per ear, grain yield per ear and grain yield per plant. In the interaction component, lines x testers was highly significant in all the characters excepting for productive tillers per plant and test weight. Hybrids exhibited significant differences for all the characters except days to maturity.

The estimates of gca and sca variance are presented in table 22. In all the cases magnitude of sca variances was greater than gca variances. The ratios of gca: sca variances for all the characters except productive tillers/plant were less than unity.

The contribution of lines was more than testers for all the characters. Contribution for lines x testers (interaction component) was of higher magnitude for ear length, days to maturity, plant height, ear head weight per ear, test weight and peduncle length.

4.3.2.2.2 Combining ability effects

The estimates of gca and sca effects of 16 parents, which included four females and twelve males for all the twelve characters, are presented in tables 23 and 24 respectively.

4.3.2.2.2.1 Days to 50 per cent flowering

Among the female parents, ICMA 842 (-1.15) was the best general combiner, while JMSA101 (0.86) was the poor general combiner for earliness. Among 12 males, IPC-828 appeared to be the best general combiner for earliness.

Only three crosses showed significant negative sca effects. The cross, ICMA 94555 x IPC-827-1 had the highest negative sca effect (-3.34).

4.3.2.2.2.2 Days to maturity

Out of the four female parents, only one parent ICMA 842(-0.98) registered significant negative gca effects. Among twelve males, only one *viz*., IPC-828 (-1.60) displayed significant negative gca effect and was the superior general combiner for earliness.

Among the crosses, two crosses *viz*., ICMA 94555 x IPC-873 and ICMA 94555 x IPC-827-1 showed significant negative sca effects for days to maturity. The cross ICMA 94555 x IPC-827-1 attained highly significant negative sca effect.

4.3.2.2.2.3 Plant height

All the four female parents registered significant gca effect and it ranged from 6.58 (ICMA 94555) to – 7.80 (ICMA 88004). After IPC-577, the next best general combiner was IPC-804. None of the male parents showed significant gca effects.

Of the 47 hybrids that showed significant sca effects, 18 exhibited significant positive sca effects for plant height. The hybrid ICMA 94555 x IPC-1104, ICMA 94555 x IPC-338, ICMA842 x IPC-804, ICMA88004 x IPC-873 were the best specific combiners showing highly significant positive sca effect. The crosses JMSA 101 x IPC-1361, ICMA842 x IPC-338, ICMA 88004 x IPC-217, JMSA101 x IPC-1104 showed highest significant negative sca effect and considered as poor specific combiners.

4.3.2.2.2.4 Productive tillers per plant

In case of testers, none of them exhibited significant gca effect. Among the male lines, four showed significant gca effect, of which IPC-338 (0.80) and IPC-1518(0.57) were considered to be the best general combiners as they registered highly significant positive gca effects. Out of two lines, that manifested negative gca effect, IPC-873 registered the maximum value (-0.75).

Six crosses showed significant sca effects for this trait. Among them ICMA842 x IPC-1394, ICMA 842 x IPC-1518, ICMA 88004 x IPC-338 were considered as the best specific

Table 21l. Mean performance of parents, hybrids, check and magnitude of heterosis for 1000 grain weight (g) in pearl millet (Expt.IIIb)

Crosses	Mean value				F_1 heterosis (%) over		
	Female	Male	F_1	MP	MP	BP	Check
ICMA94555 x IPC-577	11.80	10.00	11.33	10.90	3.94	-4.50	4.94
ICMA94555 x IPC-804	11.80	11.40	10.93	11.60	-5.78	-7.83	1.23
ICMA94555 x IPC-873	11.80	9.93	12.10	10.87	11.37	1.92	12.04**
ICMA94555 x IPC-827-1	11.80	10.90	10.23	11.35	-9.87	-13.67	-5.25
ICMA94555 x IPC-1518	11.80	11.60	10.87	11.70	-7.09	-8.33	0.62
ICMA94555 x IPC-1104	11.80	11.00	11.47	11.40	0.61	-3.33	6.17*
ICMA94555 x IPC-217	11.80	11.27	14.00	11.54	21.37**	17.75	29.63**
ICMA94555 x IPC-338	11.80	12.00	11.17	11.90	-6.13	-5.83	3.40
ICMA94555 x IPC-1361	11.80	10.00	10.87	10.90	-0.28	-8.33	0.62
ICMA94555 x IPC-1394	11.80	11.87	10.20	11.84	-13.81	-13.92	-5.56*
ICMA94555 x IPC-1503	11.80	10.57	11.67	11.19	4.34	-1.67	8.02*
ICMA94555 x IPC-828	11.80	10.23	13.00	11.02	18.02	9.42	20.37**
JMSA101 x IPC-577	12.00	10.00	14.50	11.00	31.82**	21.92*	34.26**
JMSA101 x IPC-804	12.00	11.40	12.73	11.70	8.80	7.17	17.90**
JMSA101 x IPC-873	12.00	9.93	11.40	10.97	3.97	-3.92	5.56*
JMSA101 x IPC-827-1	12.00	10.90	11.10	11.45	-3.06	-6.42	2.78
JMSA101x IPC-1518	12.00	11.60	11.60	11.80	-1.69	-2.25	7.41**
JMSA101 x IPC-1104	12.00	11.00	14.00	11.50	21.74**	17.75	29.63**
JMSA101x IPC-217	12.00	11.27	14.63	11.64	25.74**	23.00*	35.49**
JMSA101x IPC-338	12.00	12.00	11.20	12.00	-6.67	-5.58	3.70
JMSA101x IPC-1361	12.00	10.00	10.40	11.00	-5.45	-12.25	-3.70
JMSA101x IPC-1394	12.00	11.87	10.63	11.94	-10.93	-10.33	-1.54
JMSA101 x IPC-1503	12.00	10.57	11.33	11.29	0.40	-4.50	4.94
JMSA101 x IPC-828	12.00	10.23	11.13	11.12	0.13	-6.17	3.09
ICMA842 x IPC-577	11.20	10.00	10.37	10.60	-2.17	-12.50	-4.01
ICMA842 x IPC-804	11.20	11.40	10.13	11.30	-10.35	-14.50	-6.17*
ICMA842 x IPC-873	11.20	9.93	10.13	10.57	-4.12	-14.50	-6.17*
ICMA842 x IPC-827-1	11.20	10.90	11.07	11.05	0.18	-6.67	2.47
ICMA842 x IPC-1518	11.20	11.60	10.33	11.40	-9.39	-12.83	-4.32
ICMA842 x IPC-1104	11.20	11.00	10.97	11.10	-1.17	-7.50	1.54
ICMA842 x IPC-217	11.20	11.27	9.80	11.24	-12.77	-17.25	-9.26**
ICMA842 x IPC-338	11.20	12.00	9.47	11.60	-18.36*	-20.00*	-12.35**
ICMA842 x IPC-1361	11.20	10.00	14.43	10.60	36.13**	21.33*	33.64**
ICMA842 x IPC-1394	11.20	11.87	13.93	11.54	20.76*	17.17	29.01**
ICMA842 x IPC-1503	11.20	10.57	12.20	10.89	12.08	2.75	12.96**
ICMA842 x IPC-828	11.20	10.23	12.00	10.72	11.99	1.08	11.11**
ICMA88004 x IPC-577	11.20	10.00	14.17	10.60	33.68**	19.17	31.17**
ICMA88004 x IPC-804	11.20	11.40	10.07	11.30	-10.88	-15.00	-6.79*
ICMA88004 x IPC-873	11.20	9.93	10.70	10.57	1.28	-9.75	-0.93
ICMA88004 x IPC-827-1	11.20	10.90	12.53	11.05	13.39	5.50	16.05**
ICMA88004 x IPC-1518	11.20	11.60	12.20	11.40	7.02	2.75	12.96**
ICMA88004 x IPC-1104	11.20	11.00	12.13	11.10	9.28	2.17	12.35**
ICMA88004 x IPC-217	11.20	11.27	11.20	11.24	-0.31	-5.58	3.70
ICMA88004 x IPC-338	11.20	12.00	11.40	11.60	-1.72	-3.92	5.56*
ICMA88004 x IPC-1361	11.20	10.00	10.77	10.60	1.60	-9.17	-0.31
ICMA88004 x IPC-1394	11.20	11.87	11.40	11.54	-1.17	-3.92	5.56*
ICMA88004 x IPC-1503	11.20	10.57	10.83	10.89	-0.51	-8.67	0.31
ICMA88004 x IPC-828	11.20	10.23	11.27	10.72	5.18	-5.00	4.32
GHB-558 (c)		10.80					
				S. E.±	0.96	0.78	0.30
				C.D. @ 5%	1.88	1.52	0.58
				C.D.@ 1%	2.47	2.00	0.77

MP- Mid parent
BP- Better parent
* and ** -indicate significance at 5% and 1% level respect

Table 22. Analysis of variance for combining ability in respect of 12 different characters in pearl millet (Expt.IIIb)

Sources of variation	df	Days to 50% flowering	Days to maturity	Plant height (cm)	Prod. tillers /plant	Ear length (cm)	Ear girth (cm)	Flag leaf area (cm^2)	Peduncle length (cm)	Ear weight/ ear (g) (g)	Grain yield / ear (g) (g)	Grain yield/ plant (g)	1000 grain weight (g)
		Mean sum of squares											
Replication	2	6.41	33.39**	55.57	0.36**	10.94**	2.22**	12.95	26.05**	5.04	3.24	65.7**	5.01
Hybrids	47	30.11**	42.58	588.86**	0.41**	15.75**	3.52**	520.85**	36.9**	160.73**	92.97**	737.86**	5.33*
Lines	11	30.05**	4.2	102.8	0.1	4.57*	1.12**	348.93**	12.25**	30.18**	34.65**	43.13**	1.55
Testers	3	2.97	4.75	30.49	0.01	3.87	0.57**	348.11**	2.55	11.51**	63.2**	146.53**	38.51**
LxT	33	64.28**	40.23**	521.7**	0.11	16.07*	1.73**	287.36**	27.98**	135.38**	37.62**	323.97**	4.00
Error	126	8.66	6.58	10.63	0.06	2.14	0.17	12.01	2.34	3.89	3.85	6.14	2.44
		Estimates of variance											
GCA		18.21	0.55	29.00	0.03	0.37	0.21	29.77	1.73	7.04	6.25	48.89	0.15
SCA		18.54	1.21	139.02	0.02	4.64	0.52	91.75	8.85	43.82	11.25	105.9	0.51
GCA/SCA		0.98	0.45	0.20	1.50	0.08	0.40	0.32	0.20	0.16	0.55	0.46	0.29
variance of tester		0.36	0.45	21.93	-0.01	0.06	0.01	3.1	0.47	2.37	0.8	6.63	-0.02
variance of lines		71.76	0.85	50.19	0.11	1.13	0.78	109.78	5.51	21.02	22.63	175.6	0.65
Contribution													
Tester		0.55	7.91	9.69	0.61	1.84	1.36		3.34	3.55	2.24	2.12	2.44
Lines.		81.4	25.76	28.09	81.43	26.54	64.01		43.4	37.3	69.34	67.05	45.02
LxT		18.04	66.32	62.2	17.75	71.61	34.54		53.25	59.14	28.41	30.82	52.73

Expt.IIIb: refers to line x tester experiment IIIb

* and ** indicates significance at 5 % and 1 % level respectively

Table 23. Estimation of gca for 12 different characters in pearl millet (Expt.IIIb)

	gca effects											
Testers	Days to 50% flowering	Days to maturity	Plant height (cm)	Productive tillers per plant	Ear length (cm)	Ear girth (cm)	Flag leaf area (cm^2)	Peduncle length (cm)	Panicle weight per ear (g)	Grain yield per ear head (g)	Grain yield per plant (g)	1000 grain weight (g)
ICMA 94555	0.49	0.56	6.58**	0.08	1.10**	0.42**	7.2**	0.85**	5.25**	2.36**	7.25**	0.08*
JMSA101	0.86*	0.61	6.42**	-0.02	-1.75**	-0.71**	-6.33**	0.66**	-6.73**	-1.84**	-2.99**	0.55**
ICMA842	-1.15**	-0.98**	-1.38**	0.01	0.77**	0.38**	-2.03**	-1.37**	2.05**	-0.74**	-6.98**	0.04*
ICMa88004	0.29	0.37	-7.80**	0.09	0.98**	0.32**	8.36**	0.71**	4.68**	2.59**	9.97**	-0.6**0
S.E.(gi)	0.36	0.33	0.14	0.09	0.07	0.05	0.08	0.06	0.16	0.05	0.57	0.01
S.E.(gi-gj	0.51	0.45	0.20	0.14	0.09	0.14	0.11	0.09	0.23	0.09	0.76	0.03
Lines												
IPC-577	0.31	0.39	11.04	-0.31	2.09**	0.21*	-1.99**	3.61**	3.58**	5.50**	12.26	1.51**
IPC-804	0.67	1.39	7.04	-0.20	0.58**	-0.64**	7.32**	2.14**	-0.47*	1.10**	2.92	-0.45**
IPC-873	-0.354	-0.27	-8.11	-0.75**	-3.14**	-0.61**	-9.89**	0.94**	-2.12**	4.00**	4.76	0.95**
IPC-827-1	-0.90	-0.83	8.73	-0.42	1.21**	0.08	-6.50**	-1.54**	-2.31**	-1.96**	-12.63	0.61**
IPC-1518	-0.45	-0.83	-3.42	0.57**	-0.68**	-0.30**	0.09	0.25	-1.04**	-2.67**	-3.61	-0.02
IPC-1104	0.31	0.39	-4.26	0.24	-0.36**	0.26**	-3.06**	0.22**	5.30**	-2.05**	6.01	-0.67**
IPC-217	0.09	-0.16	14.65	-0.31	0.14	0.34**	9.90**	0.69**	1.32**	-1.88**	1.78	-0.69**
IPC-338	-0.45	-0.38	10.78	0.80**	2.78**	0.63**	0.08	1.04**	7.82**	3.37**	5.01	-0.71**
IPC-1361	1.31	-0.05	0.80	0.35	0.96**	0.97**	-12.46**	1.15**	-0.69	0.94**	-9.90	-0.78**
IPC-1394	-0.12	-0.38	-8.94	0.02	2.78**	0.26**	18.24**	1.20**	-0.01	-0.59	5.80	-1.10**
IPC-1503	-1.70*	-1.60*	1.85	-0.53*	-1.29**	0.34**	-0.72**	-3.26**	-1.12**	-3.55**	-15.66	0.47**
IPC-828	-0.90	1.05	-2.41	0.02	-1.40**	-0.40**	-11.84**	1.51**	-8.01**	-1.37**	0.49	1.14**
S.E.(gi)	0.72	0.75	0.31	0.23	0.15	0.10	0.17	0.15	0.35	0.16	1.20	0.05
S.E.(gi-gj)	1.11	1.01	0.45	0.32	0.20	0.14	0.24	0.21	0.50	0.22	1.71	0.06

Expt.IIIb: refers to line tester -I experiment IIIb, *and ** : indicate significance at 5% and 1 % level respectively.

Table 24. Estimation of SCA effects for 12 different characters in pearl millet (Expt.IIIb)

	sca effects											
Crosses	Days to 50% flowering	Days to maturity	Plant height (cm)	Productive tillers per plant	Ear length (cm)	Ear girth (cm)	Flag leaf area (cm^2)	Peduncle length (cm)	Ear weight per ear (g)	Grain yield / ear (g)	Grain yield per plant (g)	1000 grain weight (g)
ICMA 94555xIPC-577	-1.90	2.05	-5.44**	0.46	-1.20**	0.75**	-18.39**	1.72**	-3.15**	2.31**	-4.40*	-1.16**
ICMA 94555xIPC-804	0.57	0.71	-4.99**	-0.31	-0.23	0.36*	-14.39**	-1.93**	5.11**	1.39**	8.50**	0.48**
ICMA 94555xIPC-873	-2.65*	-2.50*	-4.52**	0.02	0.56*	-0.31	22.27**	2.21**	-13.27**	1.63**	10.94**	1.29**
ICMA 94555xIPC-827-1	-3.3*4	-3.28**	9.14**	0.24	-2.29**	-0.57**	-1.56**	-3.18**	3.08**	2.35**	11.19**	-0.51**
ICMA 94555xIPC-1518	-0.87	-0.72	-6.50*	-0.46	-0.25	-0.65**	-4.24**	0.61	-5.40**	-5.78**	-11.06**	-0.12
ICMA 94555xIPC-1104	-0.43	-0.28	24.08**	-0.86*	0.61*	-0.68**	-2.58**	1.70**	-4.78**	-0.32	13.13**	0.50**
ICMA 94555xIPC-217	2.34	0.27	-5.48**	-0.31	1.46**	0.54**	-9.20**	2.68**	4.37**	1.36**	2.24	0.57**
ICMA 94555xIPC-338	-0.43	-0.28	17.99**	0.24	0.91**	-0.42*	46.23**	-1.00**	3.99**	2.39**	11.82**	-1.17**
ICMA 94555xIPC-1361	1.45	1.60	-9.79**	0.13	0.21	-0.15	-8.57**	-0.25	8.35**	1.27**	-6.17**	-1.58**
ICMA 94555xIPC-1394	2.12	2.27	-2.59**	0.13	-0.68*	-0.02	-18.40**	-0.24	0.27	-2.52**	-15.80**	-0.68**
ICMA 94555xIPC-1503	0.34	0.49	-10.69**	0.13	0.32	0.31	7.02**	0.02	3.59**	-0.77**	7.91**	0.66**
ICMA 94555xIPC-828	0.15	0.16	-2.11**	-0.08	1.18**	0.38**	-16.77**	-2.25**	3.18**	1.05**	-3.36	0.32**
JMSA101 xIPC-577	1.39	1.31	7.12**	-0.11	1.60**	-0.13	42.34**	1.95**	-0.72	-3.25**	2.70	0.21**
JMSA101 xIPC-804	0.23	0.38	15.47**	0.35	0.65**	0.35*	5.12**	1.02*8	-1.27**	-0.93**	-7.12**	1.28**
JMSA101 xIPC-873	0.23	0.38	-8.83**	-0.20	-0.12	0.27	3.58**	0.16	-6.45**	-2.54**	-13.24**	0.54**
JMSA101 xIPC-827-1	-1.43	-1.28	-5.70**	0.66	-2.24**	-0.16	9.91**	-1.28**	7.27**	-0.80**	-4.46*	0.22**
JMSA101x IPC-1518	1.50	1.43	8.45**	-0.33	-1.61**	0.52**	-9.60**	-2.28**	-1.95**	4.35**	-17.00**	-1.37*8
JMSA101x IPC-1104	1.39	1.31	-11.98**	-0.11	-0.46	0.53**	-11.23**	0.17	-4.34**	1.54**	-1.17	0.57**
JMSA101 xIPC-217	1.05	0.98	-10.34**	-0.44	0.85**	0.30	-8.95**	0.25	-0.46	-0.67**	-10.70**	-0.38**
JMSA101 xIPC-338	0.61	0.54	-1.69**	-0.55	2.48**	0.21	8.57**	-2.39*8	2.68**	4.48**	9.61**	-0.71**
JMSA101 xIPC-1361	1.05	0.98	-27.40**	-0.22	-2.47**	0.32	-3.13**	-0.81**	13.24**	-0.14	-14.09**	-0.13
JMSA101 xIPC-1394	-0.60	-0.68	9.28**	1.00**	0.49	-0.58**	7.73**	0.608	2.82	-5.47*8	2.60	0.69**
JMSA101 xIPC-1503	0.52	-0.59	8.20**	0.59	-0.98**	-1.56	-5.98**	-2.20	2.10	4.20	-1.95	0.39
JMSA101 xIPC-828	-1.05	-1.12	-1.51**	0.44	-0.10	-0.02	-10.24**	1.76**	-0.33	-5.19**	-3.30	2.28**
ICMA 842xIPC-577	-1.60	-1.68	-0.22	-0.33	-0.17	-0.75**	-8.61**	-0.83**	-6.21**	0.76**	9.69**	-0.16**

Table.24. Contd

ICMA 842xIPC-804	-0.94	-1.01	16.61**	0.11	1.92**	0.07	4.62**	-0.83**	4.79**	1.47**	8.31**	0.40**
ICMA 842xIPC-873	-1.96	-2.03	-2.12**	-0.35	-1.37**	-0.23	-27.95**	1.55**	-12.38**	1.85**	-11.20**	-0.70**
ICMA 842xIPC-827-1	2.37	2.29	1.20**	-0.13	-1.43**	0.26	10.51**	0.02	-2.35**	-1.68**	-0.49	0.89**
ICMA 842xIPC-1518	0.25	0.18	8.19**	0.86*	-2.23**	0.44**	-4.33**	2.92**	5.87**	-1.70**	1.46	0.84**
ICMA 842xIPC-1104	-0.83	-0.90	7.96**	-0.22	-1.34**	0.00	4.06**	0.05	-4.78**	-1.36**	-5.16*	0.10
ICMA 842xIPC-217	-2.05	-2.12	4.62**	-0.77	-1.23**	-0.21	-3.62**	-0.84**	2.09**	7.22**	21.25**	0.05
ICMA 842xIPC-338	-1.27	-1.34	-11.54**	-0.22	-1.83**	-0.35*	-5.39**	-0.84**	-8.48**	-1.02**	-2.06	-0.19**
IICMA 842xIPC-1361	-0.63	-0.70	3.32**	-0.08	1.56**	0.36*	5.71**	1.78**	2.10**	0.46	0.96	-0.37**
ICMA 842xIPC-1394	1.14	1.07	-3.92**	1.08**	1.04**	-0.26	-12.66**	-0.89**	0.03	-5.98**	6.16**	0.08
ICMA 842xIPC-1503	-0.96	-1.03	-6.00**	0.31	-0.44	-0.10	-34.99**	0.06	-2.04**	-3.98**	-10.64**	0.60**
ICMA 842xIPC-828	2.37	0.18	-10.90**	0.08	0.32	0.21	-14.54**	0.66**	1.66**	-0.67	-3.80	-0.69**
ICMA 88004 xIPC-577	-1.18	-1.25	-1.09*	-1.24**	-2.21**	-0.06	-12.36**	-2.33**	-4.00**	2.94**	-13.32**	0.32**
ICMA 88004 xIPC-804	0.81	0.74	-5.84**	0.08	0.15	-0.38*	12.71**	-3.10**	1.60**	0.31	8.53**	0.22**
ICMA 88004 xIPC-873	-0.40	-0.48	11.30**	-0.13	-1.11**	0.17	18.82**	0.82**	-4.01**	3.92**	9.48**	-0.69**
ICMA88004 xIPC-827-1	-2.85*	-1.81	6.61**	-0.57	-1.14**	-0.89**	21.08**	-1.52**	-4.03**	2.18**	3.82	-0.21**
ICMA 88004 xIPC-1518	-1.29	-1.37	-3.84**	-0.68	0.70**	-0.16	10.66**	-1.24**	6.34**	3.26**	1.79	0.47**
ICMA 88004 xIPC-1104	1.37	1.29	9.06**	-0.35	0.29	0.09	5.02**	0.18	7.48**	1.77**	3.56	-0.62**
ICMA 88004 xIPC-217	2.37	0.18	-10.90**	0.08	0.32	0.21	-14.54**	0.66**	1.66**	-0.67	-3.80	-0.69**
ICMA 88004 xIPC-338	1.27	0.89	-2.58**	0.98*	2.10**	0.22	6.79**	3.01**	3.67**	-4.78**	-7.20**	-1.42**
ICMA 88004 xIPC-1361	-0.07	-0.14	-2.02**	0.86*	1.83**	0.21	22.03**	2.20**	-2.37**	-4.69**	-5.44**	-1.08**
ICMA 88004 xIPC-1394	1.03	0.96	-3.92**	0.08	1.17**	0.00	0.27	1.08**	6.10**	1.95**	9.18**	-0.38**
ICMA 88004 xIPC-1503	2.63	1.25	3.68**	0.52	0.32	-1.52**	-6.54**	-0.27	2.59**	-4.26**	6.82**	0.56**
ICMA 88004 xIPC-828	1.85	-0.98	-2.50**	0.32	-2.00**	-0.59**	5.98**	-1.62**	-4.20**	1.26**	-4.95**	0.23**
S.E.(ij)	0.36	1.25	0.55	0.38	0.25	0.17	0.32	0.24	0.59	0.26	2.10	0.08
S.E.(sij-skl)	1.92	1.78	0.76	0.54	0.36	0.25	0.43	0.41	1.84	0.38	2.97	0.12
C.D.@ 1%	3.55	3.28	1.40	1.03	0.68	0.48	0.80	0.69	1.57	0.70	5.53	0.22
C.D.@ 5%	2.65	2.47	1.04	0.76	0.50	0.17	0.63	0.48	1.18	0.53	4.18	0.16

Expt.IIIb refers to line tester experiment IIIb.

* and ** : indicate significance at 5% and 1 % level respectively

combiners. Of the crosses showing negative sca effects, ICMA88004 x IPC-577 was very poor specific combiner.

4.3.2.2.2.5 Ear length

Among the females, ICMA 94555 (1.10), ICMA 842 (0.77) and ICMA 88004 (0.98) showed significant positive gca and considered as better general combiners. Among males, eleven lines registered significant gca effects; of these, six showed significant positive gca effect and were found to be best general combiners.

Positive and significant sca effects were displayed by fifteen crosses, of which the maximum was recorded by the cross JMSA101 x IPC-338. Sixteen crosses displayed negative and significant sca effect and the rest were statistically non- significant.

4.3.2.2.2.6 Ear girth

The testers ICMA94555 (0.42), ICMA 842 (0.38) and ICMA 88004 (0.32) were good general combiners for ear girth. In contrast to this, JMSA 101 was poor general combiner as it registered negative gca value (-0.71). Among the male lines, IPC-1394 (0.97) and IPC-1361 (0.63) were the best general combiners, as they recorded highest positive gca effect. Of the four lines, which showed significant and negative gca values, IPC-804 was found to be the poorest general combiner for this trait.

Twenty crosses exhibited significant sca effects; of these, nine crosses possessed positive value and eleven crosses deviated in the negative direction. The cross, ICMA 94555 x IPC-577 was the best specific combiner, while the cross ICMA 88004 x IPC-1394 was the poorest specific combiner.

4.3.2.2.2.7 Flag leaf area

The testers, ICMA 88004 (8.36) and ICMA 94555 (7.2) were the best general combiners, while JMSA 101(-6.33) and ICMA842 (-2.03) were the poorest general combiners. Among the male parents, only three parents exhibited significant positive gca effects and were best general combiners, while IPC-1361 and IPC-828 were considered as poorest general combiners.

Out of twenty crosses that exhibited significant positive sca effects, the crosses ICMA94555 x IPC-338, JMSA 101 x IPC-577 and ICMA94555 x IPC-873 were identified as good specific combiners. Twenty-six crosses showed significant negative sca effects, and of these ICMA 842 x IPC-1503, IPC 842 x IPC-873 and IMCA 94555 x IPC-1394 were the poorest specific combiners.

4.3.2.2.2.8 Peduncle length

All the four testers displayed significant gca effects. Of them ICMA 94555, ICMA88004 and JMSA101 registered the maximum values of 0.85, 0.71 and 0.66 gca effect respectively. The remaining one (ICMA 842) registered significant negative gca effect (-1.37). With respect to the male parent, except IPC-1104, all displayed significant gca effects and the lines IPC-577 and IPC-804 were the best general combiners. The line, IPC-1503 was the poorest general combiner for this character.

Out of 48 crosses, the estimates of sca effects were significant for 34 crosses. Amongst them, ICMA94555 x IPC-217, JMSA101 x IPC-577, ICMA842 x IPC-1518, ICMA 88004 x IPC-338 were considered to be best specific combiner, while the crosses ICMA94555 x IPC-827-1, ICMA88004 x IPC-804 and JMSA 101 x IPC-338 were the poorest specific combiners.

4.3.2.2.2.9 Ear weight per ear

The testers, ICMA 94555 (5.25), ICMA 88004(4.68) and ICMA 842 (2.05) were the best general combiners, while JMSA 101(-6.73) was the poorest general combiner for this trait. Among twelve pollen parents, ten exhibited significant gca effect, of which three lines IPC-338, IPC-1104 and IPC-577 were the best general combiners with positive significant effects, while IPC-828 was the poorest general combiners.

Forty-one crosses exhibited significant sca effects, out of them twenty-one crosses showed significant positive sca effect. The crosses ICMA 94555 x IPC-1361, JMSA 101 x

IPC-1361, ICMA 88004 x IPC-1104, were best specific combiners, while ICMA 94555 x IPC-873 and ICMA842 x IPC-873 were the poorest specific combiners.

4.3.2.2.2.10 Grain yield per ear

General combining ability effects for grain yield per ear was significant and positive in testers ICMA 94555(2.36) and ICMA 88004 (2.59), which were found to be good general combiners. Out of twelve male parents IPC-577, IPC-804, IPC-873, IPC-338 and IPC1361 recorded statistically significant positive gca effects, while IPC-1503, IPC-1518 and IPC-1104 registered significant negative values and considered as poorest general combiners.

Out of 48 crosses, twenty-two crosses registered significant positive sca effect. Of them ICMA 842 x IPC-217, JMSA 101 x IPC-338, JMSA 101 x IPC-1518 and ICMA 88004 x IPC-873 were superior specific combiners for this trait. Nineteen crosses deviated significantly in negative direction.

4.3.2.2.2.11 Grain yield per plant

Two testers ICMA94555 (7.25) and ICMA88004 (9.97) manifested positive and significant gca effects. The testers JMSA 1012(-2.99) and ICMA842-6.98) possessed significant negative effect. The female parent ICMA 88004 showed highly significant positive effect. Among the twelve pollen parents, IPC-577, IPC-1104, IPC-1394 and IPC-1361 exhibited positive gca effects but statistically non-significant.

Fifteen crosses showed positive and significant sca effect, of them highest values were recorded by crosses ICMA842 x IPC-217, ICMA94555 x IPC-1104, ICMA94555 x IPC-827-1 and ICMA94555 x IPC-873.Fourteen crosses showed significant and negative sca effects and the poorest specific combiner was JMSA 101x IPC-1518.

4.3.2.2.2.12 1000-Grain weight

Among the females, ICMA 94555 (0.08), JMSA 101 (0.55) and ICMA 842 (0.04) exhibited significant positive gca effect, while ICMA 88004 showed significant negative gca effect. Among the pollen parents, five lines showed significant positive gca effect, IPC 577 and IPC 828 were the best general combiners. A total of six lines recorded significant negative gca effect, and of these IPC-1394 was found to be the poorest general combiner.

Among the crosses, 22 exhibited significant positive sca effects and the crosses JMSA 101x IPC-828, ICMA 94555 x IPC-873 and JMSA 101 x IPC-804 were best specific combiners. A total of seventeen crosses showed significant negative sca effects and of them ICMA 94555 x IPC-1361, JMSA101 x IPC-1518 and ICMA 94555 x IPC-338 were considered as the poorest specific combiners.

4.4 Inheritance of rust resistance

In the present investigation, a rust susceptible parent (81B) and three resistant donors *viz*., IP-2933-1, IP-6240-3 and 700481-1-5-1 were selected for the study. All the three resistant donors were crossed to 81B and their reciprocals were produced. A total of six F_1's, their F_2's, six BC_1 and BC_2 generations were developed subsequently. The $F_{1,}$ F_2, BC_1 and BC_2 populations and parents were scored for their reaction to rust under field conditions.

The results revealed that hybrids were always resistant in both straight and reciprocal situations. Among the parents 81B a susceptible check showed susceptibility to rust, while the resistant parents, P-2933-1, IP-6240-3 and 700481-1-5-3 showed all resistant plants (Table 25). The distribution of resistant and susceptible plants in F_2, BC_1 and BC_2 generation of the six crosses are presented in Table 26.

4.4.1 Segregation pattern in direct crosses

Of the three $F_{2,}$ BC_1 and BC_2 populations of direct crosses all showed segregation with respect to rust resistance and susceptibility. In the F_2 of a cross 81B x P-2933-1, out of 600 plants, 438 were resistant and 162 were susceptible. The segregation showed good fit to the monogenic ratio of 3:1 with a chi-square value of 1.28. In BC_1 population of this cross, out of 312 plants, 160 were resistant and 152 were susceptible. The segregation showed 1:1 ratio with a chi-square value of 0.2 per cent. In BC_2 populations, all the plants in three direct crosses were resistant.

Table 25. Reaction of parents, and F1's to rust (*Puccinia substriata*) in pearl millet

Populations	Number of plants	
Parents	Resistant	Susceptible
81 B	-	58
P-2933-1	52	-
IP-6240-3	60	-
700481-1-5-3	55	-
F1's		
A) Direct Crosses		
(81 B x P-2933-1) x 81B	54	-
(81 B x IP-6240-3) x81B	60	-
(81 B x 700481-1-5-3) x81B	55	-
B) Reciprocal crosses		-
(P-2933-1x 81 B) x P-2933	61	-
(IP-6240-3x 81 B) x IP-6240-3	58	-
(700481-1-5-3 x 81 B) x700481-1-5-3	52	-

Table 26. Pattern for rust resistance in F_2, BC_1 and BC_2 generation of pearl millet

Crosses	Generation	Number of plants		Total plants	$\chi2$	P. value	Segregation ratio (R:S)
A) Direct crosses		Resistant	Susceptible				
81 B x P-2933-1	F_2	438	162	600	1.28	0.50-0.25	3:1
	BC_1	160	152	312	0.21	0.75-0.45	1:1
	BC_2	216	-	216	-	-	-
81 B x IP-6240-3	F_2	426	174	560	0.29	0.75-0.45	3:1
	BC_1	138	162	300	1.92	0.25-0.10	1:1
	BC_2	225	-	225	-	-	-
81 B x 700481-1-5-3	F_2	292	108	400	0.85	0.50-0.25	3:1
	BC_1	149	141	290	0.22	0.75-0.45	1:1
	BC_2	275	-	275	-	-	-
B) Reciprocal crosses							
P-2933-1x81 B	F_2	320	112	432	0.20	0.75-0.50	3:1
	BC_1	240	-	240	-	-	-
	BC_2	94	88	182	0.20	0.75-0.50	1:1
IP-6240-3x81 B	F_2	246	74	320	0.60	0.50-0.25	3:1
	BC_1	223	-	223	-	-	-
	BC_2	130	110	240	1.67	0.25-0.10	1:1
700481-1-5-3x 81 B	F_2	248	92	340	0.72	0.50-0.25	3:1
	BC_1	260	-	260	-	-	-
	BC2	118	130	248	0.58	0.50-0.25	1:1

In the F_2 of a cross 81B x IP-6240-3, out of 560 plants, 426 were resistant and 174 susceptible. The segregation showed good fit to the monogenic ratio of 3:1 with a chi-square value of 0.29. In BC_1 populations, of 300 plants, 138 were resistant and 162 were susceptible. The segregation showed 1:1 ratio with a chi-square value of 1.92, In the BC_2 populations all were resistant. In the third F_2 cross of 81B x 700481-1-5-3, out of 400 plants, 292 were resistant, and 108 were susceptible. The segregation showed good fit to the monogenic ratio of 3:1 with a chi-square value of 0.85. In BC_2 populations of this cross, out of 290 plants, 149 were resistant and 141 were susceptible. The segregation showed 1:1 ratio with a chi-square value of 0.22(Table 26).

4.4.2 Segregation pattern in reciprocal crosses

Out of 432 F_2 plants of cross P-2933-1x81B, 320 were resistant and 112 were susceptible. In the cross IP-6240-3x81B, out of 320 plants, 246 were resistant and 88 were susceptible, similarly in the cross 700481-1-5-3 x 81B, out of 340 plants, 248 were resistant, and 92 were susceptible. The segregation in all the three reciprocal crosses showed a good fit to the monogenic ratio of 3:1 with chi-square values of 0.20, 0.60 and 0.72 respectively.

In BC_1 populations, all the plants of three reciprocal crosses were found resistant, while in BC_2 populations all the three reciprocal crosses showed segregation with respect to rust resistance and susceptibility. In cross P-2933-1 x 81B, out of 182 plants, 94 were resistant and 88 were susceptible. The segregation showed 1:1 ratio with a chi-square value of 0.20. In cross 130 IP-6240-3 x 81B, out of 240 plants, 130 were resistant and 110 were susceptible. The segregation showed 1:1 ratio with chi-square value of 1.67, and in cross 700481-1-5-3 x 81B, out of 248 plants, 118 were resistant and 130 found susceptible. The segregation showed 1:1 ratio with a chi-square value of 0.58 (Table 26).

5. DISCUSSION

Pearl millet [*Pennisetum glaucum* (L.) R.Br.] is one of the major food crops, particularly grown in arid and semi-arid regions of the world. It provides nutritionally superior, staple food for millions of people living in an environment that is characterized by persistent drought, unpredictable weather with limited and erratic rainfall. In addition to food it is also used as animal feed, fuel and in beverage industries.

After the discovery of cytoplasmic genetic male sterility by Burton during the year 1958, the production of commercial hybrids in pearl millet became practical. In India, first pearl millet hybrid HB-1 was released during 1965. Subsequently, many hybrids were released for commercial cultivation.

The use of cytoplasmic genetic male sterility system has made it practically feasible to exploit heterosis on a commercial basis in pearl millet .The extensive use of single source of genetic male sterility for commercial exploitation of heterosis had raised the fear of occurrence of its potential vulnerability to pest and diseases during 1970's. This led to the identification of alternative CMS sources and development of hybrids based on these sources. However, systematic studies on identification of restorers on these diverse cytoplasms are meager. In fact such studies are pre-requisite for utilizing these cytoplasmic sources for commercial exploitation. The main objective of the present investigation is to evaluate the germplasm lines for their restoring ability on diverse CMS sources to identify stable restorers and to characterize the cytoplasmic differences based on restoration pattern.

In pearl millet breeding programme emphasis is always given to develop superior hybrids because of their high yielding nature, early maturity and wider adaptability. The highly stable A_1 system of CMS still remains the principal source of male sterility for commercial development of hybrids. Hence, development of superior hybrids on this source using newly derived CMS lines and restorers is a continuous and important activity in pearl millet breeding programme. In addition to the utilization of A_1 system of male sterility, there is urgent need to develop hybrids on other alternate sources of male sterility to avoid the risk associated with single source of male sterility and to exploit the benefits associated with cytoplasmic effects on yield and other traits. To fulfill these twin objectives, two sets of line x tester experiments (Expt.IIIa and IIIb) were made, first by involving alloplasmic isonuclear (A_1, A_4 and A_5) lines and restorers on these sources, second by involving newly derived male sterile lines of A_1 source and its potential restorers. The Expt. IIIa aimed at deriving information on cytoplasmic effects on heterosis and combining ability of different quantitative characters. The Expt.IIIb will not only provide information on combining ability status of newly derived CMS lines and restorers, but also help to identify productive hybrids for commercial exploitation of heterosis.

Heterosis is dependent on genetic diversity of the parents. In this investigation it has been attempted to determine the genetic diversity present in the diverse sources of male sterility systems and the pollen parents with maintainer and restorer reactions on these sources. In addition, in the present study an attempt has also been made to study the inheritance pattern of rust, as it is a disease of considerable importance in recent years since it affects both forage and fodder value. The results obtained on these aspects are discussed here below.

5.1 RESTORATION STUDIES ON DIFFERENT CYTOPLASMIC SOURCES OF MALE STERILITY

The first male sterile line Tift 23A was developed by Burton in 1958. This source was soon utilized to develop several commercial hybrids. However, hybrids based on this source became susceptible to downy mildew in 1970's. Later, attempts were made to diversify cytoplasmic source of male sterility and this led to the development of A_1, A_2, A_3 (Athwal, 1961, 1966), A_4 (Hanna, 1989) and A_5 sources (Sujatha, *et al.*, 1994, Rai, 1995). However, commercial hybrids on these sources have not been developed so far due to non-availability of suitable restorers. Infact availability of suitable restorers is pre requisite to develop hybrids on these diverse sources. Hence, in the present study an attempt has been made to identify suitable restorers among the pool of germplasm on three diverse cytoplasmic sources viz., A_1, A_4 and $A_{5.}$

5.1.1 Identification of restorers on diverse cytoplasmic sources of male sterility

A total of 105 germplasm lines were crossed to three diverse sources of male sterility representing A_1 (Tift 23 D2A), A_4 (Hannas monodii) and A_5 (LSFP) cytoplasmic sources. Results of fertility restoration reaction of the various lines revealed that of the 105 lines, 34 exhibited satisfactory (> 60 %) seed setting on A_1 (Table-3). On A_4 cytoplasm 63 genotypes acted as restorers, which accounts for 60 per cent of the total number of lines tested. Regarding restoration behaviour on A_5 cytoplasm, 47 lines acted as restorers, which accounts for 44.76%. These results revealed that frequency of restoration on A_4 cytoplasm is quite high compared to A_1 and A_5 indicating the possibility of developing hybrids on A_4 source (Andrews and Rajewski, 1994; Rai, 1995; Rai *et al.*, 1998).

Among the three sources of male sterility the seed set percentage was highest on A_1 (78.51) followed by A_4 (76.10) and A_5 (68.72) in *kharif* season. However, during summer only on A_4 source the seed set per cent was >70 (Table 27 and Fig.8). These results indicate the scope of utilization of A_4 as an alternative source of male sterility to develop commercial hybrids for both *kharif* and summer.

5.1.2 Classification of restoration

The seed set percentage recorded on a hybrid represent the restoring ability of a pollen parent. This seed set percentage can vary from 0 to 95 per cent, thus representing wide range of variation in the restoration ability of pollen parent. Earlier, in sorghum genotypes showing just above 60 per cent seed set were broadly grouped as restorers and classified restorers into different categories based on their restoration ability (Kishan and Borikar, 1989; Biradar, 1995). In the present investigation, a total of 105 genotypes were evaluated for their restoration ability on three diverse sources of male sterility. Further these lines were grouped into six categories depending upon seed set percentage (Table-28) by following the classification model developed by Biradar (1995). The proportion of genotypes falling in different restorer classes and seed set percentage in two seasons is presented in Table-29. Mean seed set percentage (average of two seasons) observed in different restoration classes on three diverse source of male sterility is presented in Fig.8. Representative ear heads of different restoration classes are presented in the plates 4 to 9.

The values presented in Table 29 indicate that the proportion of restorers exhibiting >80 % seed set was highest on A_4 followed by A_5 and A_1 across kharif and summer season. When the seed set per cent in summer alone was considered, similar trend was seen. However, in *kharif* season the highest proportion was observed on A_4 followed by A_1 and A_5. The mean seed set percentage (across the seasons) on A_4 was highest (73.50 %) followed by on A_1 (71.60%) and 66.60% on A_5 (Table 30). This clearly indicates that A_4 cytoplasmic sources can be comfortably exploited for development of commercial hybrids.

5.1.3 Stability of restoration on different cytoplasmic source

The seasons suited for pearl millet cultivation, are mainly *kharif* and summer. The temperature variation in *kharif* season is less, which generally provides good vegetative growth and promotes grain filling in pearl millet, while in summer; variation in temperature is more and erratic. Keeping these contrasting features of the seasons, it was felt necessary to examine restoration reaction of each genotype over two seasons. It is evident from the present study that there is a reduction in proportion of lines showing high restoration and mean seed set percentage from *kharif* to summer (Table 30).

Based on change in proportion of restorers and over all seed set percentage observed in each season, it is evident that A_4 cytoplasm is less sensitive to environmental fluctuation as compared to A_1 and A_5 cytoplasmic sources. Thus, A_4 appears to be more stable source of male sterility followed by A_5 and A_1 cytoplasm. Further, if a very high seed set is desired (>90%), A_4 cytoplasm is more suited for development of hybrids for summer season.

From the Table 29, it is clear that there is reduction in number of lines showing > 90 per cent seed set from *kharif* to summer. This effect was noticed in all the cytoplasmic sources. However, this trend of decrease in proportion of restorer was not so obvious in lower classes of restoration (60-80%). This indicates that the restoring ability of strong restorers appear to be more sensitive to environmental fluctuation than in the moderate restorer. Such

Table 27. Mean seed set percentage observed in two different seasons on three diverse sources of male sterility in pearl millet.

Cytoplasm	Seasons			
	Kharif		Summer	
	Mean	Range	Mean	Range
81A_1 (Tift 23 D2A)	78.51	50.0-95.0	64.88	30.5-88.0
81A_4 (Hannas monodii)	76.10	40.0-96.0	70.75	35.0-91.6
81A_5 (LSFP)	68.72	30.0-95.0	63.29	30.0-91.0

Table 28. Classification of restoration based on mean seed set percentage (average of two seasons)

Restoration classes	Seed set %	Diverse sources of cytoplasm					
		A_1		A_4		A_5	
		No. of restorers	Mean seed set %	No. of restorers	Mean seed set %	No. of restorers	Mean seed set %
I. Strong restoration	>90	-	-	7	91.41	3	91.53
II. High restoration	>80-90	14	85.65	23	89.83	10	84.37
III.Moderate restoration	>60-80	18	70.46	17	70.79	18	68.82
IV.Partial restoration	>10-60	6	45.88	16	49.20	17	47.66
V. Low restoration	<10	-	-	-	-	-	-
VI. Maintainers	Zero	67	-	42	-	57	

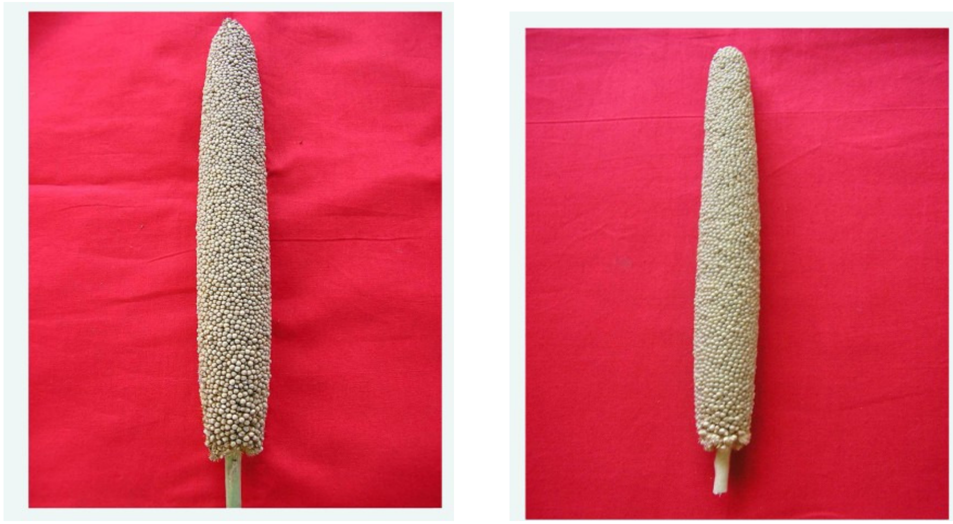

Plate.4. Strong restoration (>90%)

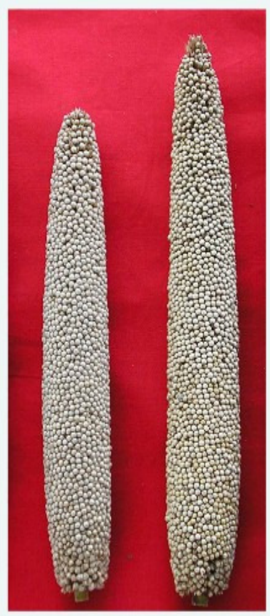

Plate 5. High restoration (80-90%)

Plate.5. High restoration (80—90%)

Plate.6. Moderate restoration (60-80%)

Plate.7. Partial restoration (10-60%)

Plate.8. Low restoration (<10%)

Plate 9. Maintainers (0%)

Plate.9. Maintainers (0%)

Table 29. Proportion of lines representing different restoration classes and seed set percentage in two season.

Restoration category	A_1		A_4		A_5	
	Kharif	Summer	Kharif	Summer	Kharif	Summer
I. Strong restorers (>90%)						
i) No.of lines	7	-	20	2	6	2
ii) Proportion	6.66	-	19.04	1.90	5.71	0.95
iii) Mean seed set %	92.60	-	92.86	91.60	93.71	91.00
II. High restorers (>80-90%)						
i) No.of lines	14	9	13	20	9	6
ii) Proportion	13.33	8.57	12.38	19.04	8.57	5.71
iii) Mean seed set %	86.82	84.51	86.07	85.16	86.55	85.38
III. Moderate restorers (>60-80%)						
i) No.of lines	12	16	18	22	16	21
ii) Proportion	11.42	15.23	17.14	20.95	15.23	20.00
iii) Mean seed set %	66.96	74.03	70.11	72.18	65.15	70.11
IV. Partial restorers (>10-60%)						
i) No.of lines	5	13	12	19	17	19
ii) Proportion	4.76	12.38	11.42	18.09	16.19	18.09
iii) Mean seed set %	54.80	51.57	48.20	51.52	49.70	43.24
V. Low restorers (<10%)						
i) No.of lines	-	-	-	-	-	-
ii) Proportion	-	-	-	-	-	-
iii) Mean seed set %	-	-	-	-	-	-
VI. Maintainers (0%)						
i) No. of lines	67	67	42	42	57	57
ii) Proportion	63.80	63.80	40.0	40.0	54.28	54.28
iii) Mean seed set %	-	-	-	-	-	-

Table 30. Proportion of restorers representing different restoration classes and seed set percentage on three cytoplasmic sources in two seasons

Restoration category	Diverse cytoplasmic sources								
	A_1			A_4			A_5		
	K	S	M	K	S	M	K	S	M
i) > 80%	31.40	23.8	27.6	48.6	41.9	45.25	29.5	27.6	28.55
ii) < 60%	4.80	12.4	5.73	11.4	18.1	14.75	16.2	18.1	17.15
iii) Mean seed set %	78.51	63.7	71.60	76.0	70.95	73.50	66.72	63.29	66.01
Total number of lies tested	105	105	-	105	105	-	105	105	-

K: Kharif , S: Summer, M: Mean

studies are not available in pearl millet. However, in sorghum Biradar (1995) observed similar phenomenon.

5.1.4 Sensitivity of different restoration classes to seasonal variation

To determine whether different restoration classes show same level of sensitivity to seasonal variation, the genotypes were regrouped into restoration classes exclusively based on seed set percentage in kharif, the season in which mean seed set percentage was highest in all the three cytoplasms. Then the seed set percentage observed in each hybrid in summer season was examined to determine the pattern of reduction in seed set across seasons. Further, mean seed set observed in each restoration class was determined and this was compared with mean seed set observed during summer season (Table 31).

Overall seed set percentage was highest in *kharif* than in summer season. However, when mean seed set percentage was examined in different restoration classes, the pattern of reduction of seed set from *kharif* to summer was more in the class of strong restorers on all the three cytoplasms. The other classes with low seed set percentage did not show this kind of sensitivity to seasonal differences. It is very difficult to give exact reason for differential sensitivity of different restoration classes.

Though majority of the lines showed reduction in seed set from *kharif* to summer some unique lines viz., IP-8726, IP-9416, IP-9440, IP-19321, IP-6510, IP-15355 showed high restoration even in summer. After confirming their consistency particularly during summer season, these lines can be specifically used for developing hybrids for summer season

5.1.5 Choice of restorers

Pearl millet hybrids are mainly grown in kharif and summer seasons. The seasonal condition in kharif and summer are distinctly different. Of the two seasons, summer is characterized by very hostile environment with high temperature and dry weather. If the hybrids are to be recommended for cultivation in both the seasons and to realize the complete yield potentiality, it is necessary that concerned male parent should have consistently high restoring ability in both the seasons. Based on the percentage of seed set observed in both seasons, the strong and consistent restorers observed in the study are listed in the Table-32. It is evident from the Table 32 that, these genotypes can be used as parents of hybrids as well as donors for transferring restorer genes. Study also revealed that, the restorer IP-16096 exhibited restoring fertility on A_1 and A_4 cytoplasms and IP-8276 showed restoring ability on A_4 and A_5 cytoplasmic source and these lines can be used to develop alloplasmic hybrids.

5.1.6 Geographic distribution of male sterility restorers and maintainers

In the present investigation, restorers and maintainers on A_1, A_4 and A_5 cytoplasm represented eleven different countries (Table 33). The distribution pattern of restorers and maintainers across these countries revealed interesting observation. Among the 26 lines of Indian origin, 65.4 % were restorers and remaining were maintainers. Similarly, out of 12 lines from Namibia 91.7 % were restorers. On the other hand out of 12 lines from Zimbabwe only 16.7 % were restorers and remaining were maintainers. These results gave a clue to search for restorers/ maintainers from different geographical areas. Earlier, Appa Rao *et al*. (1989) identified large number of restorers on Tifton source of male sterility in West Africa and maintainers in India.

In addition, identification of restorers/maintainers from different countries helps to diversify the genetic background of these lines and it is possible to develop male sterile lines in different genetic backgrounds. It is desirable to have male sterile lines with varying maturity and height levels as it gives scope for selecting restorers with good combining ability and adaptation to diverse agro climatic conditions.

5.1.7 Common restorer on diverse cytoplasmic sources

In the present study, very high proportion of restorers were noticed on A_4 (47), followed by A_5 (37) and A_1 (31) (Table 33). On the other hand, the common restorers on A_4 and A_5 (31) were highest (Table 34 and Fig.9) followed by A_1 and A_4 (28) and A_1 and A_5 (2). Over all, a total of 12 lines could restore fertility on all the three sources. These results

Table 31. Sensitivity of different restoration classes to seasonal variation

Restoration classes	Seed set percentage		
1. A_1 cytoplasm	Kharif	Summer	Mean
I. Strong restorers (>90%)			
1. IP-10186	92.00	85.00	85.50
2. IP-15220	92.00	72.00	82.00
3. IP-10085	91.00	81.00	86.00
4. IP-14942	91.00	74.00	82.50
5. IP-14038	93.60	85.00	89.30
6. IP-9306	93.60	81.60	87.60
7. IP-12682	95.00	85.00	90.00
Mean	92.60	80.42	86.51
II. High restorers (81-90%)			
1. IP-3150	84.00	65.00	74.50
2. IP-17979	90.00	80.00	85.00
3. IP-10488	84.00	75.00	79.50
4. IP-14028	88.00	80.00	84.00
5. IP-14026	90.00	45.00	67.50
6. IP-14778	90.00	80.00	85.00
7. IP-16096	85.00	85.00	85.00
8. IP-7440	90.00	80.00	85.00
9. IP-13840	85.00	78.60	81.80
10. IP-16197	84.00	30.50	57.30
11. IP-19246	85.00	78.00	81.50
12. IP-13833	90.00	85.00	87.50
13. ICMV-221	90.00	70.00	80.00
14. IP-6545	80.60	70.00	75.00
Mean	86.83	71.58	79.19
III Moderate restorer (>60-80%)			
1. IP-17566	70.00	45.00	57.50
2. IP-15829	63.60	60.00	61.80
3. IP-15257	75.00	75.00	75.00
4. IP-15700	75.00	50.00	62.50
5. IP-14497	60.60	50.00	55.30
6. IP-19321	70.00	55.00	62.50
7. IP-18625	75.00	60.00	67.50
8. IP-8818	75.00	67.00	71.00
9. IP-12768	80.00	75.00	77.50
10. IP-7838	65.00	85.00	75.00
11. ICTP-8203	75.00	60.00	67.50
Mean	71.29	62.00	66.64
IV Partial restorer (>10-60%)			
1. IP-17144	55.00	55.00	55.00
2. IP-15681	50.00	88.00	69.00
3. IP-15304	54.00	75.00	64.50
4. IP-15273	55.00	50.00	52.50
5. IP-14644	60.00	50.00	55.00
Mean	54.80	63.60	59.20

Table 31. Contd…..

V. Low restorer (<10% seed set)	-	-	-
VI. Maintainers (0%)	67 genotypes		
2. A_4 cytoplasm			
I. Strong restorers (>90%)			
1. IP-9140	92.00	85.00	88.50
2. IP-9149	94.00	91.60	92.80
3. IP-15829	95.50	86.00	90.80
4. IP-8276	92.00	90.00	91.00
5. IP-9416	90.50	90.00	90.25
6. IP-6417	92.00	75.00	83.50
7. IP-15304	95.00	85.00	90.00
8. IP-15273	92.00	85.00	88.50
9. IP-16096	90.60	84.00	87.30
10. IP-7440	92.60	90.00	91.30
11. IP-9306	91.00	85.60	88.30
12. IP-4779	91.00	84.00	87.50
13. IP-19321	95.00	91.60	93.30
14. IP-12768	92.00	86.00	89.00
15. IP-18742	92.00	89.00	90.50
16. IP-18657	91.00	85.00	88.00
17. IP-12901	98.00	81.00	89.50
18. IP-12682	95.00	78.00	86.50
19. IP-19067	91.00	85.00	88.00
20. IP-10761	95.00	84.00	89.50
Mean	92.86	65.54	89.20
II High restorers (>80-90%)			
1. IP-15899	85.00	80.00	82.50
2. IP-10394	85.00	80.00	82.50
3. IP-6510	85.00	80.00	82.50
4. IP-17028	85.00	75.00	80.00
5. IP-15681	85.00	80.00	82.50
6. IP-15700	85.00	81.50	83.30
7. IP-14028	89.00	85.00	87.00
8. IP-11211	89.00	81.00	85.00
9. IP-14497	85.00	78.00	81.50
10. IP-13840	85.00	75.00	80.00
11. IP-4695	85.00	81.00	83.00
12. IP-12779	90.00	75.00	82.50
13. IP-19388	85.00	75.00	80.00
Mean	86.00	78.96	82.48
III Moderate restorer (>60-80%)			
1. IP-9286	62.00	58.00	60.00
2. IP-10186	75.00	70.00	72.50
3. IP-10811	75.00	65.00	70.00
4. IP-10085	77.50	70.00	73.80
5. IP-15257	62.00	58.00	60.00
6. IP-14038	65.00	61.00	63.00
7. IP-17979	75.00	62.00	68.50
8. IP-8429	75.60	65.00	70.30
9. IP-14026	75.00	71.00	73.00
10. IP-14778	75.00	70.00	72.50
11. IP-14644	78.00	70.00	74.00
12. IP-16197	65.00	60.00	62.50
13. IP-13875	61.00	56.00	58.50
14. IP-6460	75.00	65.00	70.00
15. IP-7468	61.00	60.00	60.50
16. IP-13833	75.00	68.00	71.50
17. IP-19361	65.00	55.00	60.00
18. IP-16911	65.00	58.00	61.50

IV Partial restorer (>10-60%)			
1. IP-15857	48.50	51.00	49.50
2. IP-14942	55.00	50.00	52.50
3. IP-5275	60.00	50.00	55.00
4. IP-15355	60.00	54.00	57.00
5. IP-16690	55.00	50.00	52.50
6. IP-4169	55.00	45.00	50.00
7. IP-19246	55.00	51.00	53.00
8. ICMV-221	45.00	35.00	40.00
9. IP-12474	45.00	40.00	42.50
10. IP-6545	40.00	45.00	42.50
11. IP-10085	60.00	55.00	57.50
12. IP-19243	55.00	48.00	51.50
Mean	52.79	47.83	50.29
V. Low restorer (<10% seed set)	-	-	-
VI. Maitainers (0%)	42 genotypes		
3. A_5 cytoplasm			
I. Strong restorers (>90%)			
1. IP-15857	92.66	85.00	88.80
2. IP-6510	95.00	91.00	93.00
3. IP-8276	92.60	88.00	90.30
4. IP-15355	95.00	90.00	92.50
5. IP-10839	92.00	85.00	88.50
6. IP-12779	95.00	75.00	85.00
Mean	93.71	85.66	89.68
II High restorers (>80-90%)			
1. IP-15817	85.66	82.00	83.80
2. IP-15681	90.00	82.30	86.20
3. IP-6417	85.00	75.00	80.00
4. IP-8429	85.00	75.00	80.00
5. IP-14497	85.00	78.60	81.80
6. IP-4695	85.00	80.00	82.50
7. IP-4779	85.00	75.00	80.00
8. IP-4331	88.30	75.00	81.70
9. ICTP-8203	90.00	75.00	82.50
Mean	86.55	77.54	82.05
III Moderate restorer (>60-80%)			
1. IP-9286	62.30	60.30	61.30
2. IP-15899	75.00	75.00	75.00
3. IP-10820	72.00	71.00	71.50
4. IP-9416	65.00	61.00	63.00
5. IP-10811	65.00	61.00	63.00
6. IP-5275	75.00	70.00	72.50
7. IP-19321	72.00	65.00	68.50
8. IP-18625	65.00	61.00	63.00
9. IP-12768	75.00	65.00	70.00
10. IP-6125	70.60	60.00	65.30
11. IP-13645	75.00	91.00	83.00
12. IP-19388	75.00	70.00	72.50
13. IP-18742	63.00	58.00	60.50
14. IP-18657	70.60	62.30	66.50
15. IP-8540	70.00	60.60	65.30
16. IP-13833	62.00	55.00	58.50
IV Partial restorer (>10-60%)			
1. IP-9140	55.00	50.60	52.80
2. IP-10394	56.00	50.00	53.00
3. IP-10085	50.00	50.00	50.00
4. IP-15273	40.00	30.00	35.00
5. IP-7440	45.00	30.00	35.00
6. IP-13840	50.00	35.00	42.50
7. IP-9306	30.00	45.00	37.50
8. IP-14644	48.00	52.00	50.00
9. IP-18621	50.00	72.00	61.00
10. IP-4759	52.00	45.00	48.50
11. IP-4169	45.00	45.00	45.00
12. IP-7468	44.00	38.00	41.00
13. IP-19067	60.00	55.00	57.50
14. ICMV-221	45.00	40.00	42.50
15. IP-18389	60.00	45.00	52.50
16. IP-18800	55.00	50.00	52.50
17. IP-19243	60.00	48.00	54.00
V. Low restorer (<10% seed set)	-	-	-
VI. Maitainers (0%)	57 genotypes		

Table 32. List of best restorers showing consistently high restoring ability across seasons

Source of cytoplasm	Seasons		
	Kharif	Summer	Mean
1. A_1 cytoplasm			
1. IP-10186	92.00	85.00	88.50
2. IP-10085	91.00	81.00	86.00
3. IP-14038	93.60	85.00	89.30
4. IP-9306	93.60	81.60	87.60
5. IP-12682	95.00	85.00	90.00
6. IP-16096	85.00	85.00	85.00
7. IP-13833	90.00	85.00	87.50
2. A_4 cytoplasm			
1. IP-9140	92.00	85.00	88.50
2. IP-9149	94.00	91.60	92.80
3. IP-15829	95.50	96.00	95.80
4. IP-8276	92.00	90.00	91.00
5. IP-9416	90.50	90.00	90.30
6. IP-15304	95.00	85.00	90.00
7. IP-15273	92.00	85.00	88.50
8. IP-16096	90.60	84.00	87.30
9. IP-7440	92.60	90.00	91.30
10. IP-19321	95.00	91.60	93.30
11. IP-12768	92.00	86.00	89.00
12. IP-12901	98.00	81.00	89.50
13. IP-18742	92.00	89.00	90.50
14. IP-19067	91.00	85.00	88.00
15. IP-18657	91.00	85.00	88.00
3. A_5 cytoplasm			
1. IP-15857	92.66	85.00	88.80
2. IP-6510	95.00	91.00	93.00
3. IP-8276	92.60	88.00	90.30
4. IP-15355	95.00	90.00	92.50
5. IP-10839	92.00	85.00	88.50

Table 33. Distribution of sterility maintainers/fertility restorers on diverse sources of male sterility in pearl millet

Origin	Total number of lines evaluated	Number of lines				
		Restorers				Maintainers
		A_1	A_4	A_5	Total	(on A_1,A_4 & A_5)
India	26	10	14	10	17	9
ICRISAT	9	3	4	2	5	4
Togo	6	1	2	2	2	4
Sudan	7	1	1	2	2	5
Tanzania	8	2	3	1	6	2
Mali	8	3	5	3	5	3
Camerron	5	3	3	2	3	2
Zimbabwe	12	2	3	-	5	7
Namibia	12	4	7	10	11	1
Nigeria	5	-	2	2	2	3
Burkino Faso	6	2	2	2	2	4
Ghana	1	-	1	1	1	-
Total	105	31	47	37	61	44

Table 34.Common restorers on three sources of cytoplasms

Diverse sources	Restorers	Total
A_1 & A_4	IP-10186, IP-15829, IP-10085, IP-15681,IP-15257,IP-14942,IP-14038,IP-7979, IP-15700, IP-14028, IP-14026, IP-15305, IP-15372, IP-14497, IP-144778, IP-16069, IP-7440, IP-13840, IP-9306, IP-14644,IP-19321, IP-16197, IP-12768, IP-2682, IP-19246, IP-13833, ICMV-221, IP-6545.	28
A_1 & A_5	IP-18625, ICTP-8203	02
A4 & A_5	IP-9140,IP-9286,IP-15856,IP-15899,IP-10394,IP-6510,IP-8276,IP-9416,IP-10811,IP-10085,IP-15681,IP-6417,IP-8429,IP-5275,IP-15335,IP-15273,IP-14497,IP-7440,IP-13840,IP-9306,IP-1695,IP-4779,IP-12779,IP-12768,IP-19338,IP-18742,IP-18657,IP-4169,IP-7468,IP-19067,IP-19243.	31
A_1, A_4 &A_5	IP-10085,IP-15681,IP-15273,IP-14493,IP-7440,IP-13840,IP-9306,IP-14644,IP-19321,IP-12768,IP-13833,ICMV-221	12

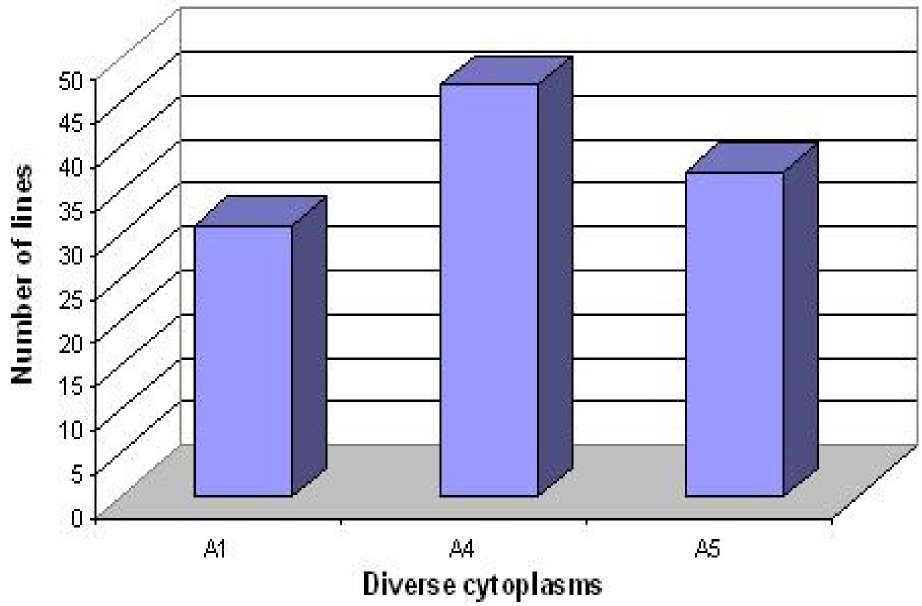

Fig.8. Distribution of sterility maintainers/fertility restores on diverse cytoplasm in pearl millet

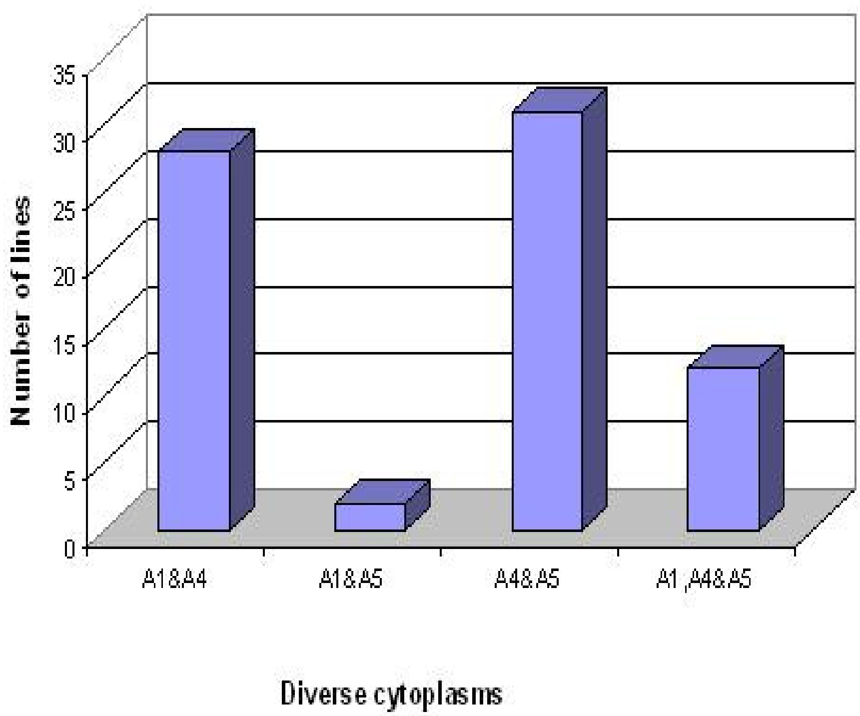

Fig.9. Common restores on three diverse sources of cytoplasm

indicated the scope of developing isonuclear alloplasmic hybrids either on all the three sources or combinations of any two sources. This would certainly reduce the risk associated with the use of single cytoplasmic source in the development of hybrids.

On the basis of commonness of restoration on different cytoplasms, it is possible to infer the probable cytoplasmic distance existing between these cytoplasms. The A_4 cytoplasm appears to be closer to the other two cytoplasms while A_1 and A_5 cytoplasms have wider cytoplasmic distance between them.

5.1.8 Effect of season on other plant characters

The effect of environment on flowering and plant height varied with hybrids. Some of the hybrids exhibited no drastic differences in plant height and days to 50 per cent flowering between seasons and this may be due to thermo and photoperiod insensitivity of the hybrids. However, in some of the hybrids greater differences were observed for plant height and days to 50 per cent flowering from season to season. Irrespective of cytoplasmic bases, the hybrids in general exhibited increased plant height in kharif and medium height in summer (Table 3). Regarding days to 50 per cent flowering, hybrids were late in kharif and early in summer season. Kishan and Borikar (1989) and Biradar (1995) in sorghum recorded such observation in hybrids developed on diverse cytoplasms.

5.2 VARIABILITY STUDIES

The success of any crop improvement programme depends on the magnitude of genetic variability for the different characters and the extent to which the desirable trait is heritable. The estimates of variability of yield and yield contributing characters and their heritable components in the material are more important in any crop-breeding programme. In the present study a pool of restorers (61) and maintainers (44) were subjected to variability studies for different characters over two years during kharif season. The results pertaining to genetic variability parameters such as genotypic variance, phenotypic variance, heritability and genetic advance over two years are presented in Table-5. The coefficient of variation expressed at phenotypic (PCV) and genotypic (GCV) levels have been compared for variability observed among different characters. The GCV indicates the amount of genetic variability present in the character, while the heritability estimates aid in determining the relative amount of heritable portion of variation for that character. Infact, heritability estimates in broad sense would be reliable if accompanied by a high genetic advance. The results on these aspects are discussed here under the following sub heads.

5.2.1 Phenotypic and genotypic coefficients of variability

The trend of phenotypic coefficient of variation (PCV) and genotypic coefficient of variation (GCV) for all the characters remained similar in both the years. The phenotypic coefficient of variation (PCV) was though higher than genotypic coefficient of variation (GCV) for all the characters under study (Table 5) but the narrow range of difference indicated that most of the characters were least influenced by the environment. High values of GCV and PCV were obtained for the characters like ear head length, ear head girth, and plant height, grain yield per plant and productive tillers per plant, indicating variation for these characters contributed markedly to the total variability. Further, narrow range of difference between PCV and GCV indicated that any selection pressure operated on these characters may help to realize improvement at early generation. Similar, results were reported by other workers in pearlmillet Mannan and Razzaque,1980; Kunjir*etal.*,1986a;Lakshmana and Gggari,2001;Lakshmana*et al.*,2003;Borkhataria *et al.*,2005;Aryana *et al.*, 1996).

5.2.2 Heritability and genetic advance

It is not just the magnitude of variation but the extent of heritable variation matters most for achieving gains in selection programme. The coefficient of variation indicates only the extent of total variability present for a character and does not demarcate the variability into heritable and non-heritable portion. Hence, the estimate of heritability, which indicates precisely the heritable expected gain assumes importance. The extent of variability, which could be transferred from parent to offspring, would suggest how for the variation in heritable portion has close bearing on response to selection.

Further, heritability in conjunction with genetic advance is more effective and reliable in predicting resultant effect of selection and based on which, selection procedures can be evaluated. In the present study the genotypes are established lines and are homozygous. Thus for prediction of response to selection, it is opt to use broad sense heritability, because the entire value is transmitted to the progeny when any selection is advanced through selfing. These values of genetic advance hold good as long as selection is practiced between lines. The results of present study on heritability for 12 characters over two years, suggested that all except days to flowering and days to maturity are highly heritable. However, the values of genetic advance suggested that real progress could be made only for a few characters such as ear head length, ear head girth and grain yield per plant. Similar observation were reported by earlier workers viz., Singh and Gupta (1979), Navale *et al*. (1991), Hepziba *et al*. (1993), Berwar *et al*.(2001), Solanki *et al*. (2002) and Lakshmana *et al*. (2003).

Some characters like grain yield per ear and 1000 grain weight had high heritability with moderate genetic advance and thus could serve as an index for selection to high grain yield per plant. These results are in line with findings of Dang *et al*. (1985) Kunjir *et al*. (1986a), Yogendra Sharma (2002) and Maharwar *et al*. (2003).

5.3 GENETIC DIVERSITY STUDIES

Genetic diversity analysis helps to identify the genetically diverse genotypes for their use in breeding programmes. Various methods have been advocated by several workers, to estimate genetic divergence in crop plants (Murthy and Quadri, 1966; Hussain, 1973). Of the several methods available Mahalanobis's generalized distance estimated by D^2 statistic (Rao, 1952) is a unique tool for discriminating population considering a set of parameters together rather than inferring from indices based on morphological similarities and polygenic relationship.

Mahalanobis's D^2 statistics has been followed by several workers on a wide range of crop species, including pearl millet, to measure the genetic distance among the breeding lines and to identify characters responsible for such divergence. In the present study, D^2 analysis has been applied to assess the diversity available among restorers as well as maintainers of three diverse source of male sterility. The D^2 study conducted among the restorers helps in identifying the combination, which can create nuclear diversity among restorer lines that further helps in developing new restorer population. Similarly D^2 study among the group of maintainer lines helps in identifying the divergent maintainer combinations, which can be in turn used in crossing programme for developing new 'B' lines.

In the present investigation D^2 analysis was done for three different categories *viz*., among restorers, maintainers and restorers plus maintainers.

5.3.1 Genetic diversity in different groups

Based on D^2 values, 105 genotypes (restorers and maintainers) were grouped in 22 clusters, while 11 and 19 clusters were formed out of 44 maintainers and 61 restorers respectively indicating the presence of large amount of diversity among the genotypes (Table, 6,9 and 12).

The inter cluster distance in the combined group (restorers + maintainers) was slightly greater than the other two groups. The inter cluster distance among restorers in general were high while, the corresponding distance among maintainers were low. In the earlier, D^2 analysis studies on pearl millet genotypes were not systematically grouped into restorers or maintainers before estimating D^2 values. However, such studies can be compared with D^2 analysis made here by involving both maintainers and restorers. Presence of diversity among pearl millet genotypes of the present study is in accordance with earlier reports (Yadav, 1994; Hepziba, *et al*., 1995; and Hendre, 1998).

The range of D^2 values in maintainer group were less (22 to 484) as compared with the range of D^2 values in restorers group (23 to 1405). Restorer group was flexible since it involved the restorers, which has restoring ability on any one of the cytoplasm. As compared to this, the maintainers group was formed with the stringent requirement that the genotypes must maintain sterility on all the three diverse cytoplasm. Hence, these 44 maintainer genotypes share greater genetic commonness among themselves because they are required to maintain sterility on three diverse cytoplasm and that is why, they may be showing lesser genetic diversity. The intermediate range (20 to 684) was observed in the combined group consisting maintainers and restorers. It was evident that this group consisted pairs of genotypes showing very high, very low as well as intermediate D^2 values. Because of this the D^2 values of this group (combined) seem to be intermediate as compared to the other two groups. Similar trend was also observed in the highly divergent pairs in restorer group, maintainer group and restorer + maintainer combined group.

5.3.2 Contribution of characters towards divergence

Among the twelve quantitative characters studied the most important characters contributing to the divergence was days to maturity, in all the three sets. The traits like productive tillers/plant, grain yield per ear, peduncle length, grain yield per plant, 1000 seed weight were next in the order. The above results implied that in order to select genetically diverse parents among these maintainers and restorers, one should classify the materials on the basis of such traits as days to maturity, productive tillers per plant, grain yield per ear, peduncle length, grain yield per plant and 1000 seed weight. These observations are in line with the observations of earlier workers (Singh and Gupta, 1979; Singh *et al.*, 1981; Hepziba *et al.*, 1995; Quendeba *et al.*, 1995; Hendre, 1998).

5.3.3 Practical utility of divergent pairs in different categories

In the combined group (restorer + maintainers), maximum diversity was observed between IP-9416 vs. ICTP-8203 followed by IP-5275 vs. IP-14644 and IP-8276 and IP-18742 (Table-35). These divergent pairs will make 'B' and 'R' line combinations at least on any one of the three sources of male sterility. If such hybrids are good, the corresponding cytoplasmic sources can be used for developing male sterile version and utilize in hybridization programme for developing hybrids or can be involved in crossing programme (B x R) for creating variability to isolate superior 'B' and 'R' lines on one or two cytoplasms.

The divergent pairs (IP-17144 vs. IP-13154 and IP-1094 vs. IP-16402) in maintainers group can be used for creating variability and isolating better 'B' lines on diverse sources of cytoplasmic male sterility.

In restorers group, maximum diversity was observed between IP-8276 and IP-10839, followed by IP-8276 and IP-19388, IP-8276 and IP-18742. Since, these pairs are restorer on different sources of cytoplasm, segregating population can be used for selecting genotypes, which restores fertility on diverse sources of cytoplasms.

5.4 HETEROSIS AND COMBINING ABILITY

Cytoplasmic genetic male sterility system is considered an efficient genetic tool in pearl millet hybrid breeding. Of the several CMS sources available in pearl millet A_1 source is the only and widely exploited to develop commercial hybrids so far. However, several alternate CMS (A_2, A_3, A_4 and A_5) systems were identified and developed for use in hybrid breeding programme to diversify the cytoplasm and nuclear genetic base of pearl millet hybrids. Though large number of A_1 based hybrids were released/marketed for commercial cultivation all over the globe, but the other sources were not being exploited due to non-availability of suitable restorers. The isonuclear lines have also been established in the background of these diverse sources, which provides an opportunity for studying cytoplasmic effect on different characters. In any hybrid breeding programme based on several CMS sources, the information on the combining ability of alloplasmic lines and relative magnitude of heterosis in cytoplasmically diverse hybrids is helpful in determining the relative chance of success with any source. Infact, the earlier studies have indicated that cytoplasm exhibit pronounced effect on heterosis and combining ability (Yang and Virmani, 1990; Yadav, 1994).

In the present study two, Line x Tester experiments (Expt.IIIa and IIIb) were planned with the following objectives.

Expt.IIIa: To study the influence of different CMS sources on heterosis and combining ability effects for different quantitative characters.

Expt.IIIb: To study the heterosis and combining ability on A_1 source for commercial exploitation.

Table 35. Highly divergent pairs in different categories

	Genotypic pairs	D^2 values
I	Restorers + Maintainers group	
1	IP-9416 vs ICTP-8203	684
2	IP-5275 vs IP-14644	682
3	IP-8276 vs IP-18742	826
4	IP-8276 vs IP-10839	822
5	IP-6510 vs IP-10839	770
6	IP-8276 vs ICTP-8203	787
7	IP-8276 vs IP-19388	721
8	IP-8276 vs IP-13875	699
II	Maintainers group	
1	IP-17144 vs IP-13154	484
2	IP-10945 vs IP-16402	469
3	IP-8229 vs IP-13154	467
4	IP-11577 vs IP-4759	466
5	IP-17566 vs IP-13875	457
III	Restorers group	
1	IP-8276 vs IP-10839	1405
2	IP-8276 vs IP-19388	1204
3	IP-8276 vs IP-18742	1123
4	IP-9416 vs IP-10839	1099
5	IP-10839 vs IP-18800	1113

5.4.1 Influence of different CMS sources on hybrid on heterosis and combining ability effects for different quantitative characters (Expt.IIIa)

To study the effect of diverse cytoplasmic sources on combining ability and heterosis for different quantitative characters, three alloplasmic lines (A_1, A_4 and A_5) and eleven pollen parents were selected. The results obtained on this aspect for twelve quantitative characters are discussed here below.

5.4.1.1 Heterosis (%) in hybrids carrying different CMS sources

There was wide range in the magnitude of heterosis among the crosses for all traits (Table 16a-16l). The mid parent heterosis for various traits revealed that the direction and magnitude of heterosis was significantly influenced by the cytoplasmic source (Table 36). As many as nine hybrids with A_1 source were significantly heterotic for ear girth while only six and three hybrids with A_4 and A_5 were significantly heterotic, respectively. The majority of the hybrids carrying the A_4 source were highly heterotic for the traits viz., days to maturity ,plant height, ear head weight, grain yield /ear, grain yield /plant and ear length. On the other hand majority of the A5 based hybrids were highly heterotic for productive tillers, ear length, flag leaf area and peduncle length.

With a view to separate out the cytoplasmic effects on heterosis for different traits the hybrids were grouped by their cytoplasmic sources (A_1, A_2 and A_3) and mean values ($F_{1's}$ and MP's) were calculated in each of the group for all the twelve traits. The mean heterosis and range (minimum and maximum) of each group are presented in the Table-37. The mean as well as range of heterosis for days to flowering, days to maturity, plant height, flag leaf area and 1000 grain weight was limited in all the three sources of cytoplasm. The magnitude of heterosis was high for ear weight, grain yield/ear and grain yield/plant.

The mean heterosis in hybrids grouped by cytoplasmic type appeared to be of similar magnitude for days to maturity, days to 50% flowering, flag leaf area and 1000-grain weight. But for other traits the cytoplasmic effect was conspicuous. The A_5 cytoplasmic source exhibited pronounced heterotic effect on productive tillers /plant and peduncle length compared to other sources (A_1 and A_4). Similarly the A_4 cytoplasmic source had greater heterotic effect on ear length, ear head weight, grain yield /ear, grain yield /plant compared to other two sources. On the other hand, A_1 source had highest heterotic effect on ear girth. These results indicate the differential effect of diverse cytoplasm on the expression of different quantitative characters. The considerable variation in expression of heterosis in hybrids based on different cytoplasm particularly for productivity traits suggest that there exist ample opportunity to exploit these diverse sources in pearl millet hybrid breeding to raise the productivity to a greater levels.

Over all, it appears that A_4 based hybrids had maximum heterosis for grain yield per plant and other panicle components, followed by A_1 and A_5 indicating a distinct advantage of these cytoplasms. However, other equally important consideration in the use of any CMS source at commercial scale depends upon its stability, availability of strong and agronomically superior restorers. Elaborate studies conducted across wide range of environments have established that A_4 and A_5 sources are more stable than A_1, but the utility of these sources has been constrained by the lack of availability of restorers (Gowda *et al*., 2006). However, by intensifying the restorer-breeding programme on these sources the cytoplasmic base of the hybrids in pearl millet can be diversified successfully

A comparison is made (Table-38) between the most productive and the most heterotic crosses in three different sources of male sterile lines. It is observed that most productive crosses figures as the most heterotic crosses and vice versa. In A_4 based hybrids, the mean grain yield was highest but the group as such showed the lowest mean heterotic value. It indicates that per cent heterosis is an indication of combining ability can be misleading, since a poor hybrid can show a high per cent of heterosis. With these observations it can be inferred that the low yielding (very poor) parental lines may give highly heterotic cross, but these crosses may not be the most productive ones. It is also indicated from the Table-38, that most productive as well as most heterotic crosses belonged to the hybrids based on A_4 cytoplasmic male sterile line. Hence it is clear that potentiality of A_1 and

Table 36. Average heterosis (%) of pearl millet hybrids carrying A_1, A_4 and A_5 cytoplasm

Characters	Range		Average heterosis (%) (A_1, A_4 &A_5)
	Maximum	Minimum	
Days to 50% flowering	4.30	-7.90	-2.35
Days to maturity	3.39	-4.91	-1.03
Plant height (cm)	9.42	-6.83	2.03
Productive tillers/plant	41.67	-18.52	7.57
Ear length (cm)	45.54	-8.75	21.08
Ear girth (cm)	23.59	-10.43	7.68
Peduncle length (cm)	43.90	-18.30	10.40
Flag leaf area (cm^2)	41.92	-45.06	3.98
Ear weight (g)	48.61	-11.67	39.70
Grain yield/Ear (g)	86.12	-18.20	21.80
Grain yield/plant (g)	68.39	-17.69	18.80
1000-seed weight (g)	33.12	-1784	5.70

Table 37. Mean and range of F_1, MP heterosis (%) in pearl millet hybrids carrying different cytoplasms

Characters	Mean & Range	Diverse cytoplasmic sources					
		A_1		A_4		A_5	
		F_1	HMP(%)	F_1	HMP (%)	F_1	HMP(%)
Days to 50% flowering	Mean	46.33	-1.77	46.64	-2.52	46.06	-2.77
	Max.	48.67	4.30	50.00	4.20	47.67	1.06
	Min.	44.67	-6.61	44.33	-7.90	44.33	-7.65
Days to maturity	Mean	83.33	0.07	82.12	-2.55	83.42	-0.61
	Max.	86.33	3.39	84.33	-0.20	85.67	2.19
	Min.	80.67	-3.20	80.67	-4.91	81.00	-3.76
Plant height (cm)	Mean	177.74	1.90	177.11	3.29	176.02	0.89
	Max.	188.00	1.19	188.43	9.13	190.10	9.42
	Min.	168.40	-3.04	171.07	-0.64	162.40	-6.83
Productive tillers/plant	Mean	2.59	-1.78	2.77	5.99	3.05	18.50
	Max.	2.80	14.86	3.10	22.50	3.40	41.67
	Min.	2.33	-18.53	2.07	-22.01	2.80	6.33
Ear length (cm)	Mean	24.76	14.06	27.13	25.79	26.51	14.92
	Max.	30.20	44.96	31.53	43.77	30.30	45.54
	Min.	20.53	-8.75	23.83	-6.34	20.17	-4.87
Ear girth (cm)	Mean	10.11	12.83	9.54	8.07	9.12	2.12
	Max.	11.00	20.90	10.73	22.13	10.57	23.59
	Min.	9.27	2.02	8.30	-10.43	8.53	-6.93
Flag leaf area (cm^2)	Mean	86.05	5.72	75.76	6.07	77.95	0.15
	Max.	98.17	24.47	90.23	26.89	111.90	41.92
	Min.	71.80	-16.64	55.80	-10.93	40.80	-45.06
Peduncle length (cm)	Mean	21.55	2.16	23.03	10.35	24.62	18.73
	Max.	25.70	22.77	28.73	42.43	30.27	43.90
	Min.	17.27	-18.30	20.33	-4.01	19.23	-9.70
Ear weight/ ear (g)	Mean	46.21	30.15	52.51	48.61	50.56	40.55
	Max.	59.83	66.05	62.93	81.68	61.07	76.82
	Min.	31.17	-11.67	40.63	13.40	36.73	4.60
Grain yield /ear (g)	Mean	26.32	21.54	28.09	29.53	24.38	14.37
	Max.	38.03	71.58	40.23	86.12	30.47	50.79
	Min.	19.70	-17.63	18.13	-18.20	18.00	16.21
Grain yield /plant (g)	Mean	61.57	14.13	63.02	30.70	59.34	11.81
	Max.	73.10	45.20	82.97	68.39	81.17	47.58
	Min.	44.17	-23.41	43.37	-17.69	45.37	-17.10
1000 grain weight (g)	Mean	11.35	6.76	11.77	7.06	11.55	3.43
	Max.	13.93	33.12	14.47	32.72	13.97	26.20
	Min.	9.07	-16.82	9.37	-17.84	10.13	-14.65

Table 38. (A) Most Productive and (B) Most heterotic crosses of the study

Crosses	(A) Most productive		Crosses	(B) Most heterotic	
	Per se yield	HMP(%)		Per se yield	HMP (%)
A_1 Based 1. $81A_1$ x IP-10085 2. $81A_1$ x IP-10811	 73.10 71.53	 24.64 45.20	A_1 based 1. $81A_1$ x IP-10811 2. $81A_1$ x IP-873	 71.53 70.63	 45.20 44.84
A_4 Based 1. $81A_4$ x IP-9140 2. $81A_4$ x IP-16197	 82.97 81.50	 60.12 68.39	A_4 Based 1. $81A_4$ x IP-873 2. $81A_4$ x IP-16197	 73.63 81.50	 70.58 68.39
A_5Based 1.81 A_5 x IP-10085 2. $81A_5$x IP-577	 81.17 71.53	 47.58 24.01	A_5 Based 1. $81A_5$ x IP-10085 2. $81A_5$ x IP-873	 81.17 60.97	 47.58 44.84

A_5 cytoplasmic sources are comparatively limited for exploitation of heterosis on commercial scale.

5.4.1.2 Combining ability effects of different CMS sources

5.4.1.2.1 Variance components

There were significant differences among the restorer lines for all the traits, indicating that selection for the hybrid parents for the study was appropriate. However, due to nuclear similarities of the isogenic lines among the testers, differences was observed only for days to maturity, plant height, flag leaf area and grain yield per plant. The significant mean squares due to the line x tester interaction indicated that hybrids differ significantly in their sca effects for all the traits. Highly significant mean squares due to ‘parents vs. hybrids’ showed presence of heterosis in hybrids for all the traits. The ratio between GCA/SCA was less than unity indicating predominance of non-additive gene action.

The general combining ability effects for grain yield /ear head was significant and positive in A_4 cytoplasm and non-significant for A_1 and significant and negative for $A_{5.}$ The lines with A_4 cytoplasm also expressed significant gca effect for ear head weight, ear length and productive tillers/ plant. The A_1 cytoplasmic based lines showed positive and significant gca effect for two traits and negative and significant gca effect for three traits. On the other hand A_5 cytoplasmic based lines exhibited no significant gca effect for any of the traits (Table 39). These results revealed that combining ability is strongly influenced by the type of cytoplasm and of the three, A_4 appears to have positive effect on many of the productive traits followed by A_1. Yadav (1999) also reported that lines with A_3 and A_4 cytoplasms were significantly better combiners for grain yield than A_1 cytoplasm in pearl millet. Virk and Brar (1993) also reported significant effect of diverse cytoplasms on the combining ability in pearl millet and Young and Virmani (1990) in rice.

Among the eleven pollinators, the line viz., IP-16197 exhibited significant and positive gca effects for six traits and the line IP-873 for four traits including grain yield/plant. Additionally the line IP-873 exhibited significant negative gca effects for time to flower indicating its utility for producing early maturity hybrids. The other two lines, which showed positive and significant gca effect for three traits including grain yield, were IP-577 and IP-10085.

5.4.1.2.2 Pooled gca effects of parents

Often we observe gca effects in desirable direction for a particular parent in respect of some characters and in undesirable direction for others. The problem of ascertaining the status of a parent with respect to gca over a number of component characters assumes importance (Arunachalam and Bandyopadhyay, 1979).

Table 39. Pooled gca effects of parents in Expt.IIIa

Parents	Characters													
Tester	1	2	3	4	5	6	7	8	9	10	11	12	Total +ve	Total –ve	GCA status
A_1	0	0	0	-1	+1	0	+1	0	-1	-1	0	0	2	3	L
A_4	0	0	0	+1	0	0	0	0	+1	+1	+1	0	4	-	H
A_5	0	0	0	0	0	0	0	0	0	0	-1	0	-	1	L
Lines															
IP-9140	0	+1	0	0	0	0	-1	+1	-1	-1	0	0	2	3	L
IP-10811	0	0	0	0	0	-1	-1	+1	0	0	0	0	1	2	L
IP-16197	-1	0	+1	0	0	0	0	+1	+1	+1	+1	+1	6	1	H
IP-12678	0	0	-1	0	-1	+1	-1	-1	+1	-1	-1	-1	2	7	L
IP-8229	0	0	0	0	0	0	0	-1	-1	-1	-1	-1	-	5	L
IP-9149	0	0	-1	0	0	0	+1	-1	0	0	-1	-1	1	4	L
IP-873	+1	0	0	0	0	-1	+1	-1	0	0	+1	+1	4	2	H
IP-804	0	0	+1	0	0	0	0	0	+1	0	-1	-1	2	2	L
IP-577	0	0	0	0	0	-1	+1	0	0	+1	+1	+1	3	1	H
IP-7440	0	0	0	0	0	+1	0	0	0	0	0	-1	1	1	L
IP-10085	0	0	0	0	-1	+1	-1	-1	-1	+1	0	+1	3	4	L

1. Days to 50% flowering 2.Days to maturity 3. Plant height 4.Productive tillers per plant
5. Ear length 6. Ear girth 7. Peduncle length 8.Flag leaf area
9. Ear weight 10. Grain yield /ear 11. Grain yield /plant 12. 1000 seed weight

In the present investigation, an attempt has been made to classify all the 14 parents involved in 3x11 crosses, which were subjected to combining ability analysis. For this purpose, the parental gca was assessed for each character using a norm in equal to the mean of significant gca effects of parents for the character. The non-significant gca effects were given a status of zero. The parents whose gca effect was greater than or equal to 'm' were classified as high (H) and assigned a score of +1, others were classified as low (L) with a score of –1. Considering the negative gca effects to be more important for characters such as days to 50 per cent and days to maturity, a parent whose effects was less than 'm' was classified as H. All the parents in Expt.IIIa were thus scored for each character and a final score was computed for each of them over twelve characters. Finally the parents were scored based on the mean of total scores as H and L. The details are presented in Table 39.

Out of 14 parents in experiment-IIIa, only four parents were found in the category of high (H) with respect to gca over twelve characters. The remaining 10 parents were classified as low (L). Among the three testers /females on A_1, A_4 and A_5 source of male sterility, the A_4 cytoplasmic source was classified under the category of high (H) as it scored four + points while, A_1 and A_5 were classified as low (L). The A_4 source found to influence gca effects significantly and positively in the expression of productive tillers, peduncle length, ear weight and grain yield per plant. On the other hand A_1 source appeared to be good source for ear girth and flag leaf area. Among the lines IP-16197, IP-873 and IP-804 were found to be excellent general combiners on over all basis. Amongst the high (H) general combiners IP-16197 appeared to have good potentiality for seed yield/plant, as well as seed weight, grain yield per ear, ear weight and plant height. Among the low (L) combiners, IP-10085 was found good combiner for seed yield, ear length and ear weight, while the other lines of this category such as IP-9140 and IP-10811 were found to be good sources of seed weight.

Specific combinations of A and R lines with good gca effects will remain the essential requirement for the production of superior hybrids. As was observed for gca effects, cytoplasmic and nuclear interaction were detected for sca effects for some of the traits in some of the nuclear combination (Table 40). On A_1 source as many as seven and six hybrids exhibited significant positive sca effects for flag leaf area and ear weight, respectively. On the other hand, on A_4 source seven hybrids exhibited significant sca effect for peduncle length and ear weight followed by six crosses for productive tillers and ear length. All the eleven hybrids on A_5 source exhibited significant and positive sca effect for 1000 grain weight followed by eight hybrids for ear weight. These results clearly indicate the differential nucleo-cytoplasmic interaction in the expression of different quantitative traits in pearl millet. Of the three sources, A_1 appears to interact significantly with nuclear genes and influence positively in the expression of flag leaf area and ear weight and A_4 source in the expression of peduncle length and ear weight. The A_5 cytoplasm influences the expression of ear weight. The differential expression of combining ability effect by the combinations of different pollen parents with different cytoplasmic sources indicates that combining ability effects are strongly modulated by cytoplasmic-nuclear interactions. The significant influence of interaction of cytoplasmic genes and nuclear genes on the expression of panicle components in pearl millet was also reported earlier by Virk and Brar (1993). Chandrashekhar *et al.* (2007) reported that cytoplasmic effects on specific combining ability and heterosis were found to be modulated by cytoplasmic-nuclear interactions. In rice the nucleo–cytoplasmic interactions on the expression of quality characters was recorded by Shivani *et al.* (2007).

5.4.2 Heterosis and combining ability studies on A_1 source for commercial exploitation (Expt.IIIb)

In pearl millet, though several alternate sources of male sterility are available but A_1 system appears to be the principal and stable source for hybrid seed production. In addition, availability of restorers on this source is not a constant. Hence, the assessment of combining ability status of newly derived lines on A_1 source and heterosis estimation in new combinations will remains as an important research activity in pearl millet breeding. In the present study, four popular male sterile lines on A_1 source and eight known restorers with tolerance to rust, were selected with an objective of identifying good combining parents and commercially useful heterotic hybrids.

Table 40. Crosses showing significant sca effects for 12 characters in Expt.IIIa

Crosses	1	2	3	4	5	6	7	8	9	10	11	12	GCA status
A_1x IP-9140	-	-	-**	-	-	-**	+*	+**	-**	-**	-**	+**	L x L
A_1x IP-10811	-	-	-**	-	-	-	-	+**	-	-	+**	+*	L x L
A_1x IP-16197	**	-	-	-	-	-	+**	-	-	-	+**	-**	L x H
A_1x IP-12678	-	-	-**	-	-*	+**	+**	-	+**	-**	-**	-**	L x L
A_1x IP-8229	**	-	-	-	-	-**	-	+**	+**	-	-**	-**	L x L
A_1x IP-9149	-	-**	-**	-	-	-	+*	-	+**	-**	-	-**	L x H
A_1x IP-873	-	-**	-	-*	-	-*	-	+**	-	-	+**	-**	L x H
A_1x IP-804	-	-**	+**	-	-	-	+**	+**	-	-**	-**	-**	L x L
A_1x IP-577	-	-**	+**	-	-	-**	-	+**	+**	+**	+**	+*	L x H
A_1x IP-7440	-	-**	-	-	-	+**	-	+**	+**	+**	+**	-**	L x H
A_1x IP-10085	-	-	-	-	-	+**	-	-	+**	-**	-	-**	L x H
# crosses with Significant desirable/ +ve sca effect	-	4	2	-	-	3	5	7	6	2	5	3	
A_4x IP-9140	-	-**	+**	+*	-**	+**	-	-**	-**	+**	+**	+*	H x L
A_4x IP-10811	-	-**	-	-	-**	-**	+**	-**	+**	+**	+**	-**	H x L
A_4x IP-16197	-	-	+**	-	-*	-**	+**	-	+**	+**	+**	-**	H x L
A_4x IP-12678	-	-	-	+*	+**	+**	+**	-	-	-**	-**	-**	H x L
A_4x IP-8229	-	-	-	+*	-*	+**	-	+*	+**	-	-**	-**	H x L
A_4x IP-9149	-	-	-**	-*	-**	-	+*	+**	+**	-	-	-**	H x L
A_4x IP-873	-	-	-	+*	-**	-**	+*	+**	+**	+**	+**	-**	H x L
A_4x IP-804	-	-	-	+**	-*	-	+**	+**	-	-**	-	-**	H x L
A_4x IP-577	-	-	-	+**	-	+**	+**	+**	+**	+**	+**	-**	H x L
A_4x IP-7440	-	-	-**	-	-**	+**	-	-*	-	-**	-**	-**	H x L
A_4x IP-10085	-	-	-*	-	-**	+**	-	-	+**	-**	-**	-**	H x L
# crosses with Significant desirable/ +ve sca effect	-	2	2	6	1	6	7	5	7	5	5	1	
A_5x IP-9140	-	-	-	-	-	+**	-	-	-	-**	-**	-**	L x L
A_5x IP-10811	-	-**	+*	-	-	-	+**	-	+**	-**	-**	+*	L x L

A_5x IP-16197	-	-**	-	-	-*	+**	+**	-	+**	+*	+**	**	L x H
A_5x IP-12678	-	-**	-	-	-	+**	+**	-	+**	+*	-	-**	L x L
A_5x IP-8229	-	-**	-**	-**	-	+**	+*	-	-	-**	-**	-**	L x L
A_5x IP-9149	-	-*	-	-	-	+*	-	-	-	-**	-**	-**	L x L
A_5x IP-873	-	-*	-**	+*	-	-	+**	-	+**	-**	-	-**	L x H
A_5x IP-804	-	-	-*	-	-*	+**	-	-	+**	-	-	-**	L x L
A_5x IP-577	-	-	-	-	-*	-**	-*	-**	+**	+**	+**	-**	L x H
A_5x IP-7440	-	-	+**	+**	-*	-	+**	-*	+**	-**	-**	-**	L x L
A_5x IP-10085	-	-	-	-	-**	-		+**	+**	+**	+**	-**	L x L
# crosses with Significant desirable/ +ve sca effect	-	6	2	2		6	6	1	8	4	3	1	

+: Positive, -Negative

*, ** Significant at 1 and 5 per cent level respectively

1. Days to 50% flowering 2.Days to maturity 3. Plant height 4.Productive tillers per plant
5. Ear girth 6. Ear length 7. Peduncle length 8.Flag leaf area
9. Ear head weight 10.Grain yield /ear 11. Grain yield /plant 12. 1000 grain weight

5.4.2.1 Heterosis

It is evident from the results that the degree of heterosis varied considerably for grain yield and its components. With a view to crystallize the results, average heterosis was calculated by using parental and F_1 generation means. The positive heterotic values were maximum for ear weight, grain yield/plant, grain yield /ear and ear girth in that order. A critical examination of the table-41 indicates that heterosis for grain yield per plant is mainly the result of heterosis for grain yield/ear and ear weight/ear. The heterosis for grain yield/ear is inturn contributed by ear girth, 1000 grain weight and ear length. The crosses showing significant heterosis for these traits are ICMA 842 x IPC-1361, JMSA 101 x IPC-217, ICMA 88004 x IPC-577, JMSA 101 x IPC-1104, ICMA 94555A x IPC-217.

In Table 42, a comparison is made between the most productive and most heterotic crosses. The top five productive crosses figured as top five heterotic crosses. However, the ranking order in productive and heterotic crosses was almost same. This indicates that highly heterotic crosses are generally productive. Interestingly majority of the vegetative traits like productive tillers/plant, peduncle length and flag leaf area showed negative heterosis. The plant height had very limited heterosis. These results revealed that heterosis for grain yield in pearl millet is mainly contributed through panicle components rather than vegetative traits. Heterosis for earliness was negative indicating the scope of developing high yielding and early maturing hybrids. Heterosis for earliness was also reported earlier by several workers (Kushwah and Singh, 1992; Chavan and Nerkar, 1994;Kulkarni *et al*., 1993). Looking to this it appears that heterosis for earliness in pearl millet is a general phenomenon.

5.4.2.2 Combining ability studies

One of the important criteria's in heterosis breeding is the choice of appropriate parents to be used in hybridization programme. It is therefore, necessary to select parents with good general combining ability for yield and its components. The combining ability analyses assess the utility of the crosses and the parents. The study also provides information on relative magnitude of GCA and SCA variances, which indicates the nature of gene action in terms of additive and non-additive genetic variances respectively.

5.4.2.2.1 Combining ability variance and effects

All the characters (Expt.IIIb) showed higher proportion of SCA variance than GCA variance indicating prominence of non-additivity for these characters. This is further supported by ratio of gca and sca variance. Higher proportion of SCA variance was probably due to adequate genetic diversity in the material used. High SCA variance for these characters was also reported by earlier workers Phul *et al*., 1973; Pokhriyal *et al*., 1976; Azhaguvel and Jayaraman, 1998, Yadav *et al*., 2002.

Among testers, ICMA 94555 emerged as best general combiner by registering positive significant gca effect for as many as 9 characters including grain yield/plant. The other two lines, which showed significant positive gca effect for four characters, were JMSA 101 and ICMA 842. The next best general combiner was ICMA8804, which showed significant positive gca effect for ear length, ear girth, peduncle length, ear weight, grain yield per ear, grain yield per plant and flag leaf area (Table 43).

Among the lines significant positive gca effect for panicle traits (ear length, ear girth, peduncle length, ear weight, grain yield and seed weight) were registered by IPC-577, IPC-804, IPC1518, IPC-1104 and IPC-1394. Among these, the line IPC-577 emerged as best general combiner on overall basis. Yadav *et al*. (2002), Manga and Dubey (2004) and Karad and Harer (2005) have also reported similar observations in their line x tester studies. The lines and testers exhibiting highly significant positive gca effect for grain yield /plant and other panicle components can be involved in crossing programme to develop superior hybrid or to derive superior recombinants.

5.4.2.2.2 Pooled gca effects of parents

Often we observe gca effects in desirable direction for a particular parent in respect of some characters and in undesirable direction for others. The problem of ascertaining the

Table 41. Average performance of parents, MP, F_1 generation and average MP heterosis (Expt.IIIb)

Characters	Parental mean				Heterosis (%)
	P1	P2	MP	F_1	MP
Days to 50% flowering	50.91	56.05	53.49	48.78	-8.67
Days to maturity	84.89	85.55	85.24	85.14	-0.11
Plant height	137.44	162.47	150.08	157.05	4.53
Productive tillers/plant	2.44	2.55	2.49	2.29	-7.90
Ear length	21.81	22.11	21.96	23.44	6.98
Ear girth	5.41	6.08	5.75	6.55	14.39
Peduncle length	29.16	27.26	28.21	25.20	-10.53
Flag leaf area	85.25	80.39	82.87	81.32	-0.76
Ear weight	31.07	35.71	33.40	46.47	39.41
Grain yield/Ear	24.28	26.51	25.40	28.85	14.66
Grain yield/plant	55.54	56.17	55.40	65.72	17.92
1000-grain weight	11.55	10.89	11.22	11.58	3.36

Table 42. (A) Most Productive and (B) Most heterotic crosses of the study (Expt.IIIb)

Crosses	(A) Most productive		Crosses	(B) Most heterotic	
	Per se yield	HMP (%)		Per se yield	HMP (%)
ICMA 842 x IPC-1361	102.57	80.58	ICMA 842 x IPC-1361	102.50	80.58
ICMA 94555 x IPC-217	100.70	72.34	JMSA 101 x IPC-217	98.50	76.37
ICMA 88004 x IPC-577	99.53	74.86	ICMA88004 x IPC-577	99.50	74.86
JMSA 101 x IPC-217	98.53	76.37	JMSA101 x IPC-1104	90.30	78.67
JMSA 101 x IPC-1104	90.33	72.67	ICMA 94555 x IPC-217	100.70	72.34

status of a parent with respect to gca over a number of component characters assumes importance (Arunachalam and Bandyopadhyay, 1979).

In the present investigation, an attempt has been made to classify all the 16 parents involved in (Expt.IIIb) crosses, which were subjected to combining ability analysis (Procedure followed is same as that of Expt.IIIa). All the parents in Expt.IIIb were thus scored for each character and a final score was computed for each of them over twelve characters. Finally the parents were scored based on the mean of total scores as H and L. The details are presented in Table 43.

Out of 16 parents, only nine were found in the category of high (H). The rest of the seven genotypes were classified as low (L). Among the four females, ICMA-94555, ICMA-842 and ICMA-88004 were found to be high (H) general combiners. The female ICMA-94555 recorded maximum plus points (9) by exhibiting significant positive gca effect for seed yield, grain weight, grain yield/ear, ear weight, ear length, ear girth, plant height, peduncle length and flag leaf area. The ICMA 842 appeared to be a good source for earliness, seed weight, ear length and ear girth in addition to high (H) general combining ability. Among the lines, IPC-577, IPC-804, IPC-217, IPC-338, IPC-1394 and IPC-1361 were found in the category of high (H). Among the high (H) general combiners, IPC-577 and IPC-1394 showed significant and positive gca effect for seed yield, ear length, ear girth and peduncle length. The line IPC-388 was found good combiner for productive tillers per plant, ear length, ear girth and ear weight.

5.4.2.2.3 Sca effects

In the present study best heterotic crosses were identified for 12 characters (Table 44). It was observed that, out of 48 crosses as many as 15 crosses were most heterotic for grain yield/plant and of these 15 hybrids on ICMA 94555, one hybrid on JMSA 101, 4 hybrids each on 842 A and ICMA 88004 were highly heterotic in desirable condition. The cross ICMA 842 x IPC 217 registered maximum sca effect (21.25). The other combinations viz., ICMA 94555 x IPC 1104 (13.13), ICMA 94555 x IPC 338 (11.82), ICMA 94555 x IPC 827-1 (10.94) and ICMA 88004 x IPC 873 (9.48) exhibited highly significant sca effect for grain yield per plant. The crosses involving lines viz., IPC-217, IPC-1104, IPC-338, IPC-827-1 and IPC-873 were found to be highly heterotic.

The crosses with significant sca effect for grain yield per plant also exhibited high specific combining ability for other panicle components indicating that improvement in grain yield /plant could be achieved by improving other panicle components. It was also observed that, crosses, which showed significant sca effect for grain yield per plant, also exhibited significant heterosis and further, such crosses invariably had one parent with significant gca effect. In addition, >50 % of the crosses showed significant and desirable sca effect for grain yield /plant and panicle components indicating the potentiality for exploiting hybrid vigor in pearl millet breeding programme. The present study and earlier reports (Balkrishna and Das (1996) and Latha and Shanmugasundaram (1998) clearly indicated that the grain yield/plant is predominantly under the control of non-additive gene action.

The information on combining ability and heterosis considered together would be more meaningful. If the heterotic hybrids involve parents with high gca effect, it implies that the parental contribution to heterosis is mainly through additive gene effects. Hence, an attempt was made to score each cross with respect to their parental gca status over 12 characters. Out of 48 crosses, 18 crosses scoring high (H x H), 24 crosses were of high and low (H x L, or L x H) parents and the remaining 24 crosses were from either H x H or L x L parents (Table 44). These results, indicated that highly heterotic hybrids (crosses showing heterosis over their better parents) could be obtained from parents with any combination of gca i.e., H x H, H x L, L x H and L x L. However, the frequency of heterotic hybrids was comparatively more in H x L or Lx H type of crosses in both experiments. Several examples are available in published literature where High x Low crosses have provided high frequency and higher magnitude of heterosis (Reddy and Arunachalam (1981). According to Langham (1961), genotypes with high gca possess genes capable of expressing high phenotypic effects but are prevented from doing so by the retarding effect of residual genetic background (RGB). Likewise genotypes with low gca possess low genes capable of expressing extremely low phenotypic effects but are again prevented from doing so by enhancing effect of RGB.

Table 43. Pooled gca effects of parents in Experiment IIIb

Parents	Characters													
Tester	1	2	3	4	5	6	7	8	9	10	11	12	Total +ve	Total –ve	GCA status
ICMA94555	0	0	+1	0	+1	+1	+1	+1	+1	+1	+1	+1	9	-	H
JMSA101	-1	0	+1	0	-1	-1	-1	+1	+1	-1	-1	-1	3	7	L
ICMA842	+1	+1	-1	0	+1	+1	-1	+1	-1	+1	-1	-1	6	5	H
ICMA88004	0	0	-1	0	+1	+1	+1	-1	+1	+1	+1	+1	7	2	H
Lines															
IPC-577	0	0	0	0	+1	+1	0	+1	+1	+1	+1	+1	6	1	H
IPC-804	0	0	0	0	+1	-1	+1	-1	+1	-1	+1	0	4	3	H
IPC-873	0	0	0	-1	-1	-1	-1	+1	+1	-1	+1	0	3	5	L
IPC-877-1	0	0	0	-1	-1	-1	-1	+1	+1	-1	+1	0	3	5	L
IPC-1518	0	0	0	+1	-1	-1	-1	0	0	-1	-1	0	1	4	L
IPC-1104	0	0	0	0	-1	+1	-1	-1	+1	+1	-1	0	3	4	L
IPC-217	0	0	0	0	0	+1	+1	-1	+1	+1	-1	0	4	2	H
IPC-338	0	0	0	+1	+1	+1	0	-1	+1	+1	+1	0	6	1	H
IPC-1361	0	0	0	0	+1	+1	-1	-1	+1	0	+1	0	4	2	H
IPC-1394	0	0	0	0	+1	+1	+1	-1	+1	0	0	+1	5	1	H
IPC-1503	+1	+1	0	-1	-1	+1	-1	+1	-1	-1	-1	0	4	6	L
IPC-828	0	0	0	0	-1	-1	-1	+1	+1	-1	-1	0	2	5	L

1. Days to 50% flowering 2.Days to maturity 3. Plant height 4.Productive tillers per plant
5. Ear length 6. Ear girth 7. Peduncle length 8.Flag leaf area
9. Ear weight 10. Grain yield /ear 11. Grain yield /plant 12. 1000 seed weight

Table 44. Crosses showing significant and desirable sca effect for 12 characters in Expt.IIIb

Crosses	Characters												
	1	2	3	4	5	6	7	8	9	10	11	12	GCA status
ICMA94555 x IPC-577	-	-	-**	-	*	+**	+**	**	**	+**	*	**	H x H
ICMA94555 x IPC-804	-	-	**	-	-	+**	**	**	+**	+**	+**	+**	H x H
ICMA94555 x IPC-873	-*	-*	**	-	+*	-	+**	+**	**	+**	+**	+**	H x L
ICMA94555 x IPC-827-1	-*	-**	+**	-	**	**	**	**	+**	+**	+**	**	H x L
ICMA94555 x IPC-1518	-	-	*	-	-	**	-	**	**	**	**	-	H x L
ICMA94555 x IPC-1104	-	-	**	-	+**	+**	+**	**	+**	+**	-	+**	H x L
ICMA94555 x IPC-217	-	-	+**	-	+**	**	**	+**	+**	+**	+**	**	H x H
ICMA94555 x IPC-338	-	-	+**	-	+**	**	**	+**	+**	+**	+**	**	H x H
ICMA94555 x IPC-1361	-	-	**	-	-	-	-	**	+**	+**	**	**	H x H
ICMA94555 x IPC-1394	-	-	**	-	*	-	-	**	-	**	**	**	H x H
ICMA94555 x IPC-1503	-	-	**	-	-	-	-	+**	+**	**	+**	+**	H x L
ICMA94555 x IPC-828	-	-	**	-	+**	+**	**	+**	+**	+**	-	+**	H x L
JMSA101 x IPC-577	-	-	+**	-	+**	-	+**	+**	-	**	-	+**	L x H
JMSA101 x IPC-804	-	-	+**	-	+**	+*	+**	+**	**	**	**	+**	L x H
JMSA101 x IPC-873	-	-	**	-	-	-	-	+**	**	**	**	+**	L x L
JMSA101 x IPC-827-1	-	-	-**	-	**	-	**	+**	+**	**	**	+**	L x L
JMSA101 x IPC-1518	-	-	+**	-	+**	+**	**	**	**	+**	**	**	L x L
JMSA101 x IPC-1104	-	-	**	-	-	+**	-	**	**	+**	-	+**	L x L
JMSA101 x IPC-217	-	-	**	-	+**	-	-	**	-	**	**	**	L x H
JMSA101 x IPC-338	-	-	**	-	+**	-	**	+**	+**	+**	+**	**	L x H
JMSA101 x IPC-1361	-	-	**	-	**	-	**	**	+**	-	**	-	L x H
JMSA101 x IPC-1394	-	-	+**	+**	-	**	**	+**	-	**	-	+**	L x H
JMSA101 x IPC-1503	-	-	+**	-	**	-	-	**	-	-	-	-	L x L
JMSA101 x IPC-828	-	-	**	-	-	-	+**	**	-	**	-	**	L x L

ICMA842 x IPC-577	-	-	-	-	-	**	**	**	**	+**	+**	**	H x H
ICMA842 x IPC-804	-	-	+**	-	+**	-	**	+**	+**	+**	+**	+**	H x H
ICMA842 x IPC-873	-	-	**	-	**	-	+**	**	**	+**	**	**	H x L
ICMA842 x IPC-827-1	-	-	+**	-	**	-	-	+**	**	**	-	+**	H x L
ICMA842 x IPC-1518	-	-	+**	+**	**	+**	+**	**	+**	**	-	+**	H x L
ICMA842 x IPC-1104	-	-	+**	-	**	-	-	+**	**	**	**	-	H x L
ICMA842 x IPC-217	-	-	+**	-	**	-	**	**	+**	+**	+**	-	H x H
ICMA842 x IPC-338	-	-	**	-	**	*	**	**	**	**	-	**	H x H
ICMA842 x IPC-1361	-	-	+**	-	+**	+**	+**	+**	+**	-	-	**	H x H
ICMA842 x IPC-1394	-	-	**	+**	+**	-	**	**	-	**	+**	-	H x H
ICMA842 x IPC-1503	-	-	**	-	-	-	-	**	**	**	**	+**	H x L
ICMA842 x IPC-828	-	-	**	-	-	-	+**	**	+***	-	-	**	H x L
ICMA88004 x IPC-577	-	-	**	**	**	-	**	**	**	+**	**	+**	H x H
ICMA88004 x IPC-804	-	-	**	-	-	*	**	+**	+**	-	+**	+**	H x H
ICMA88004 x IPC-873	-	-	+**	-	**	-	+**	+**	**	+**	+**	**	H x L
ICMA88004 x IPC-827-1	+*	-	+**	-	**	**	**	+**	**	+**	-	**	H x L
ICMA88004 x IPC-1518	-	-	**	-	+**	-	**	+**	+**	+**	-	**	H x L
ICMA88004 x IPC-1104	-	-	+**	-	-	-	-	+**	+**	+**	-	**	H x L
ICMA88004 x IPC-217	-	-	**	-	-	-	+**	**	+**	-	-	**	H x H
ICMA88004 x IPC-338	-	-	**	+*	**	-	+**	+**	**	**	**	**	H x H
ICMA88004 x IPC-1361	-	-	**	-	**	-	+**	-	+**	+**	+**	**	H x H
ICMA88004 x IPC-1394	-	-	+**	-	-	**	-	**	+**	-	+**	+**	H x H
ICMA88004 x IPC-1503	-	-	**	-	**	**	**	+**	**	+**	**	+**	H x L
ICMA88004 x IPC-828	-	-	**	-	**	-	+**	-	-	**	-	**	H x L

+**: Positive, -**: Negative
*, ** Significant at 1 and 5% level respectively

1. Days to 50% flowering
2. Days to maturity
3. Plant height
4. Productive tillers per plant
5. Ear length
6. Ear girth
7. Peduncle length
8. Flag leaf area
9. Ear weight
10. Grain yield /ear
11. Grain yield /plant
12. 1000 seed weight

Further, high genes express extremely high phenotypes when they as well as the RGB are homozygous and nearly equal phenotypes result when they and the RGB are heterozygous. But low genes can express their potential only in a 'retarding' homozygous RGB. H x H and L x L crosses result in situations resembling their parents and hence in a low frequency of heterotic crosses. But H x L crosses produces heterozygous progeny genotypes in heterozygous RGB. Their phenotypes express high effects and can be better than their superior parent for some traits.

5.5 INHERITANCE OF RUST RESISTANCE

In the present investigation, a rust susceptible parent (81B) and three resistant donors *viz*., IP-2933-1, IP-6240-3 and 700481-1-5-1 were selected for the study. All the three resistant donors were crossed to 81B and their reciprocals were produced. A total of six F_1's, their F_2's, six BC_1 and BC_2 generations were developed subsequently. The F_1, F_2, BC_1 and BC_2 populations and parents were scored for their reaction to rust under field condition. Scoring was done by following the method of Mayee and Datar (1986).

Plants were scored on visual assessment and disease severity was recorded on 0 to 100 per cent. This actually allowed the appropriate estimation of the per cent of the area of plant infected by the pathogen. Scores were also given considering 0 to 3 (1 to 10 % pustules on leaves) as resistant types and those from 5 to 9 (>10% pustules on leaves) as susceptible ones.

The F_1 plants of direct crosses (81B x IP-2933-1, 81B x IP-6240-3, 81B x 700-481-1-5-3) and their reciprocal crosses (P-2933-1 x 81B, IP 6240-3 x 81B, 700481 -1-5-3 x 81 B) showed all resistant to rust. This reveals that A_1 cytoplasmic source has no influence on rust tolerance or susceptibility.

The F_2 plants of crosses 81B x IP-2933-1, 81B x IP-6240-3, 81B x 700-481-1-5-3 and their reciprocals showed 3:1 ratio indicating monogenic dominant gene governing the resistance. Similar results were also reported by Hanna *et al*, (1985), Ramamoorti *et al*. (1995), Panna *et al*. (1996) and Ramamoorti and Jehangir (1996) on F_2 plants of pearl millet.

In the BC_1 population of direct crosses segregation pattern was 1 resistant and 1 susceptibility; while in BC_2 populations all the plants were resistant. On the other hand, in the reciprocal crosses, in BC_1 populations all the plants were resistant, while in BC_2 population segregation pattern was 1 resistant and 1 susceptibility. These results confirm single gene control of resistance. Andrews *et al.* (1985) also observed similar ratio in their studies.

5.6 FUTURE LINE OF WORK

Experiment – I (Restoration Studies)

1. The present investigation revealed that the lines of Indian origin are observed to be restorers on A_1, A_4 and A_5 source of cytoplasmic male sterility. Hence, emphasis should be laid to screen large collection of indigenous germplasm for identifying restorer genes on these diverse sources.

2. On the three cytoplasmic sources used in the present study, the germplasm lines showed difference in the extent of restoration / degree of seed set on hybrids. In fact the seed set percentage ranged from 0 to 98. In the breeding programme aimed at developing new restorers, one should use the lines showing >90 per cent seed set as a source for transferring restoring ability. However, when the seed set percentage exhibited by the genotypes is less than 90%, one may initiate population improvement programme to pyramid the modifier genes to enhance the seed set percentage. In addition to this, induction of mutation can also be opted for obtaining strong restorers.

3. In developing alloplasmic and isonuclear hybrids, it is necessary to develop a male parent which restores fertility on all the three cytoplasms. In this study twelve lines showed common restoration on all the three sources and some lines showed restoring ability on two cytoplasms. Such lines can be utilized for developing isonuclear hybrids in the all the three sources or combinations of any two sources.

4. In the present study, it was observed that A_4 source of cytoplasm was stable across environments as compared to the A_1 and A_5 sources of male sterility. It will be interesting to study in depth about the influence of temperature, photoperiod and other environmental factors on the stability of restoration on these sources.

5. The inheritance pattern of fertility restoration on diverse source of CGMS is not clearly understood. The detailed studies on this aspect using newly identified restorers on each of these sources needs to be initiated.

Experiment – II (Genetic variability and divergence studies)

1. The variance among the 105 pearl millet germplasm lines was highly significant for all the characters indicating that the genotypes under study were genetically diverse. Hence, these can be used in future breeding programme.

2. The highly divergent pairs in restorer, maintainer and combined group can be crossed for creating variability and isolating better R as well as B lines on one or two sources, respectively.

3. In the combined group, the divergent restorer and maintainer pairs will make 'B' and 'R' combinations at least on one cytoplasm. If such hybrids are good the corresponding cytoplasm (s) can be used for developing male sterile version and can be utilized for developing hybrid.

Experiment – III (Heterosis and Combining ability studies)

1. Expt. IIIa. Study indicated that the A_4 based hybrids had maximum heterosis for grain yield and other panicle components followed by A_1 and A_5 based hybrids, indicating distinct advantage of A_4 cytoplasm. But the utility of this source has been constrained by lack of availability of restorers. However, by intensifying the restorer breeding on A_4 source, the cytoplasmic base of the hybrids in pearl millet can be diversified.

2. Expt.IIIb. Among the females, ICMA 94555 and among males, IPC-577, IPC-1394 were found to be good general combiners for yield and related characters. The experiments on stability of these genotypes over environments in respect of yield and yield components can be taken up to identify stable lines.

3. Segregating populations of heterotic hybrids namely, ICMA 842 x IPC 217, and ICMA 94555 x IPC827-1 and ICMA88004 x IPC -873 can be advanced for further selection and development of new inbreds.

Experiment – IV (Inheritance of rust resistance)

1. There is a need for further confirmation of inheritance of rust resistance in reciprocal crosses and also need to study the existence of different races of rust. Selection of highly resistant genotypes in the segregating generations followed by intermating among the desirable segregants is suggested.

6. SUMMARY AND CONCLUSIONS

Identification of restorers on the diverse sources of male sterility is pre-requisite for utilizing alternate cytoplasms for commercial exploitation of heterosis and to evade the risk associated with the use of single source. The main objective of the present study was to evaluate the selected germplasm for restoring ability, to identify stable restorers and to characterize the cytoplasmic difference based on restoration pattern on three diverse sources of male sterility viz., A_1, A_4 and A_5. To achieve this objective, 105 pearl millet genotypes were crossed with these diverse sources of male sterility.

The second experiment was aimed at ascertaining the extent of genetic variability and diversity among the diverse cytoplasmic lines and the pollen parents. Here, the Mahalanobis's D^2 analysis was carried out in three sets of genotypes (i) maintainers + restorers (105), (ii) maintainers (44), (iii) restorers (61), separately.

Information on heterosis and combing ability was sought to be obtained through line x tester analysis, which formed the third experiment. For this purpose two different Line x Tester experiments were formulated. Expt.IIIa consisted of three alloplasmic isonuclear lines and 11 pollen parents. The objective here was to ascertain the degree of cytoplasmic effects on heterosis and combining ability of different quantitative characters. The second experiment (Expt.IIIb) consisted of four promising lines on A_1 source. Here, the purpose is to identifying superior combiners and combinations for commercial use.

A study on the inheritance of rust resistance was carried out by involving a rust susceptible line and three rust resistant lines, which formed the fourth experiment.

The salient features of the various experimental findings are presented below.

1. The restoration studies revealed that out of 105 lines, 38 lines (36.0%) on A_1, 63 lines (60%) on A_4 and 47 lines (44.76%) on A_5 cytoplasm restored fertility. The strength of restoring ability was measured based on seed set percentage. Among the three sources of male sterility the seed setting was high and stable on A_4 cytoplasm (>70 per cent), where as <60% on A_5 and A_1 cytoplasm. Seed set per cent was comparatively high in *kharif* than in summer on all the three sources.

2. Germplasm collection (pool of restorers and maintainers on diverse sources) was evaluated for magnitude of genetic variability and diversity. Different genetic parameters such as mean, variance, genotypic and phenotypic coefficient of variation, heritability, genetic advance and genetic advance over mean were worked out among yield and yield components separately in the study. The results indicated that both PCV and GCV were high for ear head length, ear head girth, plant height, grain yield per plant and productive tillers/plant. High heritability was observed for grain yield/plant, plant height, ear head length, ear head girth, 1000 seed weight and peduncle length. High genetic advance over mean was observed for ear head length, plant height, ear head girth, grain yield per plant, peduncle length and flag leaf area.

   Genetic diversity was adequate among the genotypes of all the three groups, which fell into 22 (maintainer + restorers), 11 (maintainers) and 19 (restorers) clusters. D^2 values were in general, high in restorers group followed by combined and maintainer groups. In the present study, the most important characters contributing towards divergence was days to maturity in all the three groups.

3. In the present study two, Line x Tester experiments were planned to study the influence of different CMS sources on heterosis and combining ability effects for different quantitative characters (Expt. IIIa) and estimate the heterosis and combining ability on A_1 source for commercial exploitation (Expt.IIIb).

In Experiment IIIa, the mid parent heterosis for various traits revealed that the direction and magnitude of heterosis was significantly influenced by the cytoplasmic source. As many as nine hybrids with A_1 source were significantly heterotic for ear girth while only six and three hybrids with A_4 and A_5 were significantly heterotic, respectively. Majority of the hybrids carrying A_4 source were highly heterotic for the traits viz., days to maturity, plant height, ear head weight, grain yield /ear, grain yield /plant and ear length. On the other hand, majority of the A_5 based hybrids were highly heterotic for productive tillers, ear length, flag leaf area and peduncle length.

In Experiment IIIb, considerable heterosis was observed for grain yield and its components. The heterosis for grain yield was largely due to ear length, ear girth, ear weight and grain weight. The most productive hybrids were ICMA 842 x IPC-1361, ICMA 94555 x IPC-217, ICMA 8804 x IPC-577, JMSA101 x IPC-1104, JMSA101 x IPC-217.

In Experiment IIIa, the general combining ability effects for grain yield /ear head was significant and positive in A_4 cytoplasm and non-significant for A_1 and significant and negative for A_5. The lines with A_4 cytoplasm also expressed significant gca effect for ear head weight, ear length and productive tillers/ plant. The A_1 cytoplasmic based lines showed positive and significant gca effect for two traits and negative and significant gca effect for three traits. The sca effects indicated the differential nucleo-cytoplasmic interaction in the expression of different quantitative traits in pearl millet. Of the three sources, A_1 appears to interact significantly with nuclear genes and influence positively in the expression of flag leaf area and ear weight and A_4 source in the expression of peduncle length and ear weight. The A_5 cytoplasm known to influences the expression of ear weight. In Expt.IIIb combining ability analysis revealed that the majority of the characters are under the control of non-additive gene action and SCA variances were greater than GCA variances. Among the testers, ICMA 94555 emerged as a best general combiner and the next best general combiners were JSMA101, ICMA 842 and ICMA 88004 which showed significant and positive gca effect for majority of the characters. The crosses ICMA 842 x IPC-217, ICMA 94555 x IPC-1104, ICMA842 x IPC-217, ICMA88004 x IPC-873 were found productive cum heterotic hybrids.

When comparison was made between combining ability and heterosis, it was observed that heterotic hybrids could be obtained from parents with any combinations of gca i.e., H x H, H x L, Lx H and L x L.

4. The inheritance pattern of rust resistance in segregating F_2 and back cross generation considered the 3:1 ratio, indicating rust resistance is monogenic dominant gene governs the susceptibility.

Based on the results obtained from the restoration studies, it was suggested to initiate the population improvement programme to enhance the seed set percentage on diverse source of male sterile lines. Utilizing divergent pairs in different groups, better 'B' and 'R' lines on diverse cytoplasmic sources may be developed. The A_4 source can be comfortably used in development of hybrids for commercial cultivation and the restorer development programme on A_4 source needs to be strengthened. By crossing common restorers on these diverse sources, alloplasmic and isonuclear hybrids may be developed. The productive crosses on A_1 source may be tried over locations/seasons to see their stability in performance. To improve the rust resistance, selection of highly resistant genotypes in the segregating generations followed by intermating among the desirable segregants is suggested.

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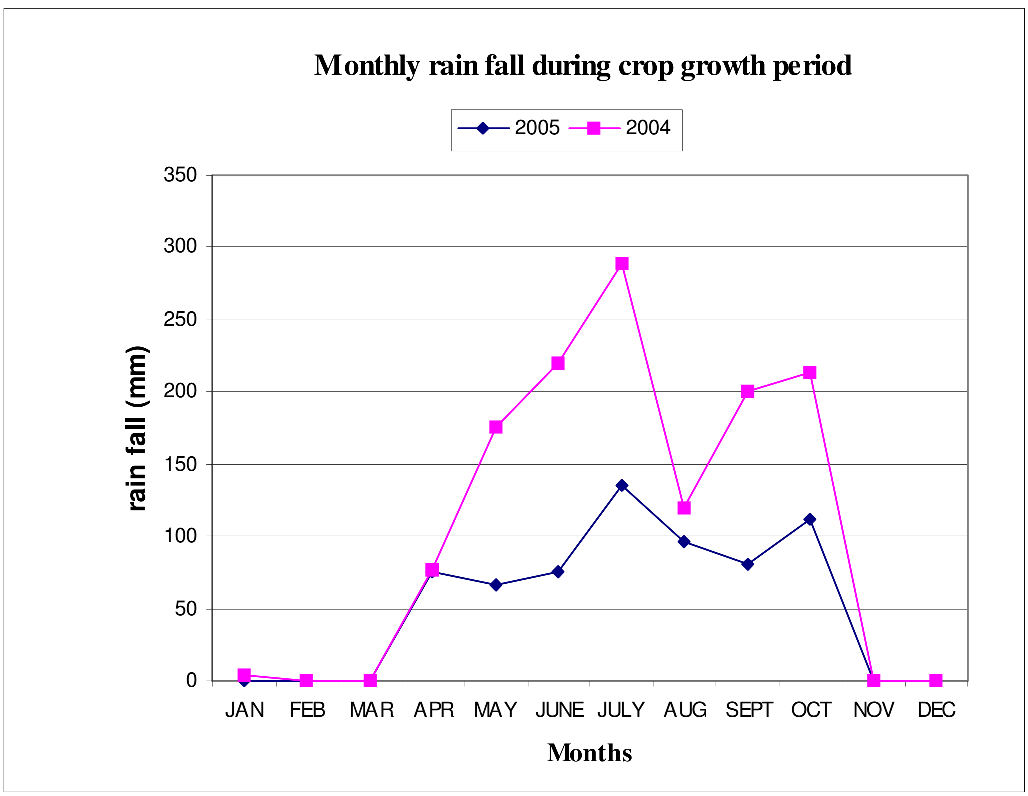
APPENDIX. I

Monthly rainfall, temperature, relative humidity data during crop growth period

Month	2004					2005				
	Rainfall (mm)	Temp (^oC)		Relative humidity (%)		Rainfall (mm)	Temp (^oC)		Relative humidity (%)	
		Max.	Min.	AM	PM		Max.	Min.	AM	PM
January	4.0	29.9	13.8	72	41	0.0	30.7	14.3	75	33
February	0.0	32.8	16.1	70	38	0.0	33.5	15.3	61	23
March	0.0	37.9	20.6	64	29	0.0	36.2	19.5	52	23
April	0.5	38.8	23.4	62	25	76.1	36.7	22.8	65	29
May	108.9	35.6	22.9	77	41	66.4	38.1	23.2	71	34
June	144.7	31.9	21.8	86	58	74.9	34.2	23.2	88	59
July	153.2	30.1	21.2	90	62	135.6	29.9	22.0	90	66
August	23.0	29.9	20.7	90	59	96.2	29.4	21.2	91	64
September	120.0	30.4	20.9	91	62	80.4	29.5	21.2	91	63
October	100.8	30.6	19.1	86	51	112.3	30.3	19.4	86	53
November	0.0	30.4	15.1	81	35	0.0	30.1	13.1	77	32
December	0.0	29.6	10.8	79	32	0.0	29.3	12.1	72	33
Annual	**655.1**	**32.3**	**18.9**	**79**	**44**	**591.9**	**32.3**	**19.0**	**76**	**43**



APPENDIX. II

Mean performance of 105 pearl millet germplasm lines for 12 different quantitative characters during 2004

S No.	Genotypes	DF	DM	PH	EL	EG	PT	PL	FLA	EWT	GYE	GYP	SWT
1	IP-9140	53.00	86.33	121.60	18.33	4.93	2.13	32.33	98.83	32.43	20.50	49.57	9.93
2	IP-9286	54.67	88.67	212.17	27.50	4.80	2.60	30.17	75.10	36.80	29.37	71.97	11.00
3	IP-15857	49.33	87.67	179.20	26.73	8.03	1.73	29.90	75.47	33.40	27.43	67.77	10.73
4	IP-15899	54.00	87.67	200.97	20.27	6.63	1.87	26.47	90.87	32.30	25.87	71.80	9.53
5	IP-9149	51.33	85.33	161.00	24.33	6.77	2.13	25.93	89.70	39.17	22.60	73.43	12.00
6	IP-3799	50.33	85.67	152.87	26.67	7.40	2.47	27.67	95.57	37.53	28.53	71.27	11.27
7	IP-3150	50.00	86.33	171.57	18.90	5.27	2.73	23.60	95.20	29.80	20.57	76.97	11.33
8	IP-10186	54.33	86.33	141.40	18.13	5.20	2.30	24.47	65.10	30.53	20.93	53.67	11.03
9	IP-10394	51.00	84.67	170.30	27.17	5.13	2.20	23.07	65.47	38.20	25.90	71.57	10.30
10	IP-10820	51.33	84.67	161.70	17.20	4.47	1.87	26.33	61.77	33.50	22.57	70.80	10.90
11	IP-15817	50.33	85.67	163.00	28.00	6.70	1.93	30.70	61.20	38.60	28.30	83.50	12.70
12	IP-15220	52.00	86.67	176.33	20.87	6.93	3.00	30.26	70.43	30.27	20.63	63.30	12.27
13	IP-15256	51.33	84.67	174.10	18.30	4.40	1.73	21.73	73.53	32.50	21.17	48.30	11.50
14	IP-17566	47.00	84.00	178.07	25.13	5.87	1.93	33.20	66.77	36.10	22.60	50.47	13.33
15	IP-17144	46.33	83.67	173.23	27.73	6.00	2.13	34.50	63.33	41.83	27.30	76.63	12.53
16	IP-15829	48.33	83.33	196.97	18.20	6.67	2.83	36.40	62.20	35.10	22.17	82.03	11.13
17	IP-6510	51.67	84.33	189.20	22.83	6.93	2.80	26.73	56.43	38.50	25.80	83.67	10.03
18	IP-8276	51.33	86.00	144.63	26.37	7.00	2.23	23.00	68.63	35.90	27.20	83.47	9.00
19	IP-9416	56.00	86.67	159.67	19.83	4.93	2.80	23.60	72.73	36.20	26.50	82.50	8.97
20	IP-17493	56.00	87.00	164.53	16.87	4.90	1.73	22.50	83.17	38.06	25.60	55.97	9.30
21	IP-17028	58.33	87.00	224.13	19.80	4.97	1.83	28.07	86.30	41.73	28.03	69.47	10.83
22	IP-10811	50.33	88.00	227.87	28.80	6.03	2.03	28.97	55.07	39.07	28.23	58.07	11.23
23	IP-10085	50.00	85.33	181.80	21.77	7.00	1.87	31.07	66.13	37.87	25.83	52.00	10.73
24	IP-15681	51.00	86.33	176.27	22.73	7.30	2.20	30.50	60.30	40.70	23.97	65.73	11.30
25	IP-15257	53.33	85.67	143.13	26.17	7.27	2.10	35.33	64.53	39.17	27.50	74.13	13.30
26	IP-14942	53.67	85.67	159.40	20.43	6.63	1.93	30.87	67.90	40.80	24.20	74.30	13.00
27	IP-14038	54.67	85.00	178.13	24.50	6.67	2.40	23.53	97.30	28.83	27.90	81.63	11.07
28	IP-17979	51.67	85.67	196.47	21.63	6.27	1.67	21.67	95.40	35.37	26.00	81.20	11.87
29	IP-17690	50.67	85.33	168.33	21.83	5.87	1.93	20.77	100.23	35.07	23.80	79.57	13.83
30	IP-17753	49.33	85.00	190.07	25.90	5.67	1.87	21.47	94.67	34.37	21.00	73.47	12.23
31	IP-17978	49.67	85.67	174.37	33.93	7.27	2.03	21.60	94.50	35.37	25.63	69.97	11.50
32	IP-10945	49.67	84.00	136.27	25.70	6.97	2.87	29.70	84.07	38.10	29.70	71.43	10.33
33	IP-10488	50.67	85.00	148.00	15.47	6.53	2.37	25.73	88.87	42.13	30.67	76.10	10.87
34	IP-8229	49.33	89.00	180.00	36.80	6.40	2.07	27.30	85.93	42.13	31.13	85.43	10.83
35	IP-6417	52.67	84.67	180.33	30.97	5.17	2.67	27.97	91.47	45.60	32.57	83.50	10.93
36	IP-8429	50.33	83.00	301.80	29.83	4.73	2.60	26.53	66.03	45.93	32.97	80.00	9.60
37	IP-5275	52.00	85.33	167.00	40.67	4.97	2.87	23.97	61.20	47.63	36.77	88.70	10.63
38	IP-15355	51.67	83.67	166.13	16.27	7.10	2.53	28.00	67.50	35.57	28.30	49.90	10.77
39	IP-15710	51.00	82.00	224.40	42.47	4.80	2.67	29.80	72.27	35.93	30.13	53.13	9.93
40	IP-14028	53.33	82.27	179.27	16.47	4.80	2.43	23.63	70.73	34.13	28.30	60.20	11.90
41	IP-14026	55.33	83.33	217.20	33.03	7.80	2.50	25.27	67.77	38.60	30.00	61.03	10.67
42	IP-11211	56.00	83.00	180.47	16.43	7.37	2.07	28.87	70.13	40.50	27.60	70.67	11.33
43	IP-11680	58.00	88.00	228.67	25.60	6.90	2.07	31.07	70.17	31.77	21.23	70.13	12.10

S No.	Genotypes	DF	DM	PH	EL	EG	PT	PL	FLA	EWT	GYE	GYP	SWT
44	IP-11577	58.00	87.67	168.93	31.63	6.83	2.17	28.80	69.50	35.07	24.13	68.50	11.03
45	IP-11503	54.33	85.00	199.47	22.33	6.27	1.97	23.80	70.93	34.33	20.83	67.03	11.53
46	IP-10914	55.00	84.67	219.67	22.67	4.53	1.80	23.17	75.43	38.07	30.53	71.03	10.37
47	IP-10839	56.33	82.33	216.67	18.57	5.90	2.53	26.83	59.93	37.23	26.37	77.93	11.00
48	IP-15364	52.67	84.00	211.90	21.30	4.87	1.67	27.77	67.17	40.90	26.27	78.83	10.60
49	IP-15273	51.00	85.00	216.47	18.47	4.57	2.13	28.23	72.30	43.00	29.83	70.17	10.33
50	IP-14497	56.33	85.33	88.53	21.27	4.83	2.10	36.13	71.90	46.60	32.10	77.80	9.40
51	IP-14778	50.67	86.67	196.23	23.13	5.37	2.40	33.00	70.93	40.30	32.10	80.67	8.63
52	IP-16196	56.33	85.67	137.87	23.33	7.00	2.57	34.50	69.77	40.37	29.93	72.83	10.60
53	IP-7440	53.00	85.00	259.73	18.57	7.03	2.07	36.33	84.83	40.60	28.20	76.63	10.97
54	IP-13840	53.33	86.00	260.07	17.17	7.10	2.80	35.60	91.57	40.57	26.17	76.83	11.83
55	IP-9301	56.33	84.00	213.50	21.40	7.20	2.80	29.47	99.73	40.20	26.30	60.10	11.37
56	IP-14644	50.67	85.00	148.50	26.77	8.43	1.93	24.00	97.50	39.47	26.00	51.97	13.73
57	IP-4695	50.33	83.33	109.67	26.30	8.87	1.97	28.87	89.10	40.40	27.03	69.60	12.40
58	IP-4779	54.00	84.33	167.63	30.73	8.27	2.23	24.27	66.83	37.20	19.67	48.17	14.33
59	IP-19321	53.67	84.67	148.97	32.27	8.20	2.87	22.07	67.83	34.00	21.30	44.50	11.40
60	IP-18621	51.50	83.00	191.05	21.70	5.00	2.20	20.70	73.30	31.20	24.55	49.50	12.65
61	IP-18625	50.67	85.00	176.50	21.60	4.77	2.40	27.40	63.10	37.77	20.83	52.03	14.53
62	IP-8818	53.00	85.33	240.40	31.67	5.47	2.33	23.13	69.37	35.70	22.00	49.20	14.03
63	IP-16197	57.33	86.67	200.47	30.20	5.47	2.73	22.93	72.20	38.43	24.17	51.20	12.63
64	IP-16690	56.00	85.67	181.70	22.30	4.87	2.40	21.63	70.53	37.10	20.47	50.17	12.13
65	IP-13875	55.33	84.33	167.30	21.80	4.77	2.60	22.03	69.03	32.23	21.60	48.53	13.57
66	IP-12779	57.00	84.33	193.63	19.60	4.47	2.00	23. 8	72. 8	38.27	22.63	48.07	12.00
67	IP-12768	58.33	83.67	179.87	19.37	5.00	2.43	29.07	78.63	35.33	23.53	51.03	11.23
68	IP-6125	55.67	85.33	16 7.33	19.87	4.73	2.07	22.27	96.50	35.67	24.10	70.13	10.50
69	IP-4331	54.33	84.00	150.90	18.97	3.80	1.80	22.67	89.53	43.10	20.67	63.30	11.13
70	IP-13645	55.33	85.67	231.00	27.07	7.03	1.93	27.87	92.13	38.83	22.30	60.93	10.93
71	IP-17144	51.00	88.67	339.67	28.53	7.20	2.40	26.87	95.73	43.53	31.87	62.47	13.60
72	IP-10339	51.67	84.00	256.07	23.20	7.23	2.53	22.67	88.77	40.27	30.50	59.00	11.13
73	IP-4759	55.67	87.00	203.03	17.73	6.30	1.87	29.20	71.23	41.17	28.47	61.47	9.95
74	IP-19388	53.33	86.67	166.80	20.20	6.47	2.17	25.13	78.43	38.93	24.90	58.47	10.77
75	IP-18742	49.67	84.33	169.57	20.83	6.90	1.67	21.43	89.43	34.93	21.67	47.83	11.13
76	IP-18657	52.00	86.00	191.80	21.03	6.00	1.53	30.13	88.47	32.00	22.10	49.00	9.60
77	IP-8540	50.67	85.33	158.73	21.97	4.77	1.57	26.57	92.47	32.63	22.77	48.33	14.80
78	IP-16402	51.33	84.67	166.43	21.73	4.67	2.50	22.30	86.90	39.40	24.37	55.43	14.43
79	IP-16638	51.00	85.33	172.27	24.93	5.10	2.30	27.63	91.80	40.57	27.37	67.93	11.73
80	IP-13154	49.67	84.67	178.47	21.03	5.50	2.77	26.00	92.17	41.63	27.43	62.50	10.47
81	IP-12901	49.67	84.00	165.57	21.13	6.80	2.60	21.37	78.17	38.37	25.47	62.50	12.27
82	IP-12682	48.00	84.67	172.40	20.40	6.67	1.97	21.77	78.47	34.67	27.83	62.10	11.53
83	IP-6460	47.67	85.00	212.47	38.17	6.93	2.17	28.60	99.47	41.33	27.33	89.83	11.33
84	IP-4169	51.33	85.00	151.80	22.30	7.03	1.90	25.17	97.83	42.90	28.53	75.77	14.17
85	IP-7468	49.33	85.67	205.67	29.00	6.40	2.33	23.87	83.80	33.33	19.87	48.17	12.37
86	IP-19246	53.00	84.67	193.93	21.60	5.30	2.03	27.17	77.30	35.87	25.93	55.83	10.67
87	IP-13833	48.33	82.33	169.30	20.37	4.67	1.97	25.17	0.73	41.23	20.57	60.97	11.07
88	IP-19067	52.00	84.67	166.60	22.13	4.47	2.47	22.83	86.83	32.93	20.83	51.50	9.27
89	IP-10761	53.00	85.00	160.00	20.20	4.17	1.90	21.57	88.67	41.27	21.50	59.87	9.93
90	IP-19361	51.00	82.00	236.07	27.70	5.80	2.57	20.97	65.53	42.60	26.97	69.00	11.00

S No.	Genotypes	DF	DM	PH	EL	EG	PT	PL	FLA	EWT	GYE	GYP	SWT
91	ICMV-221	51.67	83.33	171.93	22.30	6.27	2.10	21.33	75.13	40.73	25.23	69.80	10.90
92	IP-18389	56.67	83.33	171.33	22.20	7.23	2.67	23.17	75.80	41.10	28.50	71.67	9.53
93	IP-18800	56.33	85.00	159.43	17.37	7.03	2.03	21.20	86.83	40.97	23.43	50.10	9.80
94	IP-8069	51.67	84.67	179.27	21.43	7.13	2.23	21.90	88.53	38.97	27.63	50.10	9.73
95	IP-16449	49.67	85.00	159.37	18.53	6.37	2.10	20.93	59.80	41.20	27.17	60.47	10.87
96	IP-16911	50.61	83.67	180.40	21.07	4.87	2.63	28.07	61.57	34.70	20.70	49.13	12.37
97	IP-13137	54.00	84.00	220.03	21.73	4.20	3.03	33.50	71.63	35.77	21.27	52.87	13.13
98	IP-12474	53.67	84.00	168.83	20.27	4.20	2.27	31.83	68.50	41.57	24.63	54.47	10.43
99	IP-6545	54.33	83.67	171.77	23.40	4.73	2.20	30.53	92.10	40.73	29.47	61.13	11.30
100	IP-6451	50.33	85.33	179.27	20.53	4.93	2.00	28.37	87.73	41.03	23.93	51.67	14.43
101	IP-738	50.33	85.00	160.53	20.43	5.90	2.43	28.40	86.93	43.50	25.23	55.67	14.57
102	ICTP-8203	53.00	85.57	136.53	17.40	6.20	2.40	25.30	85.73	48.53	32.27	76.13	12.80
103	WC-C75	52.67	84.00	157.47	20.60	6.17	1.87	30.13	82.47	43.63	29.87	77.93	13.67
104	IP-10085	50.00	85.33	153.47	26.40	6.23	2.30	29.07	87.63	46.83	26.90	70.60	11.07
105	IP-19243	52.00	86.33	153.96	24.80	6.83	2.33	27.06	86.86	47.30	27.80	74.80	12.00
	Mean	52.41	85.05	181.76	23.72	6.02	2.25	26.67	78.44	38.37	25.77	65.15	11.45
	Maximum	58.33	88.67	301.8	38.17	8.87	3.00	36.40	100.23	48.53	36.77	89.83	14.80
	Minimum	46.33	82.00	121.6	15.47	3.80	1.53	20.70	55.05	28.83	19.67	47.83	8.63

DF: days to 50 % flowering DM: day to maturity PH: Plant height EL: Ear length
EG: ear girth PT: productive tillers/plant PL: Peduncle length
FLA: Flag leaf area EWT: ear weight GYE: Grain yield /ear
GYP: Grain yield /plant SWT: 1000-grain weight

APPENDIX .III

Mean performance of 105 pearl millet germplasm lines for 12 different quantitative characters during 2005.

S No	Genotypes	DF	DM	PH	EL	EG	PT	PL	FLA	EWT	GYE	GYP	GWT
1	IP-9140	51.33	83.33	186.27	20.53	7.77	2.63	17.33	90.83	38.13	23.87	70.17	10.53
2	IP-9286	52.00	90.33	190.43	21.00	8.03	2.30	23.43	100.43	33.17	22.73	73.07	10.93
3	IP-15857	50.67	86.67	183.00	22.20	6.97	2.57	19.07	68.00	32.93	20.73	50.90	11.00
4	IP-15899	51.33	87.00	169.27	20.20	7.27	2.80	24.57	82.17	35.83	21.40	52.73	12.63
5	IP-9149	47.00	87.33	189.50	15.67	9.03	2.20	20.10	91.27	40.50	27.30	63.37	10.27
6	IP-3799	49.00	85.67	187.13	22.20	8.63	2.10	26.60	54.97	38.47	27.60	70.67	9.03
7	IP-3150	50.00	86.00	155.57	22.10	8.03	2.53	23.33	70.53	41.40	29.83	58.60	6.77
8	IP-10186	47.67	87.33	164.80	24.37	8.73	2.37	23.83	99.67	40.93	21.37	43.33	7.40
9	IP-10394	48.33	84.67	172.27	24.93	9.07	2.03	24.17	88.70	52.83	29.80	74.50	10.00
10	IP-10820	46.33	85.00	170.60	20.87	8.83	2.47	25.33	69.50	51.23	25.33	57.93	10.13
11	IP-15817	48.33	85.67	171.17	20.97	8.43	2.63	28.03	76.53	46.90	25.17	55.93	11.00
12	IP-15220	49.33	86.00	181.50	21.13	8.63	2.67	24.00	104.47	40.30	21.70	43.00	10.00
13	IP-15256	52.33	89.00	150.13	21.10	7.27	2.37	20.77	104.20	60.60	33.17	60.20	7.20
14	IP-17566	52.67	90.33	200.17	20.63	7.53	2.67	22.43	76.17	40.37	20.27	37.97	7.93
15	IP-17144	54.33	90.67	166.53	22.40	8.03	2.67	22.97	83.57	39.90	19.90	42.73	7.07
16	IP-15829	53.00	90.33	190.53	21.67	8.60	2.03	28.37	76.70	40.83	21.93	58.87	8.07
17	IP-6510	54.00	92.00	203.03	20.67	9.17	1.93	27.93	71.13	42.67	20.20	43.20	6.70
18	IP-8276	49.33	87.33	165.83	21.27	9.93	1.90	25.33	118.20	43.17	22.87	46.20	6.37
19	IP-9416	49.00	83.33	174.17	21.57	10.73	1.93	19.67	114.33	51.50	30.47	61.37	7.60
20	IP-17493	48.67	85.67	187.47	23.00	9.07	2.00	18.17	85.50	53.47	28.20	64.00	7.97
21	IP-17028	47.67	86.00	188.53	25.00	8.47	2.13	23.83	87.00	49.67	25.27	67.00	9.43
22	IP-10811	50.33	85.00	185.63	24.23	6.00	2.63	22.43	87.60	53.40	30.70	73.67	10.20
23	IP-10085	52.67	89.00	188.67	24.83	6.73	2.90	26.63	99.83	53.57	27.77	67.00	11.20
24	IP-15681	53.67	89.67	187.13	20.40	6.47	2.47	25.67	101.17	60.60	30.43	72.33	10.33
25	IP-15257	53.00	90.33	189.67	28.50	7.23	2.53	22.50	78.00	53.30	25.00	58.20	10.03
26	IP-14942	50.67	84.33	168.17	22.33	8.10	2.33	21.37	76.17	60.33	27.47	63.17	7.80
27	IP-14038	50.33	89.00	189.90	27.47	8.27	2.80	25.00	85.23	41.93	23.00	50.20	6.80
28	IP-17979	49.67	91.00	184.97	27.13	8.30	2.10	26.67	78.67	40.17	20.10	42.30	8.27
29	IP-17690	51.67	85.33	143.60	24.47	6.83	2.33	19.90	87.53	59.83	31.83	47.17	8.30
30	IP-17753	51.00	84.33	169.50	21.63	7.43	2.10	18.50	92.33	47.87	29.00	64.73	10.80
31	IP-17978	49.67	86.33	190.20	29.47	8.63	1.90	23.33	78.63	39.83	30.70	74.50	9.93
32	IP-10945	49.33	90.00	173.20	31.00	9.20	1.97	20.17	102.70	40.07	28.50	58.33	9.47
33	IP-10488	50.00	87.00	170.30	21.97	11.00	2.17	21.60	70.63	48.50	27.33	60.10	9.80
34	IP-8229	50.67	86.33	189.83	20.60	8.63	2.30	21.47	79.50	51.77	28.67	60.87	11.07
35	IP-6417	49.67	85.33	174.00	16.80	9.13	2.07	22.03	70.53	46.30	23.43	64.27	11.20
36	IP-8429	50.67	83.33	167.17	22.53	9.97	1.73	20.00	81.87	53.27	25.67	60.23	9.60
37	IP-5275	51.00	83.67	161.13	19.33	9.17	2.07	22.00	93.30	61.40	36.00	80.87	12.77
38	IP-15355	51.33	88.67	160.07	26.17	7.67	1.93	21.17	60.97	43.80	19.47	39.20	9.30
39	IP-15710	51.33	87.00	172.47	30.47	6.90	2.13	19.93	62.90	51.47	21.83	46.67	9.17
40	IP-14028	52.00	87.67	165.57	25.67	8.20	2.03	20.90	70.90	49.67	25.53	53.37	10.43
41	IP-14026	53.00	89.67	174.53	21.30	7.93	2.50	26.60	77.47	45.00	27.33	69.63	11.53
42	IP-11211	53.33	91.00	170.17	21.43	7.83	2.50	18.93	81.67	51.20	30.47	71.20	12.27
43	IP-11680	51.67	90.33	168.00	19.10	7.50	1.93	19.83	93.00	47.87	20.20	32.67	7.70
44	IP-11577	50.33	90.00	175.50	23.80	6.77	2.27	25.00	88.10	46.67	17.30	30.70	7.00
45	IP-11503	51.33	90.33	165.50	29.13	6.33	2.23	21.63	88.40	51.50	24.37	59.33	9.77
46	IP-10914	52.00	89.00	190.20	30.80	5.60	2.10	26.93	77.50	60.97	31.37	67.60	9.23

S No	Genotypes	DF	DM	PH	EL	EG	PT	PL	FLA	EWT	GYE	GYP	GWT
47	IP-10839	52.00	86.33	191.67	29.83	5.63	1.93	23.57	82.97	72.10	38.43	84.17	13.43
48	IP-15364	51.33	87.67	190.67	29.80	5.73	2.07	23.37	99.40	43.33	20.23	47.97	8.83
49	IP-15273	50.67	85.33	190.83	30.30	7.40	2.33	20.50	94.67	40.07	21.90	54.53	8.97
50	IP-14497	50.00	84.33	172.83	26.17	7.50	2.03	20.50	77.50	44.83	24.50	67.17	9.47
51	IP-14778	47.67	86.67	183.83	21.33	7.73	1.80	21.27	84.13	50.60	30.43	84.67	9.40
52	IP-16196	47.67	83.33	192.47	28.83	7.20	1.63	23.63	87.03	46.80	26.13	73.50	9.00
53	IP-7440	49.00	84.33	189.20	30.60	8.37	2.13	26.83	90.53	49.03	27.17	61.13	7.80
54	IP-13840	50.33	84.67	206.27	20.87	8.40	1.73	22.63	93.47	43.80	25.33	65.67	9.70
55	IP-9301	52.33	84.67	197.97	23.67	8.37	1.63	20.33	87.67	48.50	29.17	72.33	11.23
56	IP-14644	52.33	89.33	199.87	30.00	6.47	2.17	17.60	70.80	36.73	19.73	37.50	6.73
57	IP-4695	55.33	89.33	166.77	30.17	6.27	2.33	19.57	76.03	50.83	22.33	40.60	7.53
58	IP-4779	56.33	91.33	169.47	21.70	7.07	1.97	19.03	82.87	61.60	34.00	83.17	11.33
59	IP-19321	54.00	89.67	147.97	21.60	8.10	2.20	20.50	75.33	50.50	29.47	54.83	9.17
60	IP-18621	54.67	90.00	156.80	29.60	8.97	1.87	22.33	84.33	51.70	27.17	61.00	8.50
61	IP-18625	50.33	89.33	160.30	26.60	8.23	1.47	21.40	92.00	60.43	31.37	74.77	10.27
62	IP-8818	50.00	85.33	164.33	23.10	7.63	1.87	19.50	63.17	43.20	21.27	47.00	7.10
63	IP-16197	51.33	89.00	171.23	29.17	8.23	2.23	19.03	67.93	53.07	21.43	37.53	6.80
64	IP-16690	52.67	84.67	163.43	28.83	8.10	2.10	26.70	75.40	64.50	33.43	83.63	12.00
65	IP-13875	53.00	85.33	170.83	30.17	6.83	1.87	24.43	77.17	68.60	38.47	85.33	12.20
66	IP-12779	52.33	85.67	170.83	23.47	6.67	1.93	24.03	98.80	62.67	26.37	75.83	11.27
67	IP-12768	49.00	89.00	175.07	17.03	6.73	2.13	26.73	98.23	68.40	30.07	71.50	10.77
68	IP-6125	47.00	85.00	180.67	23.37	6.87	1.97	23.20	94.33	50.27	22.50	50.83	9.47
69	IP-4331	50.33	85.00	164.50	23.33	7.03	1.93	19.90	79.93	45.67	21.00	38.37	7.17
70	IP-13645	50.00	85.33	169.77	24.33	7.60	1.97	18.43	83.30	49.17	23.50	45.43	7.50
71	IP-17144	50.33	83.67	170.27	27.87	6.23	2.70	17.43	92.40	48.77	23.43	61.90	10.00
72	IP-10339	50.33	85.00	178.63	25.97	6.00	2.03	18.17	66.47	63.03	35.13	58.73	9.17
73	IP-4759	51.67	85.67	170.17	20.60	6.97	1.87	20.17	73.67	43.43	22.30	54.17	6.90
74	IP-19388	51.67	84.67	192.60	21.63	7.07	2.27	27.20	62.13	60.13	30.53	79.87	12.20
75	IP-18742	52.67	85.33	153.67	17.30	7.97	2.53	19.83	63.83	63.27	36.60	84.83	13.20
76	IP-18657	53.67	89.67	151.97	18.67	7.23	2.07	20.67	71.17	49.57	30.17	73.77	10.00
77	IP-8540	48.67	89.67	170.20	20.37	8.00	2.03	20.00	66.83	49.00	23.83	64.53	9.27
78	IP-16402	48.33	83.67	171.67	21.20	6.37	1.87	17.37	70.70	45.50	21.27	51.60	8.27
79	IP-16638	44.67	85.00	181.33	20.97	7.13	1.40	21.97	80.97	51.17	20.27	38.13	7.40
80	IP-13154	45.00	83.67	190.83	19.27	6.97	1.57	24.00	88.17	60.97	34.67	86.00	13.70
81	IP-12901	44.33	81.67	177.43	25.67	7.93	1.37	23.33	92.27	58.93	31.17	73.53	9.33
82	IP-12682	45.00	83.67	171.00	28.57	7.47	1.87	18.37	75.17	52.43	28.50	64.83	7.83
83	IP-6460	46.33	83.33	172.00	23.90	8.10	2.00	20.53	87.37	48.17	22.73	54.13	8.47
84	IP-4169	47.67	85.00	165.77	21.20	6.77	2.00	20.47	79.00	47.97	26.33	73.33	10.00
85	IP-7468	47.67	85.00	166.50	21.00	6.87	1.97	22.17	68.33	50.27	29.17	82.03	9.47
86	IP-19246	46.67	86.00	153.00	29.50	6.13	2.87	20.53	72.50	51.47	30.37	67.00	6.80
87	IP-13833	52.67	90.00	173.50	20.63	7.07	2.70	21.20	65.83	43.00	20.90	38.54	7.20
88	IP-19067	48.67	92.33	178.97	20.93	7.97	2.37	21.90	60.53	42.13	23.00	39.50	7.57
89	IP-10761	46.67	85.33	162.67	21.07	8.80	2.03	19.97	73.37	53.20	27.50	43.50	9.17
90	IP-19361	50.00	85.00	170.10	21.63	8.10	1.97	21.33	81.03	42.33	21.73	50.13	9.00
91	ICMV-221	49.00	85.67	179.27	19.63	7.33	2.67	16.17	73.33	41.33	21.73	58.57	8.50
92	IP-18389	47.67	86.67	171.00	23.37	8.07	2.67	20.17	75.00	42.03	21.50	50.83	7.70
93	IP-18800	48.67	86.67	160.47	28.73	8.37	2.00	20.70	71.50	43.00	19.83	37.50	7.17
94	IP-8069	47.33	88.67	172.97	29.60	8.87	1.93	21.10	72.37	41.80	20.50	37.00	8.40

S No	Genotypes	DF	DM	PH	EL	EG	PT	PL	FLA	EWT	GYE	GYP	GWT
95	IP-16449	51.00	84.33	171.47	24.80	9.10	1.97	21.17	80.20	40.17	23.70	59.03	11.20
96	IP-16911	56.00	85.33	172.00	22.53	9.23	1.97	21.43	81.67	36.80	24.87	72.93	10.93
97	IP-13137	49.67	89.33	164.83	23.70	7.67	1.80	22.73	71.43	41.13	25.93	67.83	11.50
98	IP-12474	46.67	84.67	171.83	23.83	6.93	2.13	22.37	73.33	44.17	21.57	70.30	12.63
99	IP-6545	51.00	84.67	169.93	23.20	7.23	2.43	20.50	81.40	50.07	30.33	76.67	12.07
100	IP-6451	49.67	88.67	171.50	20.93	6.07	2.20	19.20	75.50	43.10	28.50	80.80	11.13
101	IP-7838	47.67	86.00	168.17	22.30	5.57	2.23	19.17	83.17	38.67	26.67	82.97	9.67
102	ICTP-8203	48.67	86.00	175.00	19.87	7.00	1.93	21.70	64.83	50.10	28.67	81.53	13.30
103	WC-C75	49.33	87.00	166.13	19.27	7.00	2.00	23.53	73.03	41.70	25.17	79.13	12.77
104	IP-10085	48.67	82.33	170.10	24.37	8.57	2.40	24.50	81.67	49.87	22.50	69.50	10.33
105	IP-19243	50.00	83.33	171.57	23.23	8.23	2.47	23.27	92.13	48.67	23.30	69.10	10.77
	Mean	**50.32**	**86.82**	**174.98**	**23.76**	**7.75**	**2.16**	**21.97**	**81.43**	**48.80**	**26.06**	**60.14**	**9.44**
	Maximum	**56.33**	**92.33**	**206.27**	**31.00**	**11.00**	**2.90**	**28.37**	**118.20**	**72.10**	**38.47**	**85.33**	**13.70**
	Minimum	**44.33**	**81.67**	**147.97**	**15.67**	**5.60**	**1.47**	**17.33**	**54.97**	**32.93**	**17.30**	**30.70**	**6.37**

DF: Days to 50 % flowering DM: Day to maturity PH: plant height EL: Ear length EG: Ear girth PT: Productive tillers/plant PL: Peduncle length FLA: Flag leaf area EWT: Ear weight GYE: Grain yield /ear GYP: Grain yield /plant SWT: 1000-grain weight

GENETIC DIVERSITY, HETEROSIS AND COMBINING ABILITY STUDIES INVOLVING DIVERSE SOURCES OF CYTOPLAMIC GENETIC MALE STERILITY IN PEARL MILLET [*Pennisetum glaucum* (L.) R.Br.]

LAKSHMANA D. 2008 Dr. B. D. BIRADAR

MAJOR ADVISOR

ABSTRACT

A total of 105 germplasm lines were crossed with three diverse sources of cytoplamic genetic male sterility viz., A_1, A_4 and A_5 to identify the restorers and to characterize the cytoplasmic difference based on restorations pattern on three sources of male sterility systems. The study revealed that, out of 105 lines, 36 lines (34.28%) on A_1, 63 lines (60%) on A_4 and 47 lines (44.76%) on A_5 cytoplasm restored fertility. The seed set percent was high and stable on A_4 (>70%), where as <60% on A_5 and A_1 cytoplasm. Seed set per cent was comparatively high in *kharif* than summer irrespective of cytoplasmic sources.

Genetic diversity among the lines tested, restorers+ maintainers (105), restorers (61) and maintainers (44) revealed that, genetic diversity was adequate among the genotypes of all the three genotypes which fell into 22 (restorers + maintainers),11 (maintainers) and 19 (restorers) clusters. D^2 values were in general high in restorers group followed by combined and maintainers group. Among the twelve quantitative characters studied the most important traits contributing to the divergence was days to maturity in all the three groups. The traits like productive tillers per plant grain yield per ear, peduncle length, grain yield per plant, 1000 seed weight were next in the order.

Information on heterosis and combining ability was sought through two sets of L x T experiments (I-involving three diverse sources cytoplasm, II-A_1 source only). In both the experiments considerable heterosis was observed for grain yield and its components. The heterosis for grain yield was largely due to ear length, ear girth, ear weight and seed weight and most productive crosses figure out as most heterotic crosses and vice versa in both the experiments. Combining ability revealed that, majority of the characters are under the control of non-additive gene action and sca variance greater than gca variance on over all basis in both the experiments. Present study revealed that heterotic hybrids could be obtained from parents with any combination of gca (viz., H x H, H x L, L x H and L x L).

A study on the inheritance pattern of rust resistance in F_2 crosses indicated that the rust resistance is monogenic dominant genes governs the susceptibility.