Genetics and Phenotypic Stability Studies in Pearl Millet [*Pennisetum glaucum* (L.) R. Br.]

बाजरा [*पेनिसेटम ग्लॉकम* (एल.) आर. बीआर.] की आनुवांशिकी एवं प्रारुपीय स्थायित्वता का अध्ययन

MOHAN DADARWAL

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DOCTOR OF PHILOSOPHY IN AGRICULTURE

(Plant Breeding and Genetics)

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By

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2017

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Date.....

Place: Bikaner **(Mohan Dadarwal)**

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1. INTRODUCTION

Pearl millet [*Pennisetum glaucum* (L.) R. Br.] locally known as *bajra* with 2n = 14 chromosome number belongs to the family Poaceae (Gramineae). It is an important coarse cereal crop of semi - arid tropics that does well on light textured soil with low moisture condition. It is believed to have originated in West Africa (Vavilov, 1950 and Murdock, 1959) from where it spread into India and other countries. Pearl millet is grown all over the world while Nigeria, Pakistan, Sudan, Saudi Arabia are the major pearl millet growing countries in the world including India.

Pearl millet is highly cross pollinated crop with protogynous condition. Inflorescence is a cylindrical spike consisting of a central rachis on which the groups of spikelets are densely packed. Spikelets bear two types of florets, one being bisexual and the other staminate. The unisexual staminate florets are sessile and born below the bisexual flowers. These have three anthers and lack the female organs. The bisexual floret consists of a single pistil with two feathery stigmas and three anthers enclosed between lemma and palea. The stigma remains receptive for one to two days. In hermaphrodite flowers anthesis starts from apex of the panicle toward the base where as the anthesis of the staminate flowers starts 2-3 days after the anthesis of hermaphrodite flowers. Anthesis occurs throughout the day and night but maximum between 10 p.m. to mid night. Pollen grains remain viable for 5-7 hrs.

It is very palatable coarse cereal with the best nutritional profile (rich in tryptophane and cystine). Pearl millet grain contains 8.5 to 15% protein, 5.03 to 6.0% fat, 1.05 to 1.7% crude fibre and 65.5 to 70% carbohydrates. As a food crop, pearl millet grain possesses the highest amount of calories per 100 gram (Burton et al., 1972), which is mainly supplied by carbohydrates, fats and proteins (Flech, 1981). Its mineral content is also comparable with other cereals. The grain is also used as feed for poultry while green fodder or stover (dry straw) is fed to cattle. Important quality aspects of pearl millet forage are

high protein (11.6%), low lignin, high dry matter yield, easy to digestible and possesses less oxalic acid which is an anti-nutritional factor (Hanna *et al.*,1999). Although, crude protein content (9.9-14%) in pearl millet stover is less than sorghum, but it is more than wheat and rice (Singh *et al*., 1977). The toxic component HCN is quantitatively less in green fodder of pearl millet in comparison to sorghum (Hanna *et al*., 1999).

Pearl millet is extensively cultivated as dual purpose crop over large areas in Asia, Africa and Australia. India is the largest producer of pearl millet with an annual production of 9.25 million tonnes from an area of 7.81 million hectares with productivity of 1184 kg/ha (Anonymous, 2015a). Pearl millet is traditionally grown as rain fed crop mostly under low fertility and rainfall condition. However, it also responses well to irrigation and improved management conditions. In India, pearl millet is mainly grown in the state of Rajasthan, Uttar Pradesh, Gujarat, Maharashtra, Haryana, Karnataka, Tamil Nadu, Madhya Pradesh, and Andhra Pradesh.

It is fourth most important cereal after rice, wheat and sorghum. It does play a vital role in stabilizing the food grain production of the country. Increased production opens new avenues of alternative food use, which can release pressure on rice and wheat production. Pearl millet has the capacity to grow and yield reasonably well on sandy and marginal soils with low fertility status. Thus, makes a staple food crop in many low-input and drought - prone areas.

Rajasthan occupies first position in area and production of pearl millet in India. In Rajasthan, it is cultivated on 4.44 million hectares area with the production of 4.13 million tonnes and productivity 930 kg/ha (Anonymous, 2015b). Major pearl millet producing districts of Rajasthan are Alwar, Sikar, Bharatpur, Karoli, Jaipur, Dausa, Dholpur, Jhunjhunu, Sikar, Nagour, Swai Madhopur, Barmer, Bikaner, Jaisalmer and Churu. The average productivity of pearl millet is far low (325 kg/ha) in Zone 1C (hyper arid and partially irrigated western plains) comprising Bikaner, Jaisalmer and four tehsils of Churu district because of low moisture and arid conditions prevailing in the zone. Therefore, it needs the attention to improve the productivity of the crop in the zone.

Development of high yielding varieties of pearl millet has led to increased productivity and stability largely in the regions with relatively better environments, while regions like Western Rajasthan, with arid and semi arid environment, still suffers from low productivity. This is because most of the hybrids recommended for this region resulted from the parents developed from programme not specifically meant for arid areas and hence lacked the desired adaptability and the characteristics required for these areas.

In the breeding of high yielding varieties of crop plants, the breeder often faces the problem of selecting the desirable parents. Combining ability is one of the important aspect for selecting the desirable parents and crosses. Apart from this, it also provides information on the nature and magnitude of gene action governing the expression of the characters which in turn helps in formulating appropriate breeding methodology. The cross combinations having high specific combining ability (SCA) are best utilized in hybrid production programme while lines having high general combining ability (GCA) may be utilized for the development of desirable synthetics and composites.

The estimates of genetic parameters obtained in one environment are biased due to the confounding of the G x E interaction effect with the genotype effects. It is therefore, necessary to take into account the G x E interaction while determining the estimates of various genetic parameters to have unbiased picture in the expression of various characters. Looking these facts, the need of the hour is to develop varieties that would give stable production from year to year and place to place even under moisture stress conditions. Therefore, for the development of hybrid varieties, the information regarding combining ability and gene action is essential to determine the choice of parents in the hybridization programme. Heterosis can then be directly exploited in pearl millet as MS systems are available. Since, Pearl Millet is cultivated over wide range of agronomical conditions; the material can be evaluated in different environments which can be created by different number of irrigations with different recommended dose of fertilizers.

Measurement of superiority of hybrids over check termed as standard heterosis, has an economic importance and is now widely used for expression of heterosis. The most important aspect for the economic exploitation of hybrid vigour is to study the extent of heterosis present for agriculturally important traits and the feasibility of its commercial use.

The present investigation was therefore, carried out using nine male sterile lines and six restorer lines of pearl millet to develop 54 hybrids using line x tester mating design grown under different environments with the following objectives:

1. To estimate the general and specific combining ability variances, effects and gene action for seed yield and its contributing characters.
2. To estimate the magnitude of standard heterosis for various yield and its contributing characters.
3. To determine the Genotype x Environment interaction and stability of the hybrids for various yield contributing characters.
4. Identification of hybrids suitable for the arid zone.

2. REVIEW OF LITERATURE

The present reviews is an attempt to bring together some of the earlier findings on combining ability, standard heterosis and genotype x environment interactions (phenotypic stability) studies in pearl millet under following headings.

2.1 Combining ability and gene action

2.2 Standard heterosis

2.3 Genotype x environment interaction (Phenotypic stability)

2.1 Combining ability and gene action

Fisher (1918) was to first to recognize the importance of biometrical techniques to study the genetics of quantitative characters. Later on, Fisher *et al.* (1932) partitioned total genetic variance in three parts, viz: additive (arising from average effect of genes), dominance (arising from allelic interactions) and epistatic (arising from non- allelic interactions).

The concept of combining ability in terms of genetic variation was first given by Sprague and Tatum (1942) using single crosses in maize. Combining ability can be defined as the ability of a genotype to transmit superior attributes to its crosses. General combining ability indicates the average performance of a line in a series of hybrid combination, whereas, specific combining ability shows those effects in some definite combinations which significantly departed from what would be expected on the basis of average performance of the lines involved (Sprague and Tatum, 1942). The significance of combining ability was first realized by Davis (1927). Combining ability studies are useful in assessing the nicking ability of parents and thus, help in selecting parents which, when crossed, would give rise to more desirable segregates during hybridization programme. It also helps to characterize the nature and magnitude of a systematic breeding approach.

Burton (1951) initiated studies on quantitative genetics of this crop and released four- way hybrids produced by open pollination and also released some important male sterile lines like Tifton 23A and Tifton 18A. Several studies were made to understand the gene action governing the quantitative characters in this crop using diallel, partial diallel and line x tester mating designs.

Several methods have been developed to estimate the general and specific combining abilities, of these top cross (inbred x variety cross) proposed by Jenkins and Brunson (1932), polycross by Tysdal *et al*. (1942), line x tester analysis by Kempthorne (1957), diallel cross by Griffing (1956a), partial diallel by kempthorne and Curnow (1961) and triallel cross by Rawlings and Cockerham (1962) are worth mentioning. The analysis of diallel cross data may be interpreted in three ways, i.e., Wr-Vr graph (Jinks and Hayman,1953), in terms of combining ability analysis of Griffing (1956b) and also in terms of components of genetic variation of Hayman (1954). Line x tester design which provides an opportunity to test more parents at a time has also been used for the estimation of GCA as well as SCA variances and effects and ultimately the nature of gene action involved in the expression of various characters (Kempthorne, 1957).

According to Griffing (1956b) 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 mating are single cross mating designs used for testing both GCA and SCA.

Kempthorne (1957) proposed a mating design analogous to North Carolina mating design II, which could be employed equally efficient to self pollinated and cross pollinated crop species. This mating design can also provide information regarding the usefulness of male and female inbreds as parents for hybridization to generate segregating population which is expected to give superior segregates.

Allard (1960) defined general combining ability as the average performance of a strain in a series of crosses and specific combining ability as the deviation of a cross mean from the performance predicted on the basis of general combining ability. In general, the combining ability is defined as the relative ability of a genotype to transmit its desirable performance to its crosses.

Singh *et al.* (1974) carried a line x tester analysis which involved five male-sterile lines from different sources and ten inbreds of pearl millet developed at Hissar (India). Additive x additive and additive x dominance types of gene interaction were found to predominate in the material under study. A high degree of association was found between general combining effects and the mean performance of lines and testers over crosses but no association was observed between per se performance of the crosses and their specific combining ability effects.

Mathur and Mathur (1983) studied combining ability for yield and its components in pearl millet and reported that both general and specific combining ability were important in the expression of the five characters under study. But the magnitude of the non-additive components was greater than that of the additive components for all the characters. They also suggested that a breeding strategy, which exploits both additive and non-additive effects, would be the most effective one for improving yield.

Dang *et al.* (1985) reported that general and specific combining ability effects were significant for yield per plant, head length & height and reciprocal effects were significant for yield & height.

Vyas and Pokhriyal (1985) in a line x tester study in pearl millet reported that specific combining ability x environment interaction was significant for grain yield and the seven yield components studied. Additive genetic effects were predominant for all 8 characters evaluated.

Kunjir and Patil (1986) studied line x tester analysis for combining ability in pearl millet and reported that GCA variances were higher than SCA variances for most of the yield components, indicating a predominance of

additive effects. They also reported that SCA effects were more important than GCA effects for grain yield, indicating a predominance of non-additive effects.

Khairwal *et al*. (1987) studied combing ability for productivity traits in pearl millet and reported that both general and specific combining ability variances were significant for grain yield per plant and the five yield related traits studied.

Maciel *et al*. (1987) studied combining ability for grain yield, plant height and days to bloom in pearl millet and reported that GCA was important for all these characters, whereas SCA was significant for height in one set of crosses and days to flowering in both. They also observed that height and days to flowering were relatively less affected than grain yield by genotype x year interactions.

Setty and Appadurai (1992) studied combining ability for six quantitative characters in 28 pearl millet hybrids. They observed that the nature of gene action was predominantly additive for penicle length, whereas dominance gene effects were important for the remaing characters. Most hybrid combinations exhibited significant heterosis for majority of the characters.

Balkrishan and Das (1996) studied the combining ability of six male sterile lines of *Pennisetum glaucum* and five restorers lines and reported that variances due to lines was greater than that of the testers for all seven yield related characters studied. They also indicated that non- additive gene action was predominant for all traits.

Naik *et al.* (1996) carried out combining ability analysis in pearl millet by crossing five male sterile lines with eight desired inbred lines. The analysis of variance revealed significant difference between parents for ear length, plant height, days to 50% flowering and maturity. The estimates of combining ability variances suggested the predominance of non-additive gene action in the control of all the yield contributing characters studied. The estimates of GCA effects revealed that the female 81A was the best general combiner for

grain yield and several other yield components. Among males, the genotype IP-12993 had the highest GCA effects for fodder and grain yield. It also had significant negative GCA effect for days to 50 percent flowering. The hybrid 842A x PMBDN-48 recorded the maximum heterosis for grain and fodder yield.

Saraswathi *et al*. (1996) studied combining ability of diverse genotypes in pearl millet and reported involvement of non-additive gene effects for grain yield, days to 50% flowering, plant height and number of productive tillers.

Devanand and Das (1997) observed higher general combining ability variance over specific combining ability variance for days to 50% flowering, crude protein and oxalate content, indicating a preponderance of additive gene action while the preponderance of non-additive gene action was recorded for plant height, number of tillers and calcium content as these showed higher SCA variance than GCA variance.

Azhaguvel *et al.* (1998) observed predominance of non-additive gene action for yield and its components.

Mohan *et al.* (1999) studied the combining ability variance in a line x tester design and reported that additive gene action was important for number of productive tillers, ear head length, ear head girth and 1000- grain weight and non-additive gene action for grain yield per plant. ICMA 91777, ICMA 92333, PT 5590 and PT 5595 were good general combiners for grain yield and its components. ICMA 91777 x PT 5590 was considered to be the best specific combination based on mean performance, SCA effects and standard heterosis for ear head length, ear head girth, 1000-grain weight and grain yield/plant.

Joshi *et al.* (2001a) carried out an experiment using seven male sterile lines and nine restorers of pearl millet and their hybrids. Information on combining ability was derived from data on eight yield contributing characters and grain yield. Among females, 95444A was the best general combiner for all the characters except ear head length. Among males, J 2257 recorded highest desirable GCA effects for grain yield/plant, ear head length, dry ear

head weight/plant and 1000-grain weight. Among the hybrids 95444A x J-2296 exhibited desirable SCA effects for days to 50% flowering, days to maturity, plant height, effective tillers/plant, ear head length, dry ear head weight, grain yield/plant, dry fodder yield/plant and 1000-grain weight. Significant desirable SCA effects for grain yield/plant were recorded by 95444A x J 2257, 89111A x J 2340, 93222A x J 108, 409A x J 108 and 95222A x J 104.

Joshi *et al.* (2001b) evaluated a 10 x 10 half diallel to study the combining ability and gene action involved in respect of yield and yield attributes in pearl millet. Analysis of variance indicated highly significant differences among mean squares due to general and specific combining ability for all the characters studied. The estimates of general combining ability (GCA) effects indicated that J 2340 was the best general combiner for grain yield/plant, 1000-grain weight, dry ear head weight, dry fodder weight/plant, effective tillers/plant, days to 50% flowering and days to maturity. Out of 45 cross combinations, only three combinations J 104 x J 2327, J 2257 x J 1188 and J 2349 x GP 619 showed significant and positive specific combining ability (sea) effects for grain yield/plant and other yield attributing characters.

Madhusudhana and Govila (2001) in a line x tester experiment observed that the contribution of CMS lines was found to be more for days to 50 % flowering, plant height, spike girth, grain density and 1000 grain weight, whereas CMS lines x restorers interaction was found important for grain yield per plant and effective tillers, indicating their ability to produce good hybrids. They observed that newly developed CMS lines 1049 A, 91777 A, 1161 A and 91444 A were good general combiners for grain yield, 1000 grain weight, spike girth and tillers.

Yadav *et al.* (2002a) determined the combining ability of sixteen landraces by evaluating their crosses in twelve environments grouped into three zones. The results indicated that GCA effects were important in the genetic control of grain yield and stover yield, while both GCA and SCA effects were more important for days to flower and 1000 grain weight. IP 3333

was the best general combiner for grain yield for north dry zone, IP 3228 for north wet zone and IP 3188 for terminal stress zone.

Yadav *et al.* (2002b) in a line x tester experiment observed that variances due to lines, testers and their combinations were significant for grain yield, fodder yield, days to 50 % flowering, days to maturity, panicle length and panicle girth. They noted that, SCA estimates were higher for dry fodder yield and number of effective tillers, indicating the predominance of non additive gene effects for these traits. Line 92777 A and 93111 A and pollinators ICR 161, 77/29-2, HP 8601 and HTP 91/32 exhibited high GCA effects for most of the traits. Crosses 93111 A x HTP 91/32, 95555 A x 91/32, 95555 A x ICR 161 and 95555 A x 77/29-2 showed high SCA effects.

Pethani *et al.* (2004) studied a line x tester analysis for yield and some component traits in pearl millet using eight male sterile lines and eight restorer lines. The results revealed that mean squares due to general and specific combining ability were significant, suggesting the importance of both additive and non-additive components. Among the lines, MS 407A and MS 2232A were good general combiners, whereas J 2349 and J 2338 were the good restorers exhibiting high GCA effects for grain yield and some of its component traits. Use of at least one good general combining parent in a particular cross is advocated.

Unnikrishnan *et al.* (2004) in a line x tester experiment observed that hybrids with high SCA effects for grain yield indicating the importance of additive gene action. They reported that among females MS 411 A was the best general combiner for grain yield per plant, 1000 grain weight and plant height. Among males PPMI 493, PPMI 814 and PPMI 575 were the best general combiners for grain yield per plant. Among the hybrids MS 575 A x D 23, MS 576 A x PPMI 295, MS 576 A x PPMI 807 and MS 411 A x PPMI 301 were the best specific combinations for grain yield per plant.

Dhuppe *et al.* (2006) in a L x T analysis reported that variance due to lines, testers and L x T were significant. The female parents 88004 A and 405A and male parents IPC-274 and Zim D were good general combiners for

grain and fodder yield. The crosses 862A x Zim D, 862A xPT1890 and 841 A x Zim T exhibited high SCA effect for most of the characters in general and grain yield in particular.

Kumhar and Singhania (2007) in a line x tester experiment observed significant differences among genotypes for all the yield contributing characters. The estimates of GCA and SCA variances were significant for most of the characters indicating the importance of both additive and non additive gene action in the inheritance. Male sterile lines 81 A, ICMA 92444, ICMA 88004, ICMA 92333 and restorers IPC 655, IPC 821, IPC 1518 and CZI/ E 88 were found to be good general combiners for majority of characters. Among hybrids ICMA 92444 x IPC 655, ICMA 92333 A x IPC 655 and 81 A x IPC 1518 showed high SCA effects for grain yield per plant.

Patel *et al.* (2008a) in a line x tester analysis observed that only non additive gene action governed most of the fodder yield attributes. For the expression of days to maturity both additive and non additive gene actions were responsible.

Patel *et al.* (2008b) in a line x tester experiment reported that non additive gene action governed the inheritance of most of the traits, while the preponderance of additive gene action was observed for ear head length, ear head girth and test weight. The cross combinations ICMA 96555 A x 187 SB and JSMA 101 A x 217 SB were the best specific combinations for grain yield.

Dangariya *et al.* (2009) evaluated a 10 x 10 half diallel excluding reciprocals to study the combining ability and gene action involved in respect of yield and its attributers in pearl millet. Analysis of variance indicated highly significant difference among mean squares due to general and specific combining ability for all the characters studied. The estimates of general combining ability (GCA) effects indicated that the parents D-23, SB-220 and J-2467 emerged as good general combiners for grain yield and its components. Out of 45 crosses combinations only five combinations such as J-2467 x J-2474, J -2454 x J-108, SB -220 x D-23, J- 2475 x D-23 and J -

2340 x D -23 showed significant and positive specific combining ability (SCA) effects for grain yield and other yield attributing characters.

Chotaliya *et al.* (2010) carried out combining ability analysis in a 10 x 10 diallel excluding reciprocals for yield and 11 yield components in pearl millet. The study revealed the importance of non-additive gene action in the inheritance of traits viz., grain yield per plant, fodder yield per plant, 1000 grain weight and harvest index. While, additive gene action was preponderant for plant height, ear head length, ear head girth and ear head weight. Both additive and non-additive gene action were important for days to 50 per cent flowering, days to maturity, number of effective tillers per plant and number of nodes. The parents like D-23, J-2480 and J-2467 could be used in hybridization programme to exploit their GCA effects for grain yield and some important attributing traits. The hybrids viz., J-2467 x J-2474, J-2454 x J-108, J-2480 x D-23, J-2475 x D-23 and J-2340 x J-2480 were the most promising having good SCA, coupled with high per se performance and heterobeltiosis for grain yield. Analyses of crosses revealed that majority of the superior crosses involved high x high or high x low general combiners, while few crosses involved low x low general combiners.

Chauhan *et al.* (2010a) studied combining ability for 13 characters in pearl millet in half diallel of eight diverse lines. General and specific combining ability variances were significant for all the characters except ear head girth and dry fodder yield per plant. The GCA : SCA variance ratio indicated the preponderance of additive genetic variance for plant height, number of grains per square centimeter, dry fodder yield per plant and harvest index; non-additive genetic variance for days to flowering, days to anthesis, days to maturity, number of effective tillers per plant, ear head length, ear head girth, ear head weight and grain yield per plant, while both the variances were equally important for 1000-grain weight. The three hybrids J-2454 × J-2340, 253-SB-07 × J-2495 and 276-SB-07 × J-2480 were found promising ones on the basis of *per se* performance, heterobeltiosis and SCA effects, which could be exploited commercially for heterosis breeding in pearl millet.

Kumar and Sagar (2010) studied the effect of cytoplasm on productivity and combining ability for grain yield and its contributing traits. They developed 144 hybrids using six male sterile lines: 81(A) and HMS 8A (A1), Pb313A (A2), Pb 402A (A3), 81A4, 81A5 representing six different cytoplasm system. They found that effect of cytoplasm was more or less equally pronounced on general combining ability effect of parents and specific combining ability of crosses. Array mean performance of 81A cytoplasmic iso-hybrids indicated that all the three cytoplasm have same potential therefore any of the cytoplasm can be used in hybrid breeding.

Lakshmana *et al.* (2010) studied the combining ability of alloplasmic iso-nuclear lines of pearl millet. The results revealed that the lines with A4 cytoplasm were significantly better general combiner for grain yield per plant, ear weight, ear length and productive tiller per plant than the lines with A1 and A5 cytoplasm. The pollinators IP-1497, IP-973, IP-872 and IP-10085 proved their utility for breeding high yielding hybrids.

Vagadiya *et al.* (2010a) studied combining ability using line × tester mating design for grain yield and 13 component traits using four male sterile lines and 12 restorers in pearl millet. The predictability ratio of GCA and SCA revealed the preponderance of non-additive gene action in the inheritance of all the traits *viz.*, grain yield per plant, days to flowering, number of nodes per plant, plant height, ear head girth, ear head length, number of effective tillers per plant, ear heads weight per plant, days to maturity, 1000-grain weight, harvest index, threshing index and fodder yield per plant. Female parent JMSA-20073 and male parents J-2290, J-2498 and H-77/833-2 were identified as the best general combiners for grain yield per plant along with many other component traits. Majority of their crosses had depicted significant and desirable SCA effects, coupled with high *per se* performance for grain yield. Among the 48 crosses, 19 displayed significant and positive SCA effects for grain yield. Of these, three hybrids *viz.*, ICMA-95444 × J-2405, JMSA-20073 × J-2474 and ICMA-98444 × J-2498 were the most promising having good specific combining ability effects in addition to high *per se* performance and heterobeltiosis for grain yield. These cross combinations

also registered significant SCA effects in desired direction for many of the yield attributing characters. Heterotic hybrids were more frequently observed in crosses involving at least one of the good combiner parents.

Jethva *et al.* (2011) studied combining ability for grain yield and its components in pearl millet over three environments (seasons) in a set of five females, ten males and their resultant F_1's with check hybrid MH 169. The pooled analysis showed that both GCA and SCA variances were highly influenced by the environments implying that the parents and crosses must be evaluated over a wide range of environments to have unbiased estimates. The analysis of variance indicated preponderance of additive type of gene action in the expression of ear head length and ear head girth, while non-additive gene action was observed to be more important for number of effective tillers per plant, ear head weight, 1000-seed weight, harvest index, threshing index, fodder yield per plant, grain yield per plant and protein content. Two female parents (ICMA 94555 and 81A) and four male parents (J 2372, J 2340, J 2440 and J 2454) had significant and positive effect for grain yield per plant. Fourteen crosses were found to be good specific combiners for grain yield with maximum SCA effect in cross ICMA 95222 x J 2372.

Lakshmana *et al.* (2011) carried out combining ability analysis in pearl millet revealed that 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, ICMA 88004 x IPC-873 were found productive cum heterotic hybrids. Among the four females, ICMA-94555, ICMA-842 and ICMA-88004 were found to be high general combiners. The female ICMA-94555 recorded maximum plus points by exhibiting significant positive GCA effect for nine quantitative traits. The crosses involving lines viz., IPC-217, IPC-1104, IPC-338, IPC-827-1 and IPC-873 were found to be highly heterotic.

Parmar *et al.* (2013) studied the combining ability analysis for yield and its component traits using line x tester mating design with five lines and ten testers. Out of 50 crosses combinations, only 25 combinations such as ICMA 96444 x J 2464, ICMA 94555 x J 2466 , JMSA 101 x J 2452, ICMA 91777 x J 2466 and ICMA 99555 x J 2477-1 showed significant and positive specific combining ability (SCA) effects for grain yield and other yield attributing characters. The estimates of general combining ability (GCA) effects indicated that the parents J 2473, J 2474-1, ICMA 91777, J 2452, J 2444 and J 2405 reported as good general combiners for grain yield and its components traits.

Bhadalia *et al.* (2014) studied combining ability in 8 x 8 diallel set, including reciprocals, for grain yield and its 11 component traits in pearl millet. Both GCA and SCA variances were highly significant for all the characters. The ratio of GCA and SCA revealed preponderance of non- additive gene action in expression of all the characters *viz*., grain yield per plant, days to flowering, days to maturity, number of effective tillers per plant, ear head length, ear head girth, ear head weight, plant height, number of grains per square cm, 1000-grain weight, dry fodder yield per plant and harvest index. Inbred J-2405 was also found to be good source of genes for earliness. The crosses *viz*., J-2454 x J-2467, J-2454 x J- 2511, J-2290 x J-2480 and J-2290 x J-2511 were the most promising having good SCA, coupled with high *per se* performance and heterobeltiosis for grain yield and some of its components.

Khandagale *et al*. (2014) conducted an experiment with 50 hybrids which were developed through line x tester mating design using five male sterile lines and ten restorers as parental material along with two standard check hybrids*, viz*., Pratibha-1666 and Shradha. The parents, hybrids and two standard checks were evaluated during *kharif* 2012 season for ten characters. Significant differences were observed for all the ten characters studied. Among females, 732A was found best general combiner for grain yield and had significant GCA effects for days to 50% flowering, days to maturity, 1000-grain weight and plant height, while in male parent, PT 4801 was the best general combiner followed by PT 4108 and PT4563 for grain yield per plant.

The cross ICMA 88004 x PT 4639 was the best specific combiner for grain yield per plant followed by ICMA 91222 x PT 4520 and ICMA 99222 x PT 4801.

Singh *et al.* (2014) studied combining ability analysis in pearl millet for dual purpose in semi arid region of Rajasthan. The experimental material consisted of 10 x 10 half-diallel crosses which were evaluated in three environments at Agronomy Research Farm, Jobner (Jaipur) during kharif, 2012. The analysis of variance for combining ability over three environments revealed that variance due to GCA and SCA were significant for all the characters under study. This indicated that both additive and non additive genes are involved in the inheritance of these characters. The parents 76-80, 41-50 and 71-75 emerged as good general combiners for dual purpose (grain and dry fodder yield). Therefore, these parents could be used intensively in hybridization programme to develop inbred with several desirable characters and grain yield improvement in pearl millet. Some promising crosses 26-30 x 41-50, 26-30 x RIB-135-144, 41-50 x 61-70, 41-50 x RIB- 135-144, RIB-20 x 71-75 and 76-80 x 51-60 were identified having high SCA effects in desirable direction for dual purpose (grain and dry fodder yield) and other related desirable traits. These crosses have immense potential for pearl millet improvement and may be utilized in multiple crossing programmes.

Singh and Sharma (2014) conducted an pearl millet experiment in L x T mating design at Raya, Mathura (U.P.) during kharif 2008, 2009 and 2010 using four male sterile lines (female parents) and nine inbreds used as testers (male parents). In general combining ability analysis, GIB 144 found with maximum GCA effects for yield, stem thickness, leaf area, panicle length, panicle-girth, and 1000-grain weight, dry weight per plant and harvest index followed by ICMA 93222, GIB 3346 and ICMA 95333. None of the parents showed significant positive GCA effects for number of nodes per main stem and number of leaves per main stem. In specific combining ability analysis, seven crosses viz., ICMA 93222 x GIB 78, ICMA 96111 x GIB 129, ICMA 93222 x GIB 144, ICMA 93222 x GIB 129, ICMA 97333 x GIB 157, ICMA 97333 x GIB 135 and ICMA 95333 x GIB 157 were identified as the best

specific combiners for yield and major yield components. Analysis of SCA effects revealed that good combining parents yield better hybrids, because parents with significant positive GCA effects were involved more in selected crosses than those with non-significant GCA effects and negative GCA effects. In the present study, the involvement of at least one good general combiner was found essential for obtaining combinations with high specific effects. Combining ability studies revealed that both general and specific combining ability variances were important but the estimates of SCA variance were higher in magnitude for all the characters. Thus, indicating the predominance of non-additive gene action.

Singh *et al.* (2014) undertaken a study for genetic analysis of forage yield and quality traits in pearl millet (*Pennisetum glaucum*). A set of 15 CMS lines and four populations as testers were crossed in L x T fashion to obtain 60 top cross hybrids. The hybrids were evaluated for general combining ability (GCA), specific combining ability (SCA), and heterosis in water stress and irrigated conditions. Analysis of variance for quality characters revealed significant differences due to genotypes, environments and significant genotype x environment interaction for all quality traits. The variance due to GCA and SCA were significant and varied with change in the environment for all quality traits. The computed variance ratio ($\sigma^2_{SCA}/\sigma^2_{GCA}$) revealed the predominance of non-additive gene action in the inheritance of quality traits. The line 05111A was found best general combiner for higher quality under both the environments. Among testers, Giant bajra was best combiner for quality under both environments. The top cross hybrids 91777A × RBC-2 and 01555A × RBC-2 were good specific combiners for high protein and fibre content. Hybrids 220A × Giant bajra, 01555A × NDFB-2 and 408A × GFB-1 exhibited high positive significant heterosis under both the environments. The existence of significant heterotic effect over commercial check also suggested the presence of non-additive gene action and dominance for quality traits.

Singh and Sharma (2014) evaluated 10 x 10 half diallel in 3 environments to study the combining ability and gene action involved in respect of yield and its attributers in pearl millet. The environment wise

combining ability analysis revealed significant differences for GCA and SCA variances for characters viz. days to 50% flowering, days to maturity, productive tillers/plant, plant height, panicle length, panicle girth, biological yield/plant, dry fodder yield/plant, harvest index, test weight and protein content in all the three environments. Out of 45 crosses only seven such as 26-30 x 71-75, 26-30 x RIB 135-144, 31-40 x 76-80, 31-40 x RIB 135-144, 31-40 x 101-105, 41-50 x RIB -20 and RIB -20 x 71-75 showed significant and positive SCA effects in all the three environments for grain yield and other yield attributing characters.

Bhardwaj *et al.* (2015) studied combining ability and heterosis through line x tester analysis of 40 hybrids developed by crossing 10 pearl millet lines as males with four cytoplasmic male sterile (CMS) lines as females. Preponderance of non-additive gene effects was realized by higher values of specific combining ability (SCA) compared to general combining ability (GCA) for all the traits studied except for dry fodder yield. The estimates of GCA effects indicated that PB 543A and PIB 258 were good general combiners for grain yield among the female and male parents, respectively. Cross combinations PB 543A x PIB 145, PB 543A x PIB 141 and PB 409A x PIB 141 were found to be the best specific combinations for grain yield. For grain yield, maximum MPH and BPH was observed in the cross PB 543A x PIB 136.

Kumar and Sagar (2015) studied the effect of cytoplasm on dry fodder yield and combining ability for dry fodder yield and its contributing traits in 144 hybrids. Six male sterile (A) lines [81A and HMS 8A (A1), Pb3l3A (A2), Pb402A (A3), 81A4 and 81A5] representing five different cytoplasm systems and their corresponding maintainer (B) lines were crossed with 12 restorer (R) lines in a line x tester design. The 24 parents (A+B and R) and 144 crosses were grown separately in contiguous block in randomized block design with two replications in six environments, three environments in each year (E1, E2 and E3) and (E4, E5 and E6). The data were reported for dry fodder yield (g/plant) and major dry fodder yield contributing characters–plant height (cm), total tillers at maturity and number of leaves per main tiller. Analysis of

variance revealed significant differences among genotypes, parents, lines (A, B), testers and hybrids (A x R, B x R). The differences due to A vs. B were non- significant except for dry fodder yield (g/plant) and number of leaves per main tiller; and A x R vs. B x R crosses were significant except for number of leaves per main tiller. Cytoplasmic effects were estimated by comparing A x R and B x R hybrids combination. The results indicated that in few characters cytoplasmic effects was significant. Both positive and negative cytoplasmic effects were observed for three characters viz., dry fodder yield (g/plant), plant height (cm) and total tillers at maturity. The (A x R vs. B x R) x E component of variance was significant for all the characters except for number of leaves per main tiller. The effects were modified by environment and were more pronounced for dry fodder yield, plant height and total tillers and negative cytoplasmic effects exceeded than the positive ones. The negative cytoplasmic effects were preponderant for dry fodder yield and significant only in one environment which was due to cytoplasm and nuclear-genome interaction. Effect of cytoplasm was more or less equally pronounced on general combining ability effects of parents and specific combining ability of crosses. The effect of cytoplasm on general combining ability both positive and negative was highest for lines HMS 8A1, 81A1, Pb402A3 and 81A5. Array mean performance of 81A cytoplasmic iso-hybrids indicated that all the three cytoplasms had same potential; therefore, any of these cytoplasms can be used in hybrid breeding.

Mungra *et al.* (2015) in a line x tester analysis using six lines and eleven testers studied the combining ability and gene action for grain yield and 14 quantitative traits in pearl millet. Among the lines, ICMA-04111, ICMA-92777 and ICMA-05333 and the testers J-2534, J-2454 and J-2507 displayed high *GCA* effect for grain yield per plant and for some desirable traits. Maximum positive SCA effect for grain yield per plant was displayed by the cross ICMA-05333 x J-2527 followed by ICMA-05333 x J-2340, JMSA-20064 x 283-SB-11, ICMA-92777 x STPT-115, ICMA-04999 x J-2539 and JMSA-20071 x J-2507.

Extensive research with regard to the inheritance of different characters has been done in pearl millet and all types of gene action have been reported in pearl millet for all the characters. This variation in the gene action is observed because of the use of different parental material involved, the environment and their interaction.

Table 2.1.1: The character wise types of gene action reported by many scientists are listed below.

Characters	Gene action	Scientists
1. Days to 50% flowering	Additive	Patel and Kudadia (1988), Singh and Singh (1988), Navale *et al.* (1991), Mane and Phatade (1992), Navale and Harinarayana (1992), Ouendeba *et al.* (1993), Sheoran and Govila (1996), Karale *et al.* (1998), Mohan *et al.*(1999) and Rasal and Patil (2003).
	Non-additive	Chawdhary and Singh (1978), Rao and Joshi (1979), Navale *et al.* (1992), Hapse *et al.* (1986), Singh (1988), Nwasike *et al.* (1992), Chavan and Nerkar (1994), aher and Ugale (1996), Naik *et al.* (1996), Saraswathi *et al.* (1996), Yadav (1997), Azhaguvel *et al.* (1998), Latha and Shanmugasundaram (1999), yadav *et al.* (2002b), Lakshmana *et al.* (2003), Rathore and Singhania (2003), Sushir *et al.* (2005), Bhanderi *et al.* (2007), Izge *et al.* (2007), Chauhan *et al.* (2010), Vagadiya *et al.* (2010), Bhadalia *et al.* (2012), Yadav *et al.* (2012) and Parmar *et al.* (2013).
	Additive and non-	Navale *et al.* (1985), Mangat and Satija (1987), Satija and Thukral (1989), Setty and

	additive	Appadurai (1992), Chavan and Nerkar (1994), Pethani and Kapoor (1995), Yadav (1997), Talukdar and Prakash Babu (1999), Sheoran *et al.* (2000), Yadav *et al.* (2000), Joshi *et al.* (2001a), Shanmuganathan and Gopalan (2006) and Chotaliya *et al.* (2010).
2. Days to maturity	Additive	Sinde and Desale (1985), Kunjir and patil (1986) and Navale and Harinarayanan (1992).
	Non-additive	Kumar *et al.* (1982), Mehndiratta and Phul (1985), Singh (1988), Satija and Thukral (1989), Kandasamy *et al.* (1993), Chavan and Nerkar (1994), Pethani and Kapoor (1995), Aher and Ugale (1995), Lakshmana *et al.* (2003), Rathore and Singhania (2003), Akanchalekum and Afribeh (2005), Bhanderi *et al.* (2007), Chauhan *et al.* (2010), Vagadiya *et al.* (2010a), Bhadalia *et al.* (2012), and Parmar *et al.(*2013).
	Additive and non-additive	Kumar *et al.* (1982), Das *et al.* (1985), Mehndiratta and Phul (1985), Mangat and Satija (1987), Satija and Thukaral (1989), Pethani and Kapoor (1995) and Sheoran and Govila (1996), Joshi *et al.* (2001a), Patel *et al.* (2008b) and Chotaliya *et al.* (2010).
3. Plant height	Additive	Bhatt (1984), Patel and Kukadia (1988), Singh and Singh (1988), Mane and Phatade (1992), Navale and Harinarayana(1992), Ouendeba *et al.* (1993), Yadav and Nijhawan (1994), Karale *et al.* (1998), Yadav *et al.* (2002a), Rasal and Patil (2003), Bhanderi *et al.* (2007), Chauhan *et*

		al. (2010), and Chotaliya *et al.* (2010).
	Non-additive	Chawdhary and Singh (1978), Rao and Joshi (1979), Mehndiratta and Phul (1985), Navale *et al.* (1985), Hapse *et al.* (1986), Singh (1988), Navale *et al.* (1991), Nawasike *et al.* (1992), Aher and Ugale (1996), Saraswathi *et al.* (1996), Naik *et al.* (1996), Sahane *et al.* (1997b), Devanand and Das (1997), Azhaguvel *et al.* (1998), Latha and Shanmugasundaram (1999), Lakshmana *et al.* (2003), Rathore and Singhania (2003), Izge *et al.* (2007), Vagadiya *et al.* (2010), Chaudhary *et al.* (2012), Yadav *et al.* (2012), and Parmar *et al.(*2013).
	Additive and non-additive	Bhatt (1984), Mehndiratta and Phul (1985), Mangat and Satija (1987), Satija and Thukral (1989), Pethani and Kapoor (1995), Sheoran and Govila (1996), Talukdar and Prakash babu (1999), Sheoran *et al.* (2000), Akanchalekum and Afribeh (2005), Shanmuganathan and Gopalan (2006) and Bhadalia *et al.*(2012).
4. Effective tillers per plant	Additive	Azhaguvel *et al.*(1998), Mohan *et al.* (1999), Rasal and Patil (2003) and Sushir *et al.* (2005)
	Non-additive	Chawdhary and Singh (1978), Rao and Joshi (1979), Nwasike *et al.*(1992), Setty and Appadarai (1992), Aher and Ugale (1996), Balakrishanan and Das (1996), Naik *et al.* (1996), Saraswathi *et al.* (1996), sheoran and govila (1996), devanand and Das (1997), Azhaguvel *et al.*(1998),Yadav

		et al. (2002), Rathore and Singhania (2003), Bhanderi *et al.* (2007), Izge *et al.* (2007), Chauhan *et al.* (2010), Vagadiya *et al.* (2010), Jethva *et al.* (2011), Chaudhary *et al.* (2012), Yadav *et al.* (2012), and Parmar *et al.(*2013).
	Additive and non-additive	Pethani and Kapoor (1995), Sheoran and Govila (1996), Sheoran *et al.* (2000), Joshi *et al.* (2001), Akanchalekum and Afribeh (2005), Shanmuganathan and Gopalan (2006) and Chotaliya *et al.* (2010), Yadav *et al.* (2012).
5. Ear head length	Additive	Chawdhary and Singh (1978), Rao and Joshi (1979), Sinde and Desale (1985), Hapse *et al.* (1986), Singh and Singh (1988), Pethani and Kapoor (1990), Mane and Phatade (1992), Nawasike *et al.* (1992), Setty and Appadurai (1992), Oendeba *et al.* (1993), Karale *et al.* (1998), Latha and Shanmugasundaram (1999), Mohan *et al.*(1999), Rasil and Patil (2003), Izge *et al.(*2007), Patel *et al.* (2008), Chotaliya *et al.* (2010), Jethva *et al.* (2011) and Yadav *et al.* (2012).
	Non-additive	Mehndiratta and Phul (1985), Gartan *et al.* (1988), Singh *et al.* (1988), Navale *et al.* (1991), Kandasamy and Ramalingam (1995), Chavan and Nerkar (1994), Ahar and Ugale (1996), Balakrishanan and Das (1996), Naik *et al.* (1996), Azhaguvel *et al.*(1998), Lakshmana *et al.* (2003), Rathore and Singhania (2003), Sushir *et al.* (2005), Lakshmana and Biradar (2008), Chauhan *et*

		al. (2010), Vagadiya *et al.* (2010), Chaudhary *et al.* (2012), Yadav *et al.*(2012) and Parmar *et al.(*2013).
	Additive and non-additive	Das *et al.*(1985), Mehndiratta and Phul (1985), Srivastava and Singh (1988), Satija and Thukral (1989), Pethani and Kapoor (1995), Sheoran and Govila (1996), Talukdar and Prakash Babu (1999), Sheoran *et al.*(2000), Akanchalekum and Afribeh (2005), Shanmuganathan and Gopalan (2006), Bhadalia *et al.* (2012) and Yadav *et al.* (2012).
6. Ear head girth	Additive	Sinde and Desale (1985), Hapse *et al.* (1986), Srivastava and singh (1988), Aher and Ugale (1995), Karale *et al.* (1998), Mohan *et al.* (1999), Rasal and Patil (2003), Sushir *et al.* (2005), Shanmuganathan and Gopalan (2006), Bhanderi *et al.* (2007),Patel *et al.* (2008b), Chotaliya *et al.* (2010) and Jethva *et al.* (2011).
	Non-additive	Mehndiratta and Phul (1985), Gartan *et al.* (1988), Setty and Appadarai (1992), Kandasamy and Ramalingam (1993), Chavan and Nerkar (1994), Balakrishanan and Das (1996), Naik *et al.* (1996), Latha and Shanmugasundaram (1999), Talukdar and Prakashbabu (1999), Lakshmana and Biradar (2008), Chauhan *et al.* (2010), Vagadiya *et al.* (2010) and Parmar *et al.(*2013).
	Additive and non-additive	Pethani and Kapoor (1995), Sheoran and Govila (1996), Rathore and Singhania (2003), Shanmuganathan and Gopalan

		(2006) and Patel *et al.* (2008).
7. Test weight	Additive	Chawdhary and Singh (1978), Rao and Joshi (1979), Das *et al.* (1984), Sinde and Desale (1985), Singh and Singh (1988) Nawasike *et al.* (1992), Mohan *et al.*(1999), Bhanderi *et al.* (2007), Izge *et al.(*2007), Patel *et al.* (2008)
	Non-additive	Vaidya *et al.* (1983), Mehndiratta and Phul (1985), Gartan *et al.* (1988), Setty and Appadarai (1992), Kandasamy and Ramalingam (1993), Yadav and Nijhawan (1994), Aher and Ugale (1995), Azhaguvel *et al.* (1998), Karale *et al.* (1998), Latha and Shanmugasundaram (1999), Rasal and Patil (2003), Lakshmana and Biradar (2008), Chotaliya *et al.* (2010), Vagadiya *et al.* (2010), Jethva *et al.* (2011), Bhadalia *et al.* (2012), Choudhary *et al.* (2012) and Parmar *et al.(*2013).
	Additive and non-additive	Mangat and Satija (1987), Pethani and Kapoor (1995), Sheoran *et al.* (2000), Yadav *et al.* (2000), Joshi *et al.* (2001), Akanchalekum and Afribeh (2005), Shanmuganathan and Gopalan (2006) and Chauhan *et al.* (2010).
8. Harvest index	Additive	Chauhan *et al.* (2010).
	Non-additive	Aher and Ugale (1995), Bidinger *et al.* (2003), Rasal and Patil (2003), Bhanderi *et al.* (2007), Izge *et al.* (2007), Chotaliya *et al.* (2010), Vagadiya *et al.* (2010), Jethva *et al.* (2011), Choudhary *et al.* (2012) and Parmar *et al.(*2013).
	Additive	Bhadalia *et al.* (2012).

	and non-additive	
9. Dry fodder yield per plant	Additive	Devanand and Das (1997) and Chauhan *et al.* (2010).
	Non-additive	Reddy and Arunachalum (1981), Aher and Ugale (1995), Naik *et al.* (1996), Sahane *et al.* (1997b), Yadav *et al.* (2002), Yagya *et al.* (2002), Bidinger *et al.* (2003), Rasal and Patil (2003), Lakshmana *et al.* (2003), Bhanderi *et al.* (2007), Izge *et al.* (2007), Patel *et al.* (2008), Chotaliya *et al.* (2010), Vagadiya *et al.* (2010), Jethva *et al.* (2011), Choudhary *et al.* (2012), Yadav *et al.* (2012) and Parmar *et al.(*2013).
	Additive and non-additive	Joshi *et al.* (2001), Rohitashwa *et al.* (2006), Shanmuganathan and Gopalan (2006), Bhadalia *et al.* (2012) and Yadav *et al.* (2012).
10. Grain yield per plant	Additive	Vaidya *et al.* (1983), Sinde and Desale (1985), Satija and Thukral (1989), Muza *et al.* (1990), Navale *et al.(1991), Ouendeba et al.*(1993), Yadav and Nijhawan (1994), Naik *et al.*(1996) and Yadav *et al.*(2000)
	Non-additive	Hapse *et al.* (1986), Gartan *et al.* (1988), Singh (1988), Singh and Singh (1988), Navale and Harinarayana (1992), Setty and Appadarai (1992), Kandasamy and Ramalingam (1993), Chavan and Nerkar (1994), Yadav and Nijhawan (1994), Aher and Ugale (1995), Balakrishanan and Das (1996), Saraswathi *et al.* (1996), Naik *et al.* (1996), Sahane *et al.* (1997b), Azhaguvel *et al.* (1998), Karale *et al.* (1998), Latha and

		Shanmugasundaram (1999), Mohan *et al.* (1999), Bidinger *et al.* (2003), Lakshmana *et al.* (2003), Rasal and Patil (2003), Rathore and Singhania (2003),Sushir *et al.* (2005), Bhanderi *et al.* (2007), Izge *et al.* (2007), Lakshmana and Biradar (2008), Patel *et al.* (2008), Arulselvi *et al.* (2009), Chauhan *et al.* (2010), Chotaliya *et al.* (2010), Vagadiya *et al.* (2010), Jethva *et al.* (2011), Choudhary *et al.* (2012), Yadav *et al.* (2012) and Parmar *et al.(*2013).
	Additive and non-additive	Das *et al.*(1985), Mehndiratta and Phul (1985), Navale *et al.* (1985), Mangat and Satija (1987), Om *et al.* (1988), Patel and Kukadia (1988), Ahuja *et al.*(1989), Mane and Phatade (1992), Nijhawan and Yadav (1993), Pethani and Kapoor (1995), Sheoran and Govila (1996), Talukdar and Prakash Babu (1999), Sheoran *et al.* (2000), Joshi *et al.* (2001), Akanchalekum and Afribeh (2005), Shanmuganathan and Gopalan (2006), Bhadalia *et al.* (2012) and Yadav *et al.* (2012).

2.2 Standard Heterosis :

Koelreuter first studied the phenomenon of hybrid vigour in artificial plant hybrids in 1763. Shull (1908) coined the term heterosis while working on maize. Heterosis is usually measured as superiority of the hybrid over the average performance of the parents and has been reported in a wide range of species including pearl millet. Superiority of hybrid over better parent actually is a measure of over-dominance and has often been taken as a synonym of

heterobeltiosis. Measurement of superiority of hybrid over check, termed as standard heterosis, has an economic importance and is now widely used for expression of heterosis. The most important aspect for the economic exploitation of hybrid vigor is to study the extent of heterosis present for agriculturally important traits and the feasibility of its commercial use. Burton (1951) reported the presence of heterosis for the first time in pearl millet. After that various workers have reported sizable amount of heterosis for all the characters in pearl millet as its utilization is possible owing to the availability of cytoplasmic – genetic male sterility. The available information on magnitude of standard heterosis in pearl millet is reviewed here.

Deore *et al*. (1997) reported significant average heterosis for grain yield and harvest index in pearl millet. For grain yield, 73.38%, 68.36% and 28.50% heterosis was observed over mid parent, superior parent and over standard check, respectively.

Dhuppe *et al.* (2005) reported heterosis for grain yield and 9 yield components in 60 F_1 hybrids derived from crosses between six male sterile lines and ten restorer males of pearl millet. The crosses MS- 862A x Zim-D and MS 841A x Zim-D exhibited highly significant positive heterosis over the better parent and the standard check Saburi for grain and fodder yield.

Sharma and Shrikant (2006) crossed twenty-five genetically diverse pearl millet inbred lines (male parents) with four male sterile lines (female parents). The experiment material thus, comprised of 100 hybrids, four fertile counterparts (B line) of male sterile lines, twenty five pollinator parents, and three commercially cultivated hybrids used as checks. The experiment was laid out in a Randomized Block Design with three replications at three different locations. Checks were included only for computation of standard heterosis. Six hybrids viz., 843A × RIB-3135-18, 841A × RIB-3135-18, 88004A × RIB-3135-18, 81A × RIB 3135-18, 843A × 20-K-86, and 81A × 20-K-86 maintained consistently their superior performance over the superior check variety and can be exploited over wide areas.

Kumhar,(2007) evaluated the magnitude of heterosis, mean performance and combining ability variances and effects using three male sterile lines, 27 male pollinators and their 81 crosses in line x tester design in pearl millet for grain yield and component characters. The resultant F_1 along with parents and one standard check hybrid RHB 121 were evaluated in randomized block design with three replications at Agricultural Research Station, Mandor during kharif 2003. Heterosis was to the extent of 16.5 and 406.5% over the standard check hybrid RHB 121 and better parent, respectively, for seed yield per plant.

Davda *et al.* (2008) estimated the nature and magnitude of heterosis for grain yield and its attributing traits through line x tester mating design involving eight CMS lines and ten pollinators in pearl millet. Maximum positive heterosis for grain yield per plant over better parent and standard check (GHB-558) was observed to be 262.15 and 41.05 per cent, respectively.

Patel *et al.* (2008a) conducted a field experiment in Anand, Gujarat, India and reported that five pearl millet hybrids exhibited higher relative heterosis, heterobeltiosis and standard heterosis for most of the fodder yield attributes, indicating their importance for commercial exploitation of heterosis. The analysis of combining ability variances indicated that only non additive gene action governed most of the fodder yield attributes. For the expression of days to maturity, both additive and non additive gene action were responsible.

Patel *et al.* (2008b) reported five pearl millet hybrids (ICMA92777 x 98 SB, ICMA 96555 x 187 SB, JMSA 20005 x 211 SB, ICMA 96555 x 211 SB and JMSA 98222 x 187 SB) exhibited higher relative heterosis, heterobeltiosis and heterosis over the standard check for most of the yield attributes.

Vetriventhan *et al.* (2008) studied 150 pearl millet hybrids obtained through line x tester crossing programme and reported that 13 hybrids recorded highly significant standard heterosis for grain yield per plant. Seven hybrids namely ICMA 88004 A x PT 5164, ICMA 88004 A x PT 5200, ICMA 88004 A x PT 5232, ICMA 88004 A x PT 5130, ICMA 88004 A x PT 5173, 732 A x PT 5172 and ICMA 88004 A x PT 5809 were selected as best crosses

since they expressed high standard heterosis over standard check hybrid (MBH163) for many of the traits studied for high grain yield.

Satyavathi *et al.* (2009) assessed the performance of the F_1 hybrids through heterosis, heterobeltiosis and economic heterosis. Higher economic heterosis was observed for yield in A1 cytoplasm compared to A4 and A5 cytoplasms.

Vagadiya *et al.* (2010b) crossed four cytoplasmic male sterile lines with 12 diverse pollinators in line x tester mating design to study the nature and magnitude of heterosis for grain yield and its seven component traits in pearl millet. Among 48 crosses, 4 hybrids exhibited significant and positive heterosis over standard check (GHB-719) (standard heterosis) for grain yield. The maximum positive heterosis, 11.30 per cent over standard check was recorded for grain yield per plant.

Devda *et al.* (2012) reported that heterosis in both the directions for most of the characters. The high standard heterosis was obtained for grain yield, harvest index, days to 50% flowering, days to maturity and length of protogyny. Medium level of heterosis was found for plant height and threshing index and low for number of nodes per plant. The highest positive heterobeltiosis and standard heterosis for grain yield per plant is 262.15 and 41.05 per cent, respectively.

Jethva *et al.* (2012) studied the heterosis for grain yield and its attributes in pearl millet [*Pennisetum glaucum* (L.) R. Br.] through Line x tester mating design in three different seasons. The degree of heterobeltiosis and standard heterosis varied for all the hybrids and for all the characters studied. The hybrids ICMA 95222 x J 2372 and JMSA 101 x J 2296 exhibited the highest significant and positive heterotic effect and mean performance for grain yield per plant and some of its important component traits. This could be exploited commercially through heterosis breeding in pearl millet.

Bhadalia *et al*. (2013) reported that magnitude of heterosis varied from cross to cross for all the characters. The high magnitude of standard heterosis was observed for grain yield per plant, number of effective tillers per plant, ear

head weight and harvest index. While moderate to low heterosis over standard check hybrid (GHB-744) was found for rest of the traits under study. The highest positive heterosis for grain yield per plant over better parent and standard check was observed to be 77.82 and 42.91 per cent, respectively.

Kathale *et al.*(2013) reported significant positive heterotic effect over standard check GHB-558 for grain yield/plant in the hybrid MS-88004 A x AIB-214(35.58%) followed by MS-841 A x IC-1179 (28.83%) and MS-99111 A x AIB-3354-2 (27.30%).

Kumar *et al.* (2013) conducted an experiment using hybrids of ten male sterile lines crossed with five diverse pollinators/testers in line x tester mating design. All the 50 crosses along with the check HHB 94 were grown in randomized block design with three replications. Out of these, only four crosses viz., ICMA95222 x CSSC46-2 (92.05%), ICMA94555 x G73-107 (77.76%), HMS13A x CSSC46-2 (66.76%) and HMS9A x CSSC46-2 (55.52%) showed more than 50 percent heterosis over check HHB94. Standard heterosis over check HHB94 for protein content was exhibited by only two crosses HMS9A x 1307 and HMS18A x H77/833-2.

Lone *et al.* (2013) studied heterosis for seed yield and yield contributing characters in pearl millet (*Pennisetum glaucum* L.) using crosses obtained through Line × tester mating design, 15 parents and two standard checks Pratibha-1666 and Shradha. The magnitude of heterosis was high for all the characters. Mid parent and better parent heterosis was high for total number of tillers per plant to the extent of 43.50 and 40.32%, respectively in the cross ICMA-95333 × PT-3999. It was followed by the character grain yield per plant in the cross ICMA-99222 × PT-4801 (37.70 and 25.23%, respectively). They observed significant and desirable SCA effects for most of the traits studied indicating potential for exploiting hybrid vigour in breeding programme.

Khandagale *et al.* (2014) conducted an experiment with 50 hybrids which were developed through line × tester mating design using five male

sterile lines and ten restorers as parental material along with two standard check hybrids viz., Pratibha-1666 and Shradha. Significant differences were observed for all the ten characters studied.

Parmar *et al.* (2015) studied the extent of heterobeltiosis and standard heterosis for grain yield per plant and quality traits in pearl millet during kharif 2007 using line × tester mating design involving five lines and 14 testers. Appreciate amount of heterobeltiosis was recorded for yield and quality traits studied. ICMA 91777 X J 2466 is the best heterotic cross which possessed significantly highest standard heterosis for grain yield per plant. None of the cross exhibited significant standard heterosis for chlorophyll content at 60 DAS.

2.3 Genotype x Environment interaction (Phenotypic Stability)

A phenotype is the result of interplay of a genotype and its environment. A specific genotype does not exhibit the same phenotype under all environments and different genotypes respond differently to a particular environment. This genotype X environment interaction is due to the difference in response of a genotype to a given change or changes in the additive environment. Thus for having an unbiased estimate of genetic variance, the population needs to be studied under different environmental conditions.

Most of the literature reported on genotype x environment interactions refers to the differential response of a genotype in a set of environments. However, the G x E interactions, in some cases may also include components like additive x environment and non-additive x environment interactions. Varietal adaptability to environmental fluctuations is important for the stabilization of crop production both over regions and years. Adaptability is the ability of a genotype to produce a relatively narrow range of phenotypes in different environments. This interaction is a result of changes in cultivar's relative performance across environments due to differential responses of the genotype to various edaphic, climatic and biotic factors (Dixon and Nukenine, 1997). Therefore, the analysis of genotype x environment interaction becomes an important tool employed by breeders for evaluating varietal adaptation.

Finlay and Wilkinson (1963) developed a dynamic approach for interaction of varietal adaptability to varying environments. They used average yield of large number of varieties at different sites and seasons for quantitative grading of environments. In this technique the linear regression of each variety and mean yield of all varieties in each environment provided a measure of phenotypic stability.

Eberhart and Russel (1966) emphasized the need of considering both linear (bi) and non linear (s^2di) components for G x E interaction for judging the phenotypic stability of a genotype. Thus, a variety having higher mean performance and unit regression with least deviation from regression (approaching zero) would be considered as stable genotype. Breese (1969), Samuel *et al.* (1970) and Paroda and Hayes (1971) opined that the linear regression of particular genotype and the deviation from linearity might be considered as a measure of stability.

Singh *et al.* (1982) in a study over the environments observed that hybrids showed more interactions with the environments than the parents for all the characters.

Dass *et al.* (1983) estimated G x E interaction in inbreds and their F_1 hybrids and standard checks for stover yield. Inconsistent performance over environments was indicative of sensitivity of genotypes to variation in environmental conditions. They observed that linear as well non-linear components contributed to total G x E interactions in almost equal proportion and parents were less responsive and more stable than their hybrids.

Kumar *et al.* (1983) investigated 120 genotypes including inbred parents, F_1 hybrids and standard cultivars and reported that the genotypes interacted significantly with the environments and both linear and nonlinear components contributed to total interactions.

Nandanwankar *et al.* (1983) crossed eight pearl millet male sterile lines of diverse origin with newly developed pollinators of wide adaptability in line x tester mating design. These hybrids along with their parents were evaluated for stability parameters for grain and fodder characters under three soil fertility

levels. Regression analysis revealed that linear and non linear genotype environment interaction was significant except for fodder yield.

Mehndiratta and Phul (1985) evaluated diallel progenies of pearl millet under different environments at a single location. They reported that for all traits there was significant genotype x environment interaction.

Pethani and Kapoor (1985) studied the genotype-environment interaction for six females, sixteen pollinator parents and their 96 F_1 hybrids along with three checks for grain yield under three environments. Both predictable (linear) and unpredictable (non-linear) portions of G x E interactions were found to be significant for heterozygous (hybrids) and homozygous (parents) populations. The magnitude of predictable portion was relatively higher among parents whereas in hybrids it was almost equal. Stability in general appeared to be a property of the individual genotype as even for significant unpredictable G x E interaction, prediction could be made in respect of many genotypes. There was lack of association between bi and S^2di and xi and S^2di both in homozygous and heterozygous populations which indicated that independent genetic systems controlled these parameters.

Bidinger *et al.* (1987) reported that yield trials of advanced lines of pearl millet were grown under midseason (panicle initiation to flowering) and terminal (flowering to maturity) drought stresses in the dry seasons of 1981, 1982, and 1983. Grain yield and its components were severely reduced by the terminal stress, but were little affected by the midseason drought, as there was compensation by later tillers for yield lost on the earlier shoots. The major factor determining grain yield of a genotype in both stress treatments was its time to flowering. Because of this, yield-yield component relationships under stress were a result of yield component-phenology relationships. Yield potential (measured in an irrigated treatment in the same field) was generally positively related to yield under stress, but accounted for a much smaller fraction of yield variation than time to flowering. These two factors together accounted for more than 50% of the total variation in grain yield under stress, suggesting that genotype drought response (drought resistance/susceptibility)

was a secondary rather than a primary factor in differences in yield under stress among the genotypes tested.

Dahiya *et al.* (1987) measured grain yield of 16 promising hybrids in five environments. Non-linear and linear components of genotype and environment interaction were significant.

Maciel *et al.* (1987) raised various genotypes in different years and observed that the plant height and days to flowering were relatively less affected than grain yield by growing in different years.

Virk (1988) revealed the importance of both linear and nonlinear genotype x environment interactions for grain yield.

Mahalakshmi *et al.* (1987) reported that the susceptibility of pearl millet to soil water deficits at different times of growth was determined in field experiments conducted over 2 years. Grain yields and yield components were expressed as ratios of stressed to non-stressed treatments. Where water deficit was imposed earlier in crop growth and then relieved. The time of termination of stress at flowering determined the extent of grain yield loss. Water stress relieved at anthesis or early grain filling had little adverse effect on the grain yield because additional tillers produced panicles. This response by tillers was less evident and grain yields were more severely reduced when water stress was not relieved until after flowering. When stress was imposed late in crop growth and not relieved, the time of initiation of stress was directly related to the extent of loss in grain yield. Thus, susceptibility to mid-season drought stress was related to the time when stress was terminated and in late-season drought to the time when stress was initiated.

Gupta and Ndoye (1991) studied G x E interaction in *Pennisetum glaucum* for grain yield by growing 10 to 12 genotypes at four locations for four years in Senegal. G x E interaction was detected; a large portion of the interaction was accounted for by the non-linear regression on the environmental means. Although the linear component was significant, its

magnitude was considerably smaller than that of the non-linear component. All the genotypes except Souna III were stable and their responses to changes in environments could be predicted.

Suryavanshi *et al.* (1991) derived information on G x E interaction from data on seven yield components in six male sterile lines of pearl millet and their maintainer lines grown during kharif, rabi and summer seasons of 1987-88. Analysis of variance for stability indicated significant G x E (linear) for days to 50% flowering and plant height and significant G x E (non linear) for productive tillers per plant and seed yield per ear. The male sterile line RHRBIA and 843A were generally stable for most of the characters over all three seasons.

Virk and Mangat (1991) studied two tests for detection of cross over genotype x environment interactions for grain yield in pearl millet varietal trials with 13 entries tested at 26 sites in India during 1987–88. The first test for a two-way table of varieties and environments detected significant cross over interactions involving directional change in the rank order of varietal means across environments for five varieties, namely, MP 122, MP 131, MP 154, MP 156 and MP 162 against the standard variety WC-C-75 at the $\alpha = 0.05$ level. When the $\alpha = 0.10$ level was used the cross over interactions were also significant for all the remaining six varieties and one hybrid against WC-C-75. The second test comparing grain yield differences of 11 varieties and one hybrid (MBH 130) with WC-C-75 in 26 environments revealed significant quantitative and cross over interactions for all the entries. The first test is conservative and use of $\alpha = 0.10$ level seems appropriate for obtaining results comparable to the second test. The two tests emphasized the importance of breeding for specific adaptation in pearl millet rather than general adaptation.

Sagar and Singh (1996) in their studies of genotype x environment interaction in pearl millet reported that the crosses showed significant interaction with environment.

Van Oosterom *et al.* (1996) reported that grain yields in drought-affected environments are often characterized by large genotype-by-environment (GE) interactions, caused by a highly variable timing and intensity of stress occurrence. The aim of the study was to assess the effectiveness of simple meteorological environmental descriptions in providing an understanding of the environmental contribution to the GE interaction of pearl millet (*Pennisetum glaucum* (L.) R. Br.) in the semi-arid tropics. The experiment comprised fourteen genotypes, grown across 24 environments in India. Data on water availability throughout the season and maximum temperatures during grain filling were used to describe the environments. ESCApes from drought and heat stress were the major factors determining the GE interaction. Both the timing and intensity of stress occurrence were important. Knowledge of the environmental causes of the GE interaction may facilitate the identification of adaptive plant traits, and may also enable a more rational choice of test locations for breeding programs.

Prajapati *et al.* (1998) studied the genotype x environment interaction and stability parameters for 9 genotypes of pearl millet screened under four weed management treatments (created environments) during the kharif seasons of the years 1991, 1992 and 1993 at GAU, Anand. Significant G x E interaction for yield and its attributes were revealed. Differential response of genotype to environment was observed in individual year as well as in pooled analysis for yield and its attributes. The mean grain yield and two stability parameters viz., regression coefficient (b_i) and deviation from regression (S^2d_i) were obtained to access the superior genotype. An ideal genotype is one that combines high yield, unit regression and least deviation from regression. Genotype GHB 229 was noticed high yielding and stable in 'no wedding' and 'hand weeding' environments whereas MH 179 appeared high yielding and stable under herbicide applications.

Shrikant *et al.* (2000) tested sixteen early hybrids of pearl millet in three environmental (location x year combination) conditions and stability parameters were worked out for days to 50 per cent flowering and yield per plant. The mean squares due to hybrids, environments and hybrids x

environment interactions were found to be highly significant for yield per plant and indicated variable response of hybrids under changing environments. However days to 50 per cent flowering was significant for hybrids but it was non significant for hybrid x environment interaction, indicating insensibility of early hybrids which could be of great value under fluctuating environmental conditions.

Shinde *et al.* (2002) tested nine pearl millet (*Pennisetum typhoides* L.) genotypes (eight hybrids and one variety) over fourteen environments (years/locations) in different zones of Maharashtra. Grain yield data were subjected to the Additive main-effects and multiplicative interaction (AMMI) analyses. Results indicated a significant genotype x environment interaction (GEI) that influenced the relative ranking of the hybrids across the environments. It was evident from AMMI analysis that genotype, environment and the first principal component of interaction effect accounted for 95.20% of treatment sum of squares and the first three principal components of interaction effect were found significant. As per the AMMI model, four genotypes (RHRBH-9802, RHRHH-8609, RHRBH-9807 and RHRBH-9808) were identified as having general adaptability. Further, two environments i.e. 1998/Rahuri-II and 2000/Rahuri-II were found Ideal for stable performance of the hybrids.

Chikurte *et al.* (2003) assessed seventeen genotypes of pearl millet for stability under four different environments for twelve characters. The major portion of G x E interaction was linear in nature for all other characters except days for 50 per cent flowering, plant height, number of total and effective tillers per plant. This indicated that prediction over environment for these characters would be possible. Significance of pooled deviation suggested importance of non-linear components for all the characters, therefore both linear and non-linear components appear to be important. The genotypes 981103 and 981064 which possessed average stability and wider adaptability for grain yield displayed either average or above and below average stability for other characters. The genotypes 981344, 981338, 981327 and 981326 exhibited above average stability for grain yield and also expressed stability for other characters. From the stability analysis, it can be concluded that none

of the genotype was found to be ideal with average stability for all the characters. However, the genotypes 981103, 981064, 981344, 981338, 981327 and 981316 showing stability for grain yield along with one or more yield components.

Yahaya *et al.* (2006) studied genotype x environment interaction in pearl millet [*Pennisetum glaucum* (L.) R.Br.] for grain yield by growing 90 genotypes consisting of 81 hybrids and 9 inbred parents at 5 locations for 2 years. Genotype x environment interaction was observed, a large component of which was accounted for by non-linear regression on the environment means. Although the linear portion was significant, its magnitude was smaller than that of the non-linear component indicating the significance of environmental effects on the genotypes. Six hybrids were found to be stable across the environments. They yielded above the average mean yield of all the genotypes under test, with a slope of unity and the mean square due to deviation from regression equal to zero.

Pabale and Pandya (2010) tested twenty four genotypes (hybrids) of pearl millet under eight environments in Gujarat. The models of Eberhart and Russell (1966), Perkins and Jinks (1968) and Freeman and Perkins (1971) applied to study genotype x environment interaction and were compared for their efficiency empirically. The genotypes GHB-788, GHB-832 and GHB-840 were observed as most stable and widely adapted over environments in all three models. On the basis of simplicity and computational convenience, Eberhart and Russell (1966) model was recommended.

Abuali *et al. (*2014) studied to identify the yield stability and adaptability of the grain maize genotypes (parental inbred lines, F1-hybrids and check varieties) using Additive Main Effects and Multiplicative Interaction (AMMI). A field experiment was executed during the winter and summer seasons of 2009 and 2010 at two locations, Shambat and Elrawakeeb, Sudan. The inbred lines and their F1-hybrids were evaluated in the field under normal irrigation and water-stress conditions. The results showed that highly significant differences were detected among genotypes, environments and for G×E interaction, indicated differential performance of genotypes over environments.

Considering mean grain yield, and the Linear Regression parameters *bi* and S^2d values jointly, the F1-hybrids 160×2, 160×3 and 6×3 gave above average mean of grain yield/ha and were most stable for grain yield/ha. AMMI analysis differentiated the genotypes (parental inbred lines and F1-hybrids), based on their grain yield, into different adaptation pattern and stability. Based on AMMI analysis, the F1- hybrids 66y×6 and 6×3 were highly stable with considerable high yield and adapted to favourable environments. However, the F1- hybrids 160×66y and 160×3 exhibited the highest mean grain yield/ha (4.1 tons and 3.5 tons, respectively), with slightly low interaction scores, hence they are regarded as superior hybrids.

Ezeaku *et al.* (2014) evaluated twenty- four parental lines of pearl millet and a seed parent (ZATIB) as check in five different locations in northern Nigeria to determine their yield levels and stability across the environments. Identification of stable parental lines will improve the performance of resulting pearl millet hybrids. Location and genotype effects were highly significant ($P < 0.05$) for all the parameters sampled while interaction between locations and genotype were significant ($P < 0.05$) for stand count, days to 50% flowering, downy mildew score, panicle length and grain yield (kg/ ha). Estimates of environmental index showed that samara was the best performing environment while Bagauda and Panda were the poorest grain yielding environments. Most of the lines were adapted to high rainfall environment of Samaru while others showed specific adaptation to low rain fall locations, indicating the possibility of developing specific lines adapted to low and high rainfall areas. Mean grain yield ranged from 504.8 (kg/ha.) for G3 (20A-2) to 1920 (kg/ha.) for G24 (75B-3). Genotypes G10, G14 and G15 were found suitable for favourable conditions with predictable performance as they gave high mean grain yield along with average responsiveness (bi >1) and non-significant deviation from regression line. While, G13, G17 and G18 were considered suitable for poor environments. Regression coefficient and deviation from regression indicated that G23 and G24 (75A-3 and 75B-3) and ZATIB were most stable in performance across the test environments.

3. MATERIALS AND METHODS

The present investigation entitled “Genetics and Phenotypic Stability Studies in Pearl Millet [*Pennisetum glaucum* (L.) R. Br.] ” was undertaken to obtained the information on genetic architecture of grain yield and its components in pearl millet [*Pennisetum glaucum* (L.) R. Br.] as influenced by different environments i.e. irrigation levels.

3.1 Experimental material

The experimental material for the present study generated by using nine male sterile lines (Female) and six restorer lines (Male pollinator) of Pearl millet. These lines were crossed in Line X Tester mating design to develop 54 hybrids at ICRISAT, Hyderabad.

The main characteristics of the parents used for the study are presented in Table 3.1.1

Table 3.1.1 Description of the parental material

S.No.	Name	Source	Characteristics
Females (MS lines)			
1	RMS 6A	ARS, Durgapura, Jaipur	Early maturity, medium tall, high tillering, medium long, thick, compact and cylindrical heads
2	RMS 21A	ARS, Durgapura, Jaipur	Long ear head, Early maturity, medium tall, high tillering, Long ear head
3	ICMA 843-22	ICRISAT, Patancheru, Hyderabad	Early maturity, medium tall, high tillering, medium long and thick cylindrical heads , grain bold and light grey in colour
4	ICMA 93333	ICRISAT, Patancheru, Hyderabad	Late maturity, tall, medium tillering, thin stem ,thick, medium long, compact and cylindrical heads

5	ICMA 97111	ICRISAT, Patancheru, Hyderabad	Extra early maturity, medium tall, high tillering, medium long and thick cylindrical heads.
6	ICMA 04999	ICRISAT, Patancheru, Hyderabad	Medium late in maturity, medium tall, medium tillering
7	ICMA 05444	ICRISAT, Patancheru, Hyderabad	Medium late in maturity, medium tall, medium tillering
8	ICMA 06999	ICRISAT, Patancheru, Hyderabad	Medium in maturity, high tillering, medium long and thick cylindrical heads
9	JMSA 20042	Jamnagar, Gujarat	Extra early maturity, medium tall, high tillering, medium long and thick cylindrical heads.
Males (Testers)			
1	BIB - 8	ARS, Beechhwal, Bikaner	Extra early in maturity, medium tall, high tillering, medium long ears.
2	BIB - 15	ARS, Beechhwal, Bikaner	Early in maturity, high tillering, compact ear head
3	BIB - 27	ARS, Beechhwal, Bikaner	Late in maturity, high tillering, tall, thin long cylindrical heads
4	BIB - 46	ARS, Beechhwal, Bikaner	Early to medium in maturity, high tillering, medium tall
5	BIB - 58	ARS ,Beechhwal, Bikaner	Medium to late in maturity, high tillering, medium tall
6	BIB - 65	ARS, Beechhwal, Bikaner	Extra early in maturity, medium tall, high tillering and medium long ear heads.

3.1.1 GENERATION OF EXPERIMENTAL MATERIAL

The experimental material for the present study generated by using nine male sterile lines (female parents) and six genetically diverse restorer lines (male parents) of pearl millet. These lines were crossed in Line X Tester mating design to develop 54 single cross hybrids (F_1's) during *Summer*, 2015 at ICRISAT, Hyderabad.

3.2 EXPERIMENTAL LAYOUT

Three sets of experiments were laid out during *Kharif,* 2015 at Agriculture Research Station farm, ARS Beechhwal, Bikaner. The Research farm is situated between $27^0$11' N latitude and 71^0 54' E longitudes at an altitude of 228.5 meters above mean sea level. This region falls under Agro-climatic Zone 1C of Rajasthan. The climate of the region is typically hyper-arid which is characterized by extremes of temperature during summer and winter with aridity of atmosphere and salinity of rhizosphere. The average rainfall is about 260 mm, which is mostly received during July-September. The meteorological data on maximum and minimum temperature, relative humidity, wind velocity and rainfall and rainy days during the crop growing period are given in Appendix- II.

The three environments thus created were as follows –

Environment	Fertilizer (N:P:K/ha)	Irrigation (No.)
E_1	40:20:0	One
E_2	60:30:0	Two
E_3	80:40:0	Three

Pearl millet faces drought at critical stages which affects its productivity to a great extent in North-Western Rajasthan. Low rainfall pattern at critical stages have urged the need to create above three different environments on the basis of irrigations at critical stages [pre flowering (30-35 DAS), flowering

(45-50 DAS) and grain filling (60-65 DAS)] which is expected to be useful in planning of breeding strategies to develop suitable hybrids for such an harsh environment with unique adaptation.

Each experiment was laid out in a Randomized Block Design (RBD) with three replications. Each plot consisted of two rows each of 4 meter length. The spacing between row to row was 50 cm and between plant to plant was 15 cm. Normal and uniform cultural operations were followed during the crop season to raise a good crop. The experimental material was sown on 11 July, 2015 with pre sowing irrigation with the basal application of full dose of P and half dose of N.

The experimental material comprised 54 hybrids and three commercially cultivated hybrids (HHB-67 Improved, RHB-177 and GHB-538) as checks in each replication. Checks were included only for computation of standard heterosis.

Standard checks			
S.No.	**Hybrids**	**Developed at**	**Characteristics**
1	HHB - 67 Improved	AICPMIP CCS HAU Hisar	Extra early maturity, highly resistant to moisture stresses, resistant to downy mildew.
2	RHB177	AICPMIP,SKRAU, Jaipur	Early maturing, medium tall, cylindrical bristled ear heads, resistant to downy mildew, light yellow anthers
3	GHB 538	AICPMIP MRS, Jamnagar	Early maturity, highly resistant to moisture stresses, resistance to Downy mildew and lodging.

3.3 CHARACTERS STUDIED AND OBSERAVATIONAL PROCEDURE

Ten randomly selected plants were tagged before completion of flowering to be unbiased about the plant selection from each plot of every replication for recording any observations. Every care was taken to select only competitive plants and border plants were avoided. All the observations except

days to flowering and days to maturity (which were based on whole plot) were recorded on these selected plants and averaged to obtain the plot mean. Details of the procedure followed for recording data on different characters are described below:

1. **Days to 50 per cent flowering:**

   The number of days taken from the date of sowing to the date when stigma had appeared on the ears of the main tillers of the 50 per cent plants in a plot.

2. **Days to maturity:**

   The number of days taken from the date of sowing to the date when grains on the ear head matured.

3. **Plant height (cm):**

   Plant height was measured in centimetres at the time of maturity from the base of the plant to the tip of ear on the main tiller.

4. **Number of effective tillers per plant:**

   The number of tillers bearing ear head including main tiller were counted at the time of maturity.

5. **Ear head length (cm):**

   The ear head length was measured in centimetres from the base of the ear to its tip.

6. **Ear head diameter (cm):**

   The ear head diameter in centimetres was measured at middle of the ear of main tiller with the help of vernier calliper at the time of maturity.

7. **Test weight (g):**

   A random sample of thousand seeds was drawn from the threshed seed of each hybrid in each replication and weighed in grams.

8. Harvest index (%):

Harvest index was computed by using following formula as suggested by Singh and Stoskoff (1971).

$$\text{Harvest index}\% = \frac{\text{Grain yield per plant (g)}}{\text{Biological yield per plant (g)}} \times 100$$

9. Dry Stover yield per plant (g):

Ten randomly selected and tagged plants including all plant parts above ground were dried in sunlight and weighed in grams and averaged.

10. Grain yield per plant (g):

The ear heads of the ten tagged plants were threshed together, weighed and averaged to obtain grain yield per plant.

3.4 STATISTICAL ANALYSIS

Replication wise mean values will be subjected to following statistical analyses.

(1) Analysis of variance
(2) Analysis of combining ability variances, effects and gene action
(3) Estimation of standard heterosis
(4) Phenotypic Stability analysis

3.4.1 Analysis of variance

The mean values of different F_1s (hybrids) for all the characters were subjected to analysis of variance as described by Panse and Sukhatme, (1985) separately for individual environment as well as over the environments to determine the significance of differences between genotypes, environments and genotype x environment interaction effects. The analysis of variance for individual environment and over the environments is present in Table 3.4.1 and 3.4.2, respectively based on the following models:

The model used for the analysis of variance for individual environment is

$$Y_{ij} = \mu + r_j + g_i + e_{ij}$$

Where,

Y_{ij} = mean performance of i^{th} genotype in j^{th} replication

μ = general mean

r_j = effect of j^{th} replication

g_i = effect of i^{th} genotype

e_{ij} = random error associated with particular measurement.

Table 3.4.1: Analysis of variance for individual environment

Sources of variations	**d.f.**	**M. S.**	**Expectations of M.S.**
Replication	r-1	Mr	$\sigma^2_e + g\,\sigma^2_R$
Genotypes	g-1	Mg	$\sigma^2_e + r\,\sigma^2_G$
Error	(r-1) (g-1)	Me	σ^2_e
Total	r g - 1		

Where,

r and g are the number of replications and genotypes respectively. The "F" values so obtained were tested at 5 per cent and 1 per cent level of significance.

S.E. (Diff.) = $(2 \times \text{Error MS} / \text{No. of replications})^{1/2}$

Mathematical model for pooled analysis:

$$Y_{ijk} = \mu + n_k + r_j + g_i + (gn)_{ki} + e_{ijk}$$

Where,

Y_{ijk} = mean performance of i^{th} genotype in j^{th} replication at the k^{th} environment

μ = general mean

n_k = effect of k^{th} environment

r_j = effect of j^{th} replication with k^{th} environment

g_i = effect of i^{th} genotype

$(gn)_{ki}$ = interaction of i^{th} genotype at the k^{th} environment and

e_{ijk} = error associated with the i^{th} genotype in j^{th} replication at k^{th} environment

The structure of analysis of variance for over the environments is given below in Table – 3.4.2

Table 3.4.2: ANOVA over the environments

Source of variation	d. f.	M.S.	Expected M.S.
Environment	e-1	Me	$\sigma^2_e + rg\sigma^2_E$
Replications/Env.	(r-1) e	Mre	$\sigma^2_e + g\sigma^2_R$
Genotypes	g-1	Mg	$\sigma^2_e + r\sigma^2_{GE} + rs\sigma^2_G$
Genotype x Env.	(g-1)(e-1)	Mge	$\sigma^2_e + r\sigma^2_{GE}$
Pooled Error	e(g-1)(r-1)	Mse	σ^2_e

Where,

e = number of environments

g = number of genotypes

σ^2_{GE} = variance due to genotype x environment Interaction

σ^2_{G} = variance due to genotype

σ^2_{R} = variance due to replication

σ^2_{E} = variance due to environments

3.4.2 Combining Ability variances, effects and gene action

Combining ability analysis was computed as per Kempthorne (1957) and ANOVA form is presented in Table 3.4.3 and 3.4.4

Mathematical model for combining ability in single environment:

$$Y_{ijk} = \mu + g_i + g_j + s_{ij} + r_k + e_{ijk}$$

Where,

Y_{ijk} = mean value of ij^{th} cross in k^{th} replication

μ = general mean

g_i = gca effect of i^{th} line

g_j = gca effect of j^{th} tester

s_{ij} = sca effect due to ij^{th} cross combination

r_k = effect due to k^{th} replication, and

e_{ijk} = random error associated with ij th cross in k^{th} replication

Table– 3.4.3 Analysis of variance for combining ability in single environment:

Source of variation	d. f.	M.S	Expectations of M.S.	Expectations of covariances
Replication	r-1			
Crosses	lt-1			
line	l-1	M_1	$\sigma^2_e + r\sigma^2_{LT} + rt\sigma^2_L$	σ^2_e + r [cov.(F.S.) – 2 Cov.(H.S.) + rt cov.(H.S.)]
tester	t-1	M_2	$\sigma^2_e + r\sigma^2_{LT} + rl\sigma^2_T$	σ^2_e + r [cov.(F.S.) – 2 Cov.(H.S.) + rl cov.(H.S.)]
Lines x testers	(l-1)(t-1)	M_3	$\sigma^2_e + r\sigma^2_{LT}$	σ^2_e + r [cov.(F.S.) – 2 Cov.(H.S.)
Error	(r-1)(lt-1)	M_4	σ^2_e	
Total	(rlt-1)			

Where, r, t and l are the number of replications, testers and lines respectively and

σ^2_T = variance due to testers

σ^2_L = variance due to lines

σ^2_{LT} = variance due to line x tester

σ^2_e = variance due to error

Cov (F.S.) = covariance of full – sibs, and

Cov (H.S.) = covariance of half – sibs

The Cov (H.S.) for lines as well as testers is equal to $1/2\sigma^2_A$.

When mean squares for lines, testers and lines x testers are significant Cov (H.S.) for lines and testers is calculated as follows:

σ^2_L = Cov (H.S.) lines = $M_1 - M_3$ / rt = $1/2\,\sigma^2_A = \sigma^2_{gca}$

σ^2_T = Cov (H.S.) testers = $M_2 - M_3$ / rl = $1/2\,\sigma^2_A = \sigma^2_{gca}$

σ^2_{LT} = [cov. (F.S.) – 2 Cov. (H.S.)] = $M_3 - M_4$ / r = $\sigma^2_D = \sigma^2_{sca}$

Average Cov (H.S.) over lines and testers may be computed as

$$\sigma^2_{gca} = \frac{(M_l - M_{lt}) + (M_t - M_{lt})}{r(l+t)} \quad \text{or} \quad \sigma^2_{gca} = \frac{M_1 + M_2 - 2M_3}{r(l+t)}$$

Mathematical model for combining ability for over the environments:

$$Y_{ijk} = \mu + g_i + g_j + s_k + (lt)_{ij} + (le)_{jk} + (te)_{jk} + (lte)_{ijk} + e_{ijk}$$

Where,

Y_{ijk} = Mean value of ij^{th} cross in k^{th} environments

μ = general mean

g_i = effect of i^{th} line

g_j = effect of j^{th} tester

e_k = effect of k^{th} environment

$(lt)_{ij}$ = interaction effect due to ij^{th} cross combination,

$(le)_{jk}$ = effect of i^{th} line at k^{th} environment

$(te)_{jk}$ = effect of j^{th}tester at k^{th} environment

$(le)_{ijk}$ = effect of ij^{th} cross at k^{th} environment and

e_{ijk} = random error associated with ij th cross in k^{th} environment

Table– 3.4.4 Analysis of variance for combining ability over the environments:

Source of variation	d. f.	M.S.	Expectations of M.S.
Environments (e)	e-1	M_1	$\sigma^2_e + r\sigma^2_{LTE} + rl\sigma^2_{TE} + rt\sigma^2_{LE} + rlt\sigma^2_E$
Rep./ Env.	e(r-1)		$\sigma^2_e + lts\sigma^2_R$
line (l)	l-1	M_2	$\sigma^2_e + r\sigma^2_{LTE} + rs\sigma^2_{LT} + rt\sigma^2_{LE} + rts\sigma^2_L$
tester (t)	t-1	M_3	$\sigma^2_e + r\sigma^2_{LTE} + rs\sigma^2_{LT} + rl\sigma^2_{TE} + rls\sigma^2_T$
l x t	(l-1)(t-1)	M_4	$\sigma^2_e + r\sigma^2_{LTE} + rs\sigma^2_{LT}$
l x e	(l-1)(e-1)	M_5	$\sigma^2_e + r\sigma^2_{LTE} + rt\sigma^2_{LE}$
t x e	(t-1)(e-1)	M_6	$\sigma^2_e + r\sigma^2_{LTE} + rl\sigma^2_{TE}$
l x t x e	(l-1)(t-1)(e-1)	M_7	$\sigma^2_e + r\sigma^2_{LTE}$
Error	e(r-1)(lt-1)	M_8	σ^2_e

Where,

e = number of environments

l = number of lines (Female parents)

t = number of testers (Male parents)

r = number of replications

σ^2_e = variance due to error

σ^2_L = variance due to lines

σ^2_T = variance due to testers

σ^2_{LT} = variance due to interaction between lines and testers,

σ^2_{LE} = variance due to interaction between lines and environments,

σ^2_{TE} = variance due to interaction between testers and environments,

σ^2_{LTE} = variance due to interaction among lines, testers and environments,

Estimation of combining ability variances, effects and gene action:

Various variances were estimated as follows:

For single environment – (Table – 3.4.3)

$$\sigma^2_{gca} = \frac{(M_l - M_{lt}) + (M_t - M_{lt})}{r(l+t)} \quad \text{or} \quad \sigma^2_{gca} = \frac{M_1 + M_2 - 2M_3}{r(l+t)}$$

$$\sigma^2_{sca} = \frac{(M_{lxt} - M_e)}{r} \quad \text{or} \quad \sigma^2_{sca} = \frac{(M_3 - M_4)}{r}$$

For pooled analysis – (Table -3.4.4)

$$\sigma^2_{gca} = \frac{M_2 + M_3 - 2M_4 - M_5 - M_6 + 2M_7}{re(l+t)}$$

$$\sigma^2_{sca} = \frac{(M_4 - M_7)}{re}$$

$$\sigma^2_{gca\ x\ e} = \frac{M_5 + M_6 - 2M_7}{r(l+t)}$$

$$\sigma^2_{sca}\ xe = \frac{M_7 - M_8}{r}$$

$\sigma^2 A = 2\sigma^2 gca$, $\sigma^2 D = \sigma^2_{sca}$ and Degree of Dominance $= \sqrt{\sigma^2 D / \sigma^2 A}$

Where,

$\sigma^2 gca$ = General combining ability variance

$\sigma^2 sca$ = Specific combining ability variance

$\sigma^2 A$ = Additive variance

$\sigma^2 D$ = Dominance variance

$$Heritability\ (ns)\% = \frac{\sigma^2_A}{\sigma^2_{Ph}} x100$$

Genetic Advance: - Genetic advance (GA) was estimated using the formula suggested by Robinson *et al.* (1949), Johnson *et al* (1955).

$$GA = k\, h^2_{ns} \times \sqrt{\sigma^2_{Ph}}$$

Where,

σ^2_{Ph} = Phenotypic variance

h^2_{ns} = Heritability narrow sense

K = Selection differential (constant) at 5 % selection intensity (Allard,1960) i.e. 2.06

The gca and sca effects were estimated from two way table of lines vs. testers where each figure was a total over replications for single environment and over replication and environment for pooled data.

$$\mu = \frac{X\ ....}{ltre}$$

Estimation of GCA effects

a) Lines (g_i) = $\frac{X\ i...}{tre} - \frac{X\ ....}{ltre}$

$\Sigma g_i = 0$

Where,

X.... = Sum of all the (ij th) hybrid combinations (Grand total)

$Xi...$ = total of i^{th} line over all testers, replications and environments

b) Testers (g_j) = $\frac{X.j..}{lre} - \frac{X....}{ltre}$

$\Sigma g_j = 0$

Where,

$X.j..$ = Total of j^{th} tester over all lines, replications and environments

Estimation of SCA effects

$$S_{ij} = \frac{Xij..}{re} - \frac{Xi...}{tre} - \frac{X.j..}{lre} + \frac{X....}{ltre}$$

$$\sum_i \sum_j S_{ij} = 0$$

Where,

$Xij..$ = ijth cross combination total over all replications and environments

Standard errors for combining ability effects:

The standard errors for gca and sca effects will be calculated as follows.

S.E. (gca for lines) g_i = (Me / rte) ½

S.E. (gca for tester) g_j = (Me / rle) ½

S.E. (sca effects)s_{ij} = (Me / re) ½

S.E. (g_i-g_j) line = (2Me / rte) ½

S.E. (g_i-g_j) tester = (2Me/ rle) ½

S.E. (S_{ij}-S_{kl}) = (2Me/ re) ½

Significance of gca effects of lines is tested as:

$$t = \frac{g_i - 0}{S.E.g_i}$$

Significance of gca effects of testers is tested as:

$$t = \frac{g_j - 0}{S.E.g_j}$$

Significance of sca effects of crosses is as:

$$t = \frac{s_{ij} - 0}{S.E.s_{ij}}$$

Critical difference (CD) :

CD = SE x t value at 5% level of significance and error d.f.

Test of significance of estimates of variances:

Significance of GCA and SCA variances and their interaction with environments was tested by 'F' test as follows:

I. To test σ^2_{gca} in single environment, F (n_1, n2 d.f.) = $\frac{M^+}{M_3}$

Where, $M^+ = t M_1 + l M_2 / (l+t)$ and

d.f. $n_1 = \frac{(l-1)(t-1)(tM_1 + lM_2)^2}{(l-1)t^2 M_1^{\,2} + (t-1)l^2 M_2^{\,2}}$

$n_2 = (l-1)(t-1)$

II. To test σ^2_{sca} in single environment, F (n_1, n_2 d.f.) = $\frac{M_3}{M_4}$

Where, $M^+ = t M_1 + l M_2 / (l+t)$ and

d.f. $n_1 = (l-1)(t-1)$

$n_2 = (r-1)(lt-1)$

In all the cases n_1 and n_2 reffered to the degrees of freedom for numerator and denominator, respectively.

Per cent contribution of lines, testers, and crosses

The proportional contribution of lines, testers and their interaction will be determined by following formula.

1) Contribution of testers $= \frac{S.S.(t)}{S.S.(crosses)} \times 100$

2) Contribution of lines $= \frac{S.S.(l)}{S.S.(crosses)} \times 100$

3) Contribution of line x tester interaction $= \frac{S.S.(l \times t)}{S.S.(crosses)} \times 100$

Where,

$S.S.(t)$ = sum of square due to tester

$S.S.(l)$ = sum of square due to line

$S.S.(lxt)$ = sum of square due to line x tester

$S.S.(crosses)$ = total sum of square of two way table

$[S.S.(lxt) = S.S.(crosses) - S.S.(l) - S.S.(t)]$

3.4.3 Estimation of Standard heterosis:

Per cent standard heterosis was calculated for all the characters under study over standard check as follows.

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

Where,

$\overline{F_1}$ = Mean over replications of hybrid between i_{th} and j_{th} parent

$\overline{SC}$ = Mean performance of superior check hybrid used in the present investigation was the one with the best mean among the three checks evaluated.

Test of significance

The significance of the standard heterosis estimates was done using t – test. The S.E. for testing the significance was calculated by the following formula:

$$SE_{\left(\overline{F_1}-\overline{SC}\right)} = \sqrt{\frac{2Ems}{re}}$$

Where,

Ems = Error mean square.

r = number of replications.

e = number of environments.

The t- value was estimated by the formula:

$$t = \frac{\overline{F_1} - \overline{SC}}{SE_{\left(\overline{F_1}-\overline{SC}\right)}}$$

The calculated t value was compared with the table value at error degrees of freedom.

3.4.4 Phenotypic Stability Analysis

Stability parameters were computed using the model proposed by Eberhart and Russell (1966).

$$Y_{ij} = \mu_i + \beta_i I_j + \delta_{ij}$$

Where,

Y_{ij} = mean performance of i^{th} genotype in j^{th} environment

μ_i = mean performance if i^{th} genotype over all environments

β_i = the regression coefficient that measuers the response of the i^{th} genotypes to varying environments

δ_{ij} = deviation from regression of the i^{th} genotype at the j^{th} environment

I_j = the environmental index obtained as the mean of all genotypes at the j^{th} environment minus the grand mean, This can be expresses as

$$I_j = \left(\sum_i Y_{ij} \Big/ g \right) - \sum_i \sum_j Y_{ij} \Big/ ge \qquad , \quad \sum_j I_j = 0$$

The first stability parameter, regression coefficient (bi) for the individual genotype was estimated as

$$b_i = \sum_j Y_{ij} I_j \Big/ \sum_j I_j^{\,2}$$

The second stability parameter (s^2d_i) was estimated using the following formula:

$$S^2 d_i = \left[\sum_j \delta_{ij}^{\,2} \Big/ (e-2) \right] - S_e^{\,2} / r$$

Where, S_e^2/r was the estimate of pooled error and

$$\sum_i \delta_{ij}^{\,2} = \left[\sum_j Y_{ij}^{\,2} - Y_{i.}^{\,2} / e \right] - \left[\left(\sum_j Y_{ij} I_j \right)^2 \Big/ \sum_j I_j^{\,2} \right]$$

The expectations of the mean square in the joint regression analysis is given in Table – 3.4.5

Table– 3.4.5 Joint regression analysis of variance (Eberhert and Russell, 1966):

Source	**d.f.**	**S.S.**	**M.S.**
Genotypes (g)	g -1	$\frac{1}{e}\sum_i Y_{i.}^{\,2} - C.F.$	MS_1
Environment (e)	e-1	$\frac{1}{g}\sum_j Y_{.j}^{\,2} - C.F.$	

Geno. X Env.	(g-1) (e-1)	$\sum_i \sum_j Y_{ij}^{\ 2} - \frac{\sum Y_{i.}^{\ 2}}{e} - \frac{\sum Y_{.j}^{\ 2}}{g} + C.F.$	
Env.+ (Geno. X Env.)	g(e-1)	$\sum_i \sum_j Y_{ij}^{\ 2} - \frac{\sum Y_{i.}^{\ 2}}{e}$	
Environment (Linear)	1	$\frac{1}{g}\left(\sum_j Y_{.j} I_j\right)^2 \Big/ \sum_j I_j^{\ 2}$	
Geno. X Env. (Linear)	(g-1)	$\sum_i \left[\left(\sum_j Y_{ij} I_j\right)^2 \Big/ \sum_j I_j^{\ 2}\right] - Env.(Linear\ SS)$	MS_2
Pooled deviation	g(e-2)	$\sum_{i=1}^{g}\left[\left\{\sum_j \delta_{ij}^{\ 2} \Big/ (e-2)\right\} - \left(S_e^{\ 2}/r\right)\right]$	MS_3
Pooled deviation due to genotype	e-2	$\left[\sum_j Y_{ij}^{\ 2} - \frac{Y_{i.}^{\ 2}}{e}\right] - \left(\sum_j Y_{ij} I_j\right)^2 \Big/ \sum_j I_j^{\ 2} = \sum_j \delta_{ij}^{\ 2}$	
Pooled error	e(r-1)(g-1)		MS_4

Where,

g = number of genotypes, e = number of environments and

r = number of replications

Test of significance was done as follows:

I The mean square for pooled deviation is tested against the pooled error mean square as follows:

$$F = \frac{MS_3}{MS_4}$$

II Test of significance of differences among the mean performance of genotypes was done using the 'F' test,

$$F = \frac{MS_1}{MS_3}$$

III The genetic difference among genotypes for their regression, on environmental index were tested using, the 'F' test,

$$F = \frac{MS_2}{MS_3}$$

IV The deviation of b_i values from unity was tested using the 'F' test,

$$t_{\text{at (e-2) d.f}} = \frac{b_i - 1}{S.E.b_i}$$

$$S.E.(b_i) \pm = \sqrt{\frac{Pooled \quad deviation \quad M.S.}{\sum_j I_j^2}}$$

V Deviation from linear regression for each genotype was tested using the 'F' test

$$F = \frac{\left[\sum_j \delta_{ij}^2 \Big/ (e-2)\right]}{Pooled \quad error}$$

4. EXPERIMENTAL RESULTS

The present study was undertaken to estimate the combining ability, standard heterosis and phenotypic stability in pearl millet [*Pennisetum glaucum* (L.) R. Br.]. The experimental material for present study was consisting of 54 hybrids of pearl millet which were developed by crossing of nine male sterile lines (female parents) and six genetically diverse restorer lines (male parents) in line x tester mating design. These hybrids along with three standard check hybrids were evaluated in three environments created by different irrigation levels i.e. one irrigation (E_1), two irrigations (E_2) and three irrigations (E_3) at Agriculture Research Station, Bikaner during *Kharif,* 2015.

The results obtained on various aspects are presented below under the following sub heads:

(A) Analysis of variances

(B) Estimation of combining ability variances, effects and gene action

(C) Estimation of standard heterosis

(D) Estimation of phenotypic stability analysis

4.1 ANALYSIS OF VARIANCES

Analysis of variances indicated the presence of significant genetic variability among the crosses for all the ten characters studied i.e. days to flowering, days to maturity, plant height, number of effective tillers per plant, ear head length, ear head diameter, test weight, dry stover yield per plant, grain yield per plant and harvest index in E_1, E_2, E_3 environment as well as over the environments (Table 4.1.1 to 4.1.4). Pooled analysis of variance over the environments computed for yield and its components further indicated that mean squares due to the environments were highly significant for all the traits which revealed the sufficient diversity among the environments. Crosses x environment interaction were found highly significant for all the characters indicating the differential responses of the genotypes to the environments for all the traits.

Table 4.1.1: ANOVA for grain yield per plant and its components in environment- I

Source of variation	d.f.	Mean squares									
		Days to 50% flowering	Days to maturity	Plant height	Number of effective tillers / plant	Ear head length	Ear head diameter	Test weight	Dry Stover yield / plant	Grain yield / plant	Harvest index
Replication	2	3.432	3.685*	57.298	0.143*	3.660	0.009	1.316	13.555*	0.292	3.662
Crosses	53	15.646**	15.049**	272.378**	0.069*	21.121**	0.139**	4.293**	87.394**	36.318**	138.764**
Error	106	1.269	1.119	125.938	0.045	1.963	0.019	0.753	4.128	1.435	5.040
Total	161	6.028	5.737	173.292	0.054	8.291	0.058	1.925	31.656	12.904	49.044

***, ** Significant at 5% and 1% level of significance, respectively.**

Table 4.1.2: ANOVA for grain yield per plant and its components in environment- II

Source of variation	d.f.	Mean squares									
		Days to 50% flowering	Days to maturity	Plant height	Number of effective tillers / plant	Ear head length	Ear head diameter	Test weight	Dry Stover yield / plant	Grain yield / plant	Harvest index
Replication	2	3.821	1.685	180.841	0.047	4.343	0.029	0.850	7.603	0.956	0.048
Crosses	53	20.338**	19.807**	437.600**	0.162**	10.882**	0.085**	2.972**	119.321**	57.781**	175.76**
Error	106	2.142	0.761	123.922	0.019	1.692	0.010	0.519	2.823	1.025	3.039
Total	161	8.153	7.042	227.889	0.067	4.750	0.035	1.330	41.233	19.707	59.860

***, ** Significant at 5% and 1% level of significance, respectively.**

Table 4.1.3: ANOVA for grain yield per plant and its components in environment- III

Source of variation	d.f.	Mean squares									
		Days to 50% flowering	Days to maturity	Plant height	Number of effective tillers / plant	Ear head length	Ear head diameter	Test weight	Dry Stover yield / plant	Grain yield / plant	Harvest index
Replication	2	2.463*	1.932	108.434*	0.033	2.193	0.027	0.971*	6.133*	2.674	0.878
Crosses	53	30.726**	22.443**	517.117**	0.072**	12.230**	0.099**	3.391**	84.625**	26.828**	73.245**
Error	106	0.671	0.643	30.652	0.027	1.963	0.012	0.278	1.629	1.199	3.315
Total	161	10.587	7.835	191.759	0.042	5.346	0.041	1.311	29.007	9.655	26.305

***, ** Significant at 5% and 1% level of significance, respectively.**

Table 4.1.4: ANOVA for grain yield per plant and its components based on data pooled over the environments

Source of variation	d.f.	Mean squares									
		Days to 50% flowering	Days to maturity	Plant height	Number of effective tillers / plant	Ear head length	Ear head diameter	Test weight	Dry Stover yield / plant	Grain yield / plant	Harvest index
Replication (r)	2	6.562**	3.718*	117.640	0.073	7.842*	0.006	1.508	14.102**	1.333	1.301
Environments	2	11.932**	1602.496**	973.42**	1.193**	122.316**	1.406**	99.045**	1284.313**	1300.033**	1628.686**
Rep. / Env.	4	1.577	1.792	114.466	0.075*	1.177	0.029	0.814	6.595	1.294	1.643
Crosses	53	58.825**	54.358**	792.353**	0.136**	33.348**	0.282**	8.082**	262.392**	59.911**	223.014**
Crosses x Environment	106	3.943**	1.471**	217.371**	0.083**	5.443**	0.021**	1.287**	14.474**	30.508**	82.378**
Pooled Error	318	1.360	0.841	93.504	0.031	1.873	0.014	0.517	2.860	1.220	3.798
Total	485	8.271	13.451	200.846	0.059	6.608	0.050	1.924	39.121	19.392	51.600

***, ** Significant at 5% and 1% level of significance, respectively.**

4.2 COMBINING ABILITY VARIANCES, EFFECTS AND GENE ACTION

Analysis of variance of combining ability for grain yield and its components in E_1 environment showed that variance due to lines was significant for all the traits except number of effective tillers per plant. The mean squares due to testers was found significant for all the characters studied. The mean squares due to line x tester was also significant for all the traits except days to maturity, plant height and number of effective tillers per plant (Table 4.2.1).

Analysis of variance for combining ability in E_2 environment exhibited that variance due to lines was significant for all the traits studied. Variance due to testers was also significant for all the traits except number of effective tillers per plant. Variance due to line x tester was significant for all the characters except plant height (Table 4.2.2).

Analysis of variance for combining ability in E_3 environment showed that mean squares due to lines and line x tester interaction was significant for all the traits. Variance due to tester was also found significant for all the traits except number of effective tillers per plant (Table 4.2.3).

Analysis of variance for combining ability over the environments showed that mean squares due to lines, testers and line x tester interaction was significant for all the characters indicating the presence of significant variations among the lines and testers used for the present study. The variance due to l x e was significant for all the characters except number of effective tillers per plant. The variance due to t x e was significant for plant height and ear head length only. This indicated that lines are highly influenced by the environments for these characters as compared to the testers. The variance due to (l x t) x e was significant for all the traits except days to maturity and ear head diameter (Table 4.2.4). This indicated that the

Table 4.2.1: ANOVA for combining ability for grain yield per plant and its components in environment- I

Source of variation	d.f.	Mean squares									
		Days to 50% flowering	Days to maturity	Plant height	Number of effective tillers / plant	Ear head length	Ear head diameter	Test weight	Dry Stover yield / plant	Grain yield / plant	Harvest index
Replication	2	3.432	3.685*	57.298	0.143*	3.660	0.009	1.316	13.555*	0.292	3.662
Crosses	53	15.646**	15.049**	272.378**	0.069*	21.121**	0.139**	4.293**	87.394**	36.318**	138.764**
line (L)	8	47.96**	75.611**	460.102*	0.026	50.121**	0.315**	9.831**	154.086**	138.855**	506.949**
tester (T)	5	31.995**	27.241**	816.725**	0.231**	104.55**	0.710**	12.957**	307.921**	62.086**	279.093**
Lx T	40	7.140**	1.413	166.789	0.057	4.893**	0.032*	2.102**	46.489**	12.590**	47.586**
Error	106	1.269	1.119	125.938	0.045	1.963	0.019	0.753	4.128	1.435	5.040
Total	161	6.028	5.737	173.292	0.054	8.291	0.058	1.925	31.656	12.904	49.044

***, ** Significant at 5% and 1% level of significance, respectively.**

Table 4.2.2: ANOVA for combining ability for grain yield per plant and its components in environment- II

Source of variation	d.f.	Mean squares									
		Days to 50% flowering	Days to maturity	Plant height	Number of effective tillers / plant	Ear head length	Ear head diameter	Test weight	Dry Stover yield / plant	Grain yield / plant	Harvest index
Replication	2	3.821	1.685	180.841	0.047	4.343	0.029	0.850	7.603	0.956	0.048
Crosses	53	20.338**	19.807**	437.600**	0.162**	10.882**	0.085**	2.972**	119.321**	57.781**	175.760**
line (L)	8	62.960**	102.167**	615.585**	0.476**	28.219**	0.141**	8.291**	262.863**	119.566**	506.320**
tester (T)	5	66.765**	35.052**	2217.393**	0.206	22.810**	0.431**	9.699**	378.270**	177.716**	389.314**
L x T	40	6.010**	1.430**	179.529	0.094**	5.924**	0.031**	1.067**	58.244**	30.432**	82.953**
Error	106	2.142	0.761	123.922	0.019	1.692	0.010	0.519	2.823	1.025	3.039
Total	161	8.153	7.042	227.889	0.067	4.750	0.035	1.330	41.233	19.707	59.860

***, ** Significant at 5% and 1% level of significance, respectively.**

Table 4.2.3: ANOVA for combining ability for grain yield per plant and its components in environment- III

Source of variation	d.f.	Mean squares									
		Days to 50% flowering	Days to maturity	Plant height	Number of effective tillers / plant	Ear head length	Ear head diameter	Test weight	Dry Stover yield / plant	Grain yield / plant	Harvest index
Replication	2	2.463*	1.932	108.434*	0.033	2.193	0.027	0.971*	6.133*	2.674	0.878
Crosses	53	30.726**	22.443**	517.117**	0.072**	12.230**	0.099**	3.391**	84.625**	26.828**	73.245**
line (L)	8	97.306**	117.099**	1168.828**	0.141*	28.613**	0.063*	10.930**	145.948**	45.352*	106.335
tester (T)	5	66.293**	42.677**	2303.116**	0.071	57.750**	0.753**	11.556**	320.088**	72.673**	208.784**
L x T	40	12.965**	0.982*	163.524**	0.058**	3.264*	0.025**	0.863**	42.927**	17.393**	49.684**
Error	106	0.671	0.643	30.652	0.027	1.963	0.012	0.278	1.629	1.199	3.315
Total	161	10.587	7.835	191.759	0.042	5.346	0.041	1.311	29.007	9.655	26.305

***, ** Significant at 5% and 1% level of significance, respectively.**

Table 4.2.4: ANOVA for combining ability for grain yield per plant and its components based on data pooled over the environments

Source of variation	d.f.	Mean squares									
		Days to 50% flowering	Days to maturity	Plant height	Number of effective tillers / plant	Ear head length	Ear head diameter	Test weight	Dry Stover yield / plant	Grain yield / plant	Harvest index
Replication	2	6.562**	3.718*	117.640	0.073	7.842*	0.006	1.508	14.102**	1.333	1.301
Environments	2	11.932**	1602.496**	973.420**	1.193**	122.316**	1.406**	99.045**	1284.313**	1300.033**	1628.686**
Rep. / Env.	4	1.577	1.792	114.466	0.075*	1.177	0.029	0.814	6.595	1.294	1.643
Crosses	53	58.825**	54.358**	792.353**	0.136**	33.348**	0.282**	8.082**	262.392**	59.911**	223.014**
line (L)	8	191.736**	283.709**	1413.947**	0.400**	82.213**	0.419**	24.523**	504.355**	131.009**	652.494**
tester (T)	5	155.485**	103.78**	4403.061**	0.356**	167.609**	1.85**	32.063**	988.851**	255.832**	763.785**
L x T	40	20.160**	2.309**	216.695**	0.056**	6.793**	0.058**	1.797**	123.191**	21.202**	69.521**
Crosses x Environment	106	3.943**	1.471**	217.371**	0.083**	5.443**	0.021**	1.287**	14.474**	30.508**	82.378**
L x E	16	8.245**	5.584**	415.285**	0.121	12.369**	0.050**	2.265*	29.271**	86.382**	233.555**
T x E	10	4.784	0.595	467.087**	0.076	8.751*	0.022	1.074	8.714	28.322	56.703
L x T x E	80	2.977**	0.758	146.574**	0.076**	3.644**	0.015	1.118**	12.234**	19.606**	55.351**
Pooled Error	318	1.360	0.841	93.504	0.031	1.873	0.014	0.517	2.860	1.220	3.798
Total	485	8.271	13.451	200.846	0.059	6.608	0.050	1.924	39.121	19.392	51.600

***, ** Significant at 5% and 1% level of significance, respectively.**

Table 4.2.5: Estimates of combining ability variances for various traits in E_1, E_2 and E_3 environments and over the environments

Source of variation	Environment	Days to 50% flowering	Days to maturity	Plant height	Number of effective tillers / plant	Ear head length	Ear head diameter	Test weight	Dry Stover yield / plant	Grain yield / plant	Harvest index
$\sigma^2 GCA$	E-I	1.459**	2.223**	20.961**	0.003	3.219**	0.021	0.413**	8.201**	3.906**	15.352**
	E-II	2.615**	2.986**	54.976**	0.011	0.871**	0.011	0.352	11.658**	5.254**	16.216**
	E-III	3.059**	3.507	69.886**	0.002	1.774**	0.017	0.461	8.448**	1.849**	4.794**
	Pooled	2.221**	2.801**	35.514**	0.004*	1.647**	0.015**	0.384**	9.135**	1.992	8.131
$\sigma^2 SCA$	E-I	1.957**	0.098	13.617	0.004	0.976**	0.004*	0.449**	14.120**	3.718**	14.182**
	E-II	1.289**	0.223**	18.535	0.025**	1.411**	0.007**	0.182**	18.473**	9.802**	26.638**
	E-III	4.098**	0.113*	44.291**	0.010**	0.434*	0.004**	0.195**	13.766**	5.398**	15.456**
	Pooled	1.909**	0.172**	7.791	0.002	0.349**	0.005**	0.075*	12.328**	0.177	1.574
$\sigma^2 GCA / \sigma^2 SCA$	E-I	0.746	22.705	1.539	0.821	3.297	4.841	0.918	0.581	1.050	1.082
	E-II	2.028	13.389	2.966	0.445	0.617	1.638	1.929	0.631	0.536	0.608
	E-III	0.746	31.007	1.578	0.208	4.091	4.047	2.364	0.614	0.343	0.310
	Pooled	1.163	16.250	4.558	1.913	4.709	3.183	5.091	0.741	11.243	5.164

***, ** Significant at 5% and 1% level of significance, respectively.**

Table 4.2.6: Genetic components for various traits

Genetic components	Days to 50% flowering	Days to maturity	Plant height	Number of effective tillers / plant	Ear head length	Ear head diameter	Test weight	Dry Stover yield / plant	Grain yield / plant	Harvest index
$\sigma^2 A$	4.442	5.603	71.028	0.009	3.295	0.031	0.768	18.271	3.984	16.262
$\sigma^2 D$	1.909	0.172	7.791	0.002	0.349	0.005	0.075	12.329	0.177	1.574
$\sigma^2 A / \sigma^2 D$	2.326	32.495	9.116	3.859	9.418	6.416	10.187	1.482	22.480	10.329
Degree of dominance	0.655	0.175	0.331	0.509	0.326	0.395	0.313	0.821	0.211	0.311
Heritability (ns)%	60.388	92.636	53.369	32.687	65.142	78.481	66.789	52.741	28.912	37.450
Genetic Advance (5%)	3.374	4.693	12.683	0.111	3.018	0.323	1.476	6.394	2.211	5.083

Table 4.2.7: Proportional contribution of lines, testers and their interactions to total variance (%)

Components	Days to 50% flowering	Days to maturity	Plant height	Number of effective tillers / plant	Ear head length	Ear head diameter	Test weight	Dry Stover yield / plant	Grain yield / plant	Harvest index
Line (L)	49.199	78.782	26.935	44.436	37.212	22.449	45.797	29.013	33.007	44.163
Tester (T)	24.936	18.011	52.424	24.664	47.415	61.916	37.425	35.553	40.284	32.309
Line x Tester (L xT)	25.865	3.206	20.640	30.899	15.372	15.634	16.777	35.433	26.708	23.527

expressions of the hybrids were modified by the environments for the above studied characters. Significant mean squares due to L x E, T x E, (L x T) x E indicated their sensitivity to the environment and for this reason; estimates based over the environments might be biased.

Perusal of Table 4.2.5 indicated the magnitude of variance due to GCA was higher as compared to the magnitude of SCA in each environment for almost all the characters. Significant variance due to GCA and SCA indicated the importance of additive as well as non- additive components in the inheritance of days to flowering, days to maturity, ear head length, ear head diameter, test weight and dry stover yield per plant. The ratio of variances due to GCA/SCA was greater than unity which indicated the preponderance of additive components for days to flowering, days to maturity, plant height, ear head length, ear head diameter, test weight, grain yield per plant and harvest index. Whereas non-additive component was predominant for number of effective tillers per plant and dry stover yield per plant in all the environments.

The genetic components for various traits presented in Table 4.2.6 further showed that the ratio of additive variance to dominance variance was greater than unity for all the traits which indicated the preponderance of additive gene action in the inheritance of these characters. The estimates of heritability (ns) was higher (> 50%) for all the characters except number of effective tillers per plant, grain yield per plant and harvest index.

Proportional contribution of line, tester and their interaction to total variance (%) is presented in Table 4.2.7. The Maximum contribution of lines to total variance was for days to maturity (78.78%) followed by days to 50% flowering. The maximum contribution of tester to total variance was for ear head diameter (60.91%) followed by plant height while dry stover yield per plant (35.43%) displayed maximum contribution to total variance in line x tester.

The estimates of general combining ability (GCA) effects of lines (g_i), testers (g_j) and specific combining ability (SCA) effects of crosses (s_{ij}) were

computed for each environment as well as over the environments. The results obtained are presented in Table 4.2.8.a to 4.2.8.e and described below:

4.2.1 Days to 50 % flowering:

Early flowering is desirable in pearl millet which is reflected by the negative combining ability effects. The results revealed that out of nine female lines, four, three, five, and five lines were desirable for this trait in E_1, E_2, E_3 and over the environments, respectively. The female line JMSA 20042 had the maximum GCA effects (-2.142**), (-2.525**), (-2.722**), (-2.463**) in E_1, E_2, E_3 and over the environments, respectively. The female line JMSA 20042 was followed by the line ICMA 843-22 in E_1, RMS 6A in E_2, RMS 6A in E_3 and over the environments.

Among the testers (male parents), two, two, three, and three testers were desirable for this trait in E_1, E_2, E_3 and over the environments, respectively. The tester BIB-65 had the maximum GCA effects (-1.42**), (-2.284**), (-2.019**), (-1.907**) in E_1, E_2, E_3 and over the environments, respectively.

The results further revealed that two female lines ICMA 843-22 and JMSA 20042, and testers BIB-46 and BIB-65 had significant negative GCA effects in all the three environments as well as over the environments. These above lines and testers were considered as good general combiners for days to 50% flowering.

The results further revealed that 6 crosses in E_1, 3 crosses in E_2, 10 crosses in E_3 and 10 crosses over the environments exhibited significant negative SCA effects. The cross ICMA 93333 x BIB-27 had the maximum SCA effects (-3.617**) followed by ICMA 93333 x BIB-46 in E_1. The cross ICMA93333 x BIB-46 had the maximum SCA effects (-3.864**), (-5.907**), (-4.352**) in E_2, E_3 and over the environments, respectively. This cross was followed by RMS 21A x BIB-8 in E_2, E_3 and ICMA 93333 x BIB-65 over the environments.

Table 4.2.8.a: Estimates of general combining ability (GCA) effects and specific combining ability (SCA) effects for various characters in pearl millet

`	Days to 50% flowering				Days to maturity			
	E_1	E_2	E_3	Pooled	E_1	E_2	E_3	Pooled
				GCA Effects				
Lines (Females)								
RMS 6A	-0.253	-1.747**	-1.944**	-1.315**	-1.815**	-2.185**	-2.414**	-2.138**
RMS 21A	-1.031**	-0.414	-0.833**	-0.759**	-1.648**	-1.574**	-2.247**	-1.823**
ICMA 843-22	-1.309**	-1.191**	-1.167**	-1.222**	-1.148**	-0.907**	-1.247**	-1.101**
ICMA93333	2.358**	3.642**	4.833**	3.611**	3.796**	4.704**	4.253**	4.251**
ICMA 97111	-1.198**	-0.525	-1.389**	-1.037**	-1.648**	-1.407**	-1.414**	-1.490**
ICMA 04999	0.136	0.920**	1.444**	0.833**	0.407	1.037**	1.198**	0.881**
ICMA 05444	2.414**	1.586**	1.611**	1.870**	2.407**	2.259**	1.809**	2.158**
ICMA 06999	1.025**	0.253	0.167	0.481**	1.074**	0.648**	2.753**	1.492**
JMSA 20042	-2.142**	-2.525**	-2.722**	-2.463**	-1.426**	-2.574**	-2.691**	-2.230**
SE (g_i) ±	**0.265**	**0.344**	**0.193**	**0.158**	**0.249**	**0.205**	**0.189**	**0.124**
CD 5%	**0.526**	**0.683**	**0.382**	**0.312**	**0.494**	**0.407**	**0.374**	**0.245**
SE (g_i-g_j) ±	**0.375**	**0.487**	**0.272**	**0.224**	**0.352**	**0.290**	**0.267**	**0.176**
CD 5%	**0.744**	**0.967**	**0.541**	**0.441**	**0.699**	**0.576**	**0.529**	**0.347**
Testers (Males)								

BIB - 8	-0.160	-0.469	-0.426**	-0.352**	-0.870**	-0.963**	-1.025**	-0.953**
BIB - 15	1.728**	1.494**	2.019**	1.747**	-0.019	-0.037	0.123	0.023
BIB - 27	0.617**	1.716**	1.241**	1.191**	1.278**	1.593**	1.642**	1.504**
BIB - 46	-0.716**	-1.136**	-1.426**	-1.093**	0.056	-0.111	0.012	-0.014
BIB - 58	-0.049	0.679*	0.611**	0.414**	0.907**	0.963**	1.012**	0.961**
BIB - 65	-1.420**	-2.284**	-2.019**	-1.907**	-1.352**	-1.444**	-1.765**	-1.521**
SE (g_j) ±	**0.216**	**0.281**	**0.157**	**0.129**	**0.203**	**0.167**	**0.154**	**0.101**
CD 5%	**0.429**	**0.558**	**0.312**	**0.255**	**0.403**	**0.332**	**0.305**	**0.200**
SE (g_i-g_j) ±	**0.306**	**0.398**	**0.222**	**0.183**	**0.287**	**0.237**	**0.218**	**0.144**
CD 5%	**0.607**	**0.789**	**0.441**	**0.360**	**0.570**	**0.470**	**0.432**	**0.283**
				SCA Effects				
Crosses								
RMS 6A x BIB-8	-0.895	-0.142	0.870	-0.056	0.259	-0.481	-0.475	-0.233
RMS 6A x BIB-15	-0.117	-0.105	-0.241	-0.154	-0.259	-0.407	-0.290	-0.319
RMS 6A x BIB-27	0.66	0.006	-0.463	0.068	-0.222	-0.037	0.191	-0.023
RMS 6A x BIB-46	-0.006	0.858	0.204	0.352	0.148	0.333	0.154	0.163
RMS 6A x BIB-58	-0.006	-0.957	-1.167*	-0.710	0.148	0.593	0.488	0.409
RMS 6A x BIB-65	0.364	0.340	0.796	0.500	0.074	0.000	-0.068	0.002
RMS 21A x BIB-8	-0.784	-2.475**	-2.241**	-1.833**	-0.574	-0.426	0.025	-0.325
RMS 21A x BIB-15	-0.34	0.228	0.315	0.068	-0.093	-0.352	-0.123	-0.189

RMS 21Ax BIB-27	0.772	0.340	-0.907	0.068	-0.056	-0.315	0.025	-0.115
RMS 21A x BIB-46	0.105	0.858	0.426	0.463	0.167	0.056	-0.346	-0.041
RMS 21A x BIB-58	0.105	0.710	1.056*	0.623	0.648	0.315	0.321	0.428
RMS 21A x BIB-65	0.142	0.340	1.352**	0.611	-0.093	0.722	0.099	0.243
ICMA 843-22 x BIB-8	-0.173	-0.698	-0.241	-0.370	-0.074	0.241	0.358	0.175
ICMA 843-22 x BIB-15	-0.062	0.340	0.981*	0.420	-0.259	-0.685	-0.790	-0.578
ICMA 843-22 x BIB-27	0.383	1.117	-0.574	0.309	0.111	0.352	-0.309	0.051
ICMA 843-22 x BIB-46	0.383	-0.364	0.759	0.259	0.333	0.056	0.321	0.237
ICMA 843-22 x BIB-58	-0.951	-0.512	-0.944*	-0.802*	0.481	0.981	0.321	0.595
ICMA 843-22 x BIB-65	0.420	0.117	0.019	0.185	-0.593	-0.944	0.099	-0.479
ICMA93333 x BIB-8	2.827**	3.802**	2.093**	2.907**	-0.019	-0.37	0.525	0.045
ICMA93333 x BIB-15	3.272**	2.840**	0.648	2.253**	0.463	0.037	0.043	0.181
ICMA93333 x BIB-27	-3.617**	-0.049	1.426**	-0.747	0.500	0.407	-0.475	0.144
ICMA93333 x BIB-46	-3.284**	-3.864**	-5.907**	-4.352**	0.056	-0.222	0.154	-0.004
ICMA93333 x BIB-58	3.716**	0.988	7.389**	4.031**	-0.796	0.370	0.154	-0.091
ICMA93333 x BIB-65	-2.914**	-3.716	-5.648**	-4.093**	-0.204	-0.222	-0.401	-0.276
ICMA 97111 x BIB-8	0.383	-0.698	-0.352	-0.222	-0.574	-0.926	-0.809	-0.770*
ICMA 97111 x BIB-15	0.827	0.673	1.537**	1.012**	-0.093	-0.185	-0.623	-0.300
ICMA 97111 x BIB-27	-0.062	-0.216	-0.352	-0.210	0.611	0.185	-0.142	0.218
ICMA 97111 x BIB-46	0.272	0.636	0.981*	0.630	0.167	0.222	1.154*	0.514

ICMA 97111 x BIB-58	-1.062	-0.179	-1.722**	-0.988*	-0.352	0.148	0.821	0.206
ICMA 97111 x BIB-65	-0.358	-0.216	-0.093	-0.222	0.241	0.556	-0.401	0.132
ICMA 04999 x BIB-8	-0.284	1.525	1.148*	0.796*	0.370	0.630	0.247	0.416
ICMA 04999 x BIB-15	-2.173**	-2.105*	-1.630**	-1.969**	-0.148	0.370	1.099*	0.440
ICMA 04999 x BIB-27	-0.062	-0.660	-0.852	-0.525	0.222	0.074	0.247	0.181
ICMA 04999 x BIB-46	0.605	0.858	1.481**	0.981*	-0.222	-0.222	-1.457**	-0.634*
ICMA 04999 x BIB-58	0.605	0.043	-0.889	-0.080	-0.741	-0.630	-0.457	-0.609*
ICMA 04999 x BIB-65	1.309*	0.340	0.741	0.796*	0.519	-0.222	0.321	0.206
ICMA 05444 x BIB-8	-1.228	-0.809	-0.685	-0.907*	-1.630**	-1.259*	-0.698	-1.195**
ICMA 05444 x BIB-15	-0.784	-1.105	-1.130*	-1.006*	-0.148	-0.185	0.154	-0.06
ICMA 05444 x BIB-27	1.327*	-0.327	-0.019	0.327	0.889	0.519	-0.031	0.459
ICMA 05444 x BIB-46	1.327*	0.858	1.315**	1.167**	0.111	0.889	0.599	0.533
ICMA 05444 x BIB-58	-0.673	0.043	-0.722	-0.451	-0.074	0.148	-0.401	-0.109
ICMA 05444 x BIB-65	0.031	1.340	1.241**	0.87	0.852	-0.111	0.377	0.372
ICMA 06999 x BIB-8	-0.173	-0.142	-0.907	-0.407	1.037	1.019*	0.025	0.693*
ICMA 06999 x BIB-15	0.938	-0.105	-0.019	0.272	1.185	1.426**	0.210	0.940**
ICMA 06999 x BIB-27	-0.284	-0.327	1.426**	0.272	-1.111	-0.537	0.358	-0.430
ICMA 06999 x BIB-46	0.049	0.191	0.426	0.222	-0.222	-0.833	-0.012	-0.356
ICMA 06999 x BIB-58	-1.951**	0.043	-1.611**	-1.173**	-0.741	-0.907	-0.346	-0.665*
ICMA 06999 x BIB-65	1.420*	0.340	0.685	0.815*	-0.148	-0.167	-0.235	-0.183

JMSA 20042 x BIB-8	0.327	-0.364	0.315	0.093	1.204	1.574**	0.802	1.193**
JMSA 20042 x BIB-15	-1.562*	-0.660	-0.463	-0.895*	-0.648	-0.019	0.321	-0.115
JMSA 20042 x BIB-27	0.883	0.117	0.315	0.438	-0.944	-0.648	0.136	-0.486
JMSA 20042 x BIB-46	0.549	-0.031	0.315	0.278	-0.389	-0.278	-0.568	-0.412
JMSA 20042 x BIB-58	0.216	-0.179	-1.389**	-0.451	1.426*	-1.019*	-0.901	-0.165
JMSA 20042 x BIB-65	-0.414	1.117	0.907	0.537	-0.648	0.389	0.210	-0.016
SE (s_{ij}) ±	**0.650**	**0.844**	**0.472**	**0.388**	**0.610**	**0.503**	**0.462**	**0.305**
CD 5%	**1.289**	**1.675**	**0.937**	**0.764**	**1.210**	**0.998**	**0.917**	**0.601**
SE (S_{ij}-S_{kl})±	**0.919**	**1.194**	**0.668**	**0.549**	**0.863**	**0.712**	**0.654**	**0.432**
CD 5%	**1.823**	**2.36**	**1.325**	**1.081**	**1.712**	**1.411**	**1.297**	**0.850**
SE (S_{ij}-S_{ik})±	**1.187**	**1.542**	**0.863**	**0.709**	**1.115**	**0.919**	**0.845**	**0.558**
CD 5%	**2.353**	**3.058**	**1.711**	**1.396**	**2.210**	**1.822**	**1.675**	**1.098**

***, ** Significant at 5% and 1% level of significance, respectively.**

Table 4.2.8.b: Estimates of general combining ability (GCA) effects and specific combining ability (SCA) effects for various characters in pearl millet

`	Plant height				Number of effective tillers per plant			
	E_1	E_2	E_3	Pooled	E_1	E_2	E_3	Pooled
				GCA Effects				
Lines (Females)								
RMS 6A	-3.086	-3.045	2.775*	-1.119	-0.011	0.116**	0.100*	0.068**
RMS 21A	4.152	8.666**	5.020**	5.946**	0.022	0.064	0.080*	0.055*
ICMA 843-22	6.680*	7.444**	1.386	5.17**	0.055	0.359**	0.120**	0.178**
ICMA93333	1.980	2.527	12.653**	5.72**	0.015	-0.037	-0.076	-0.033
ICMA 97111	6.991**	-6.867*	-0.125	0.00	-0.001	-0.060	-0.088*	-0.049*
ICMA 04999	-3.381	-8.395**	-16.014**	-9.263**	-0.049	-0.133**	-0.125**	-0.102**
ICMA 05444	-5.336*	1.722	4.009**	0.131	-0.002	-0.156**	-0.045	-0.068**
ICMA 06999	-6.048*	-2.562	-6.425**	-5.011**	0.035	-0.131**	0.004	-0.031
JMSA 20042	-1.953	0.510	-3.280	-1.574	-0.064	-0.023	0.03	-0.019
SE (g_i) ±	**2.645**	**2.623**	**1.304**	**1.315**	**0.050**	**0.032**	**0.038**	**0.023**
CD 5%	**5.244**	**5.202**	**2.587**	**2.589**	**0.099**	**0.065**	**0.077**	**0.046**
SE (g_i-g_j) ±	**3.740**	**3.710**	**1.845**	**1.860**	**0.071**	**0.046**	**0.055**	**0.033**
CD 5%	**7.416**	**7.356**	**3.658**	**3.661**	**0.140**	**0.092**	**0.109**	**0.066**
Testers (Males)								

BIB - 8	-4.712*	-7.415**	-9.569**	-7.232**	0.093*	0.086**	0.045	0.075**
BIB - 15	-2.531	9.422**	11.001**	5.964**	-0.083*	-0.009	-0.020	-0.037
BIB - 27	10.814**	13.207**	10.312**	11.444**	-0.110**	-0.055*	-0.091**	-0.085**
BIB - 46	-1.335	-6.767**	-6.369**	-4.824**	0.032	-0.126**	-0.001	-0.032
BIB - 58	-0.275	-1.878	2.438*	0.095	-0.044	-0.005	0.04	-0.003
BIB - 65	-1.960	-6.567**	-7.814**	-5.447**	0.111**	0.108**	0.027	0.082**
SE (g_j) ±	**2.159**	**2.142**	**1.065**	**1.074**	**0.041**	**0.026**	**0.031**	**0.019**
CD 5%	**4.281**	**4.247**	**2.112**	**2.113**	**0.081**	**0.053**	**0.063**	**0.038**
SE (g_i-g_j) ±	**3.054**	**3.029**	**1.506**	**1.519**	**0.058**	**0.037**	**0.044**	**0.027**
CD 5%	**6.055**	**6.006**	**2.987**	**2.989**	**0.115**	**0.075**	**0.089**	**0.054**
				SCA Effects				
Crosses								
RMS 6A x BIB-8	-1.543	9.504	-1.553	2.136	-0.027	-0.032	-0.089	-0.049
RMS 6A x BIB-15	-6.858	-3.899	-14.790**	-8.516**	-0.068	0.236**	-0.071	0.032
RMS 6A x BIB-27	-4.269	-5.951	-8.501**	-6.241	-0.024	0.008	-0.090	-0.035
RMS 6A x BIB-46	5.279	4.023	21.180**	10.161**	-0.03	-0.093	0.203*	0.027
RMS 6A x BIB-58	2.753	-1.866	-4.227	-1.113	0.043	0.015	0.079	0.046
RMS 6A x BIB-65	4.638	-1.810	7.891*	3.573	0.105	-0.135	-0.032	-0.02
RMS 21A x BIB-8	7.351	-7.873	1.802	0.427	0.263*	-0.164*	0.061	0.054
RMS 21A x BIB-15	-6.997	8.823	-2.368	-0.181	-0.131	-0.116	0.246*	0.00

RMS 21Ax BIB-27	1.759	4.638	4.854	3.75	-0.094	0.097	-0.189*	-0.062
RMS 21A x BIB-46	-0.493	-2.488	-6.664*	-3.215	0.090	0.029	-0.150	-0.010
RMS 21A x BIB-58	-1.552	5.456	10.062**	4.655	-0.104	0.170*	0.110	0.059
RMS 21A x BIB-65	-0.067	-8.555	-7.686*	-5.436	-0.025	-0.016	-0.078	-0.040
ICMA 843-22 x BIB-8	6.157	11.082	-5.564	3.892	0.134	0.018	-0.116	0.012
ICMA 843-22 x BIB-15	-5.291	-10.522	0.065	-5.249	-0.183	-0.334**	-0.038	-0.185**
ICMA 843-22 x BIB-27	10.698	-0.073	-1.579	3.015	-0.143	-0.095	-0.020	-0.086
ICMA 843-22 x BIB-46	-6.154	-0.199	2.769	-1.195	0.292*	0.337**	-0.051	0.193**
ICMA 843-22 x BIB-58	-4.214	-7.988	1.828	-3.458	-0.069	-0.118	0.006	-0.06
ICMA 843-22 x BIB-65	-1.195	7.701	2.480	2.995	-0.03	0.192*	0.218*	0.127*
ICMA93333 x BIB-8	-12.877*	-3.201	-3.164	-6.414*	-0.046	0.298**	-0.003	0.083
ICMA93333 x BIB-15	0.142	16.128*	15.399**	10.556**	0.023	0.079	-0.098	0.001
ICMA93333 x BIB-27	2.064	-2.923	-0.979	-0.613	0.000	-0.162*	0.246*	0.028
ICMA93333 x BIB-46	6.012	2.117	-3.031	1.700	0.038	-0.156	-0.014	-0.044
ICMA93333 x BIB-58	-2.714	-11.572	-7.838*	-7.374*	0.184	-0.241**	-0.111	-0.056
ICMA93333 x BIB-65	7.372	-0.549	-0.386	2.145	-0.200	0.182*	-0.019	-0.012
ICMA 97111 x BIB-8	-6.488	-3.073	2.147	-2.471	-0.130	0.187*	-0.055	0.001
ICMA 97111 x BIB-15	5.398	-8.344	-1.823	-1.59	0.186	-0.219**	-0.040	-0.024
ICMA 97111 x BIB-27	1.253	4.071	3.665	2.997	0.016	0.004	0.115	0.045
ICMA 97111 x BIB-46	-1.732	1.045	-9.986**	-3.558	-0.04	-0.054	-0.013	-0.035

ICMA 97111 x BIB-58	8.075	5.790	3.140	5.668	-0.22	0.184*	-0.113	-0.05
ICMA 97111 x BIB-65	-6.506	0.512	2.858	-1.045	0.189	-0.102	0.106	0.064
ICMA 04999 x BIB-8	9.518	-0.879	1.236	3.292	-0.062	-0.230**	0.069	-0.074
ICMA 04999 x BIB-15	15.236**	-0.083	5.665	6.940*	0.100	0.181*	0.077	0.120*
ICMA 04999 x BIB-27	-0.108	-4.568	3.021	-0.552	0.003	0.324**	0.019	0.115*
ICMA 04999 x BIB-46	-5.293	4.173	1.569	0.15	-0.032	-0.041	-0.072	-0.048
ICMA 04999 x BIB-58	-10.886	3.451	-9.438**	-5.624	-0.062	0.014	0.007	-0.014
ICMA 04999 x BIB-65	-8.467	-2.094	-2.053	-4.205	0.053	-0.249**	-0.100	-0.099
ICMA 05444 x BIB-8	1.107	-2.296	4.080	0.964	0.116	-0.083	-0.184	-0.128*
ICMA 05444 x BIB-15	7.259	0.967	-4.090	1.379	0.040	0.295**	-0.065	0.090
ICMA 05444 x BIB-27	0.114	0.649	7.265*	2.676	0.137	-0.049	-0.008	0.027
ICMA 05444 x BIB-46	-7.538	3.156	-1.053	-1.812	-0.028	-0.041	0.028	-0.014
ICMA 05444 x BIB-58	-4.397	-3.699	-1.527	-3.208	0.038	-0.102	0.198*	0.044
ICMA 05444 x BIB-65	3.455	1.223	-4.675	0.001	-0.07	-0.019	0.031	-0.020
ICMA 06999 x BIB-8	1.185	0.788	-1.153	0.273	-0.166	0.048	0.391**	0.091
ICMA 06999 x BIB-15	-14.430*	13.151*	5.543	1.421	0.000	-0.008	-0.121	-0.043
ICMA 06999 x BIB-27	-8.975	2.632	2.499	-1.281	0.027	-0.052	0.047	0.007
ICMA 06999 x BIB-46	7.573	-4.427	-5.020	-0.624	-0.145	-0.056	-0.087	-0.096
ICMA 06999 x BIB-58	14.381*	-5.283	5.640	4.913	0.281*	0.085	-0.134	0.077
ICMA 06999 x BIB-65	0.266	-6.860	-7.509*	-4.701	0.003	-0.018	-0.095	-0.037

JMSA 20042 x BIB-8	-4.410	-4.051	2.169	-2.097	0.15	-0.043	-0.073	0.011
JMSA 20042 x BIB-15	5.542	-16.222*	-3.601	-4.76	0.032	-0.115	0.109	0.009
JMSA 20042 x BIB-27	-2.536	1.527	-10.246**	-3.752	0.079	-0.075	-0.120	-0.039
JMSA 20042 x BIB-46	2.346	-7.399	0.236	-1.606	-0.146	0.076	0.156	0.029
JMSA 20042 x BIB-58	-1.447	15.712*	2.362	5.542	-0.09	-0.008	-0.041	-0.047
JMSA 20042 x BIB-65	0.505	10.434	9.080**	6.673*	-0.025	0.165*	-0.032	0.036
SE (s_{ij}) ±	**6.479**	**6.427**	**3.196**	**3.223**	**0.123**	**0.080**	**0.095**	**0.058**
CD 5%	**12.845**	**12.742**	**6.337**	**6.341**	**0.244**	**0.159**	**0.189**	**0.114**
SE (S_{ij}-S_{kl})±	**9.162**	**9.089**	**4.520**	**4.558**	**0.174**	**0.113**	**0.134**	**0.082**
CD 5%	**18.166**	**18.020**	**8.962**	**8.968**	**0.345**	**0.225**	**0.267**	**0.162**
SE (S_{ij}-S_{ik})±	**11.829**	**11.734**	**5.835**	**5.884**	**0.224**	**0.147**	**0.174**	**0.106**
CD 5%	**23.452**	**23.264**	**11.570**	**11.578**	**0.445**	**0.291**	**0.345**	**0.209**

***, ** Significant at 5% and 1% level of significance, respectively.**

Table 4.2.8.c: Estimates of general combining ability (GCA) effects and specific combining ability (SCA) effects for various characters in pearl millet

	Ear head length				Ear head diameter			
	E_1	E_2	E_3	Pooled	E_1	E_2	E_3	Pooled
				GCA Effects				
Lines (Females)								
RMS 6A	-1.321**	-1.759**	-2.059**	-1.713**	-0.092**	-0.077**	0.079**	-0.083**
RMS 21A	3.865**	1.605**	2.435**	2.575**	-0.143**	-0.004	-0.057*	-0.068**
ICMA 843-22	-1.123**	-0.151	-0.522	-0.599**	-0.010	0.045	0.046	0.027
ICMA93333	-1.801**	1.069**	-0.431	-0.387*	-0.176**	-0.170**	-0.045	-0.131**
ICMA 97111	-0.054	-0.093	0.400	0.084	0.217**	0.113**	0.102**	0.144**
ICMA 04999	1.164**	-0.045	-0.089	0.343	0.151**	0.048	0.011	0.070**
ICMA 05444	0.199	1.706**	1.199**	1.035**	-0.005	-0.049*	-0.027	-0.027
ICMA 06999	0.246	-1.349**	-0.628	-0.577**	-0.034	0.002	-0.007	-0.013
JMSA 20042	-0.996**	-0.984**	-0.305	-0.762**	0.092**	0.092**	0.056*	0.08**
SE (g_i) ±	**0.330**	**0.306**	**0.330**	**0.186**	**0.032**	**0.024**	**0.025**	**0.015**
CD 5%	**0.654**	**0.607**	**0.654**	**0.366**	**0.064**	**0.047**	**0.050**	**0.031**
SE (g_i-g_j) ±	**0.467**	**0.433**	**0.467**	**0.263**	**0.045**	**0.034**	**0.036**	**0.022**
CD 5%	**0.926**	**0.859**	**0.925**	**0.518**	**0.090**	**0.067**	**0.072**	**0.044**
Testers (Males)								

BIB - 8	-0.672*	-0.159	-0.498	-0.443**	-0.017	0.028	0.038	0.016
BIB - 15	-1.841**	-0.810**	-0.978**	-1.210**	-0.020	-0.011	-0.031	-0.021
BIB - 27	3.830**	1.742**	2.958**	2.843**	-0.299**	-0.246**	-0.315**	-0.286**
BIB - 46	-0.478	-0.077	-0.571*	-3.75*	0.161**	0.098**	0.157**	0.138**
BIB - 58	-0.050	0.011	-0.420	-0.153	0.080**	0.051*	0.043*	0.058**
BIB - 65	-0.790**	-0.708**	-0.491	-0.663**	0.096**	0.080**	0.108**	0.095**
SE (g_j) ±	**0.269**	**0.250**	**0.269**	**0.152**	**0.026**	**0.019**	**0.021**	**0.013**
CD 5%	**0.534**	**0.496**	**0.534**	**0.299**	**0.052**	**0.039**	**0.041**	**0.025**
SE (g_i-g_j) ±	**0.381**	**0.354**	**0.381**	**0.215**	**0.037**	**0.027**	**0.029**	**0.018**
CD 5%	**0.756**	**0.701**	**0.756**	**0.423**	**0.074**	**0.055**	**0.058**	**0.036**
				SCA Effects				
Crosses								
RMS 6A x BIB-8	0.254	2.404**	1.820*	1.493**	0.073	0.039	0.087	0.067
RMS 6A x BIB-15	-0.584	-1.284	-1.913*	-1.260**	-0.340**	-0.341**	-0.304**	-0.328**
RMS 6A x BIB-27	-0.921	0.683	-0.049	-0.095	0.008	0.056	0.030	0.031
RMS 6A x BIB-46	-0.700	-0.877	0.413	-0.388	0.105	0.156**	0.038	0.100*
RMS 6A x BIB-58	2.572**	-1.833*	-0.171	0.189	0.070	0.146*	0.089	0.101**
RMS 6A x BIB-65	-0.621	0.907	-0.100	0.062	0.084	-0.056	0.060	0.029
RMS 21A x BIB-8	0.608	-2.173**	-0.160	-0.575	0.061	-0.117	-0.042	-0.032
RMS 21A x BIB-15	-1.456	0.626	-0.226	-0.352	0.048	0.159**	0.041	0.082*

RMS 21Ax BIB-27	0.267	-1.887*	1.158	-0.154	0.003	0.147*	0.051	0.067
RMS 21A x BIB-46	-1.412	-0.794	-0.247	-0.818	-0.111	-0.167**	-0.120	-0.133**
RMS 21A x BIB-58	2.073*	2.444**	1.169	1.895**	0.051	0.036	0.133*	0.073
RMS 21A x BIB-65	-0.080	1.784*	-1.694*	0.003	-0.052	-0.059	-0.062	-0.058
ICMA 843-22 x BIB-8	0.243	-0.327	-0.230	-0.105	0.028	-0.086	0.072	0.005
ICMA 843-22 x BIB-15	-0.595	-0.372	0.450	-0.172	0.078	0.070	-0.002	0.048
ICMA 843-22 x BIB-27	2.308**	3.052**	0.581	1.981**	0.176*	-0.056	0.041	0.054
ICMA 843-22 x BIB-46	-1.878*	-1.712*	-0.724	-1.438**	-0.081	0.057	-0.117	-0.047
ICMA 843-22 x BIB-58	-0.493	-0.587	-0.174	-0.418	-0.082	0.000	-0.040	-0.041
ICMA 843-22 x BIB-65	0.415	-0.054	0.096	0.152	-0.118	0.015	0.045	-0.019
ICMA93333 x BIB-8	-1.733*	-1.617*	0.146	-1.068*	-0.045	0.056	0.117	0.042
ICMA93333 x BIB-15	1.436	0.521	0.726	0.894	-0.009	0.151*	0.010	0.051
ICMA93333 x BIB-27	-1.128	0.849	-0.676	-0.318	-0.004	-0.031	-0.054	-0.030
ICMA93333 x BIB-46	0.640	0.875	0.132	0.549	-0.074	-0.111	0.045	-0.047
ICMA93333 x BIB-58	-0.768	0.253	-1.999*	-0.838	0.024	-0.028	-0.081	-0.028
ICMA93333 x BIB-65	1.552	-0.881	1.672*	0.781	0.108	-0.037	-0.037	0.012
ICMA 97111 x BIB-8	-2.406**	0.839	0.415	-0.384	-0.093	0.040	-0.034	-0.029
ICMA 97111 x BIB-15	0.710	-2.263**	-0.572	-0.709	-0.006	-0.017	0.092	0.023
ICMA 97111 x BIB-27	0.526	1.284	-0.741	0.356	-0.088	-0.123*	-0.015	-0.075
ICMA 97111 x BIB-46	0.633	-1.166	-0.846	-0.460	0.135	0.113	0.004	0.084*

ICMA 97111 x BIB-58	-0.182	0.842	1.804*	0.821	0.104	0.003	0.044	0.050
ICMA 97111 x BIB-65	0.719	0.465	-0.059	0.375	-0.052	-0.016	-0.091	-0.053
ICMA 04999 x BIB-8	1.410	-0.156	-0.830	0.141	0.011	0.095	-0.039	0.022
ICMA 04999 x BIB-15	-0.502	-0.264	1.284	0.173	0.034	0.014	0.047	0.032
ICMA 04999 x BIB-27	0.221	-0.790	-0.385	-0.318	0.105	-0.12	-0.013	0.027
ICMA 04999 x BIB-46	0.169	1.636*	-1.190	0.205	-0.005	-0.108	-0.048	-0.053
ICMA 04999 x BIB-58	-1.093	-0.659	0.392	-0.453	-0.133	-0.049	-0.007	-0.063
ICMA 04999 x BIB-65	-0.205	0.234	0.730	0.253	-0.012	0.059	0.06	0.036
ICMA 05444 x BIB-8	0.294	0.726	-0.924	0.032	0.053	-0.018	-0.115	-0.027
ICMA 05444 x BIB-15	0.130	-0.149	0.262	0.081	-0.034	-0.059	-0.056	-0.050
ICMA 05444 x BIB-27	1.192	-0.661	1.794*	0.775	-0.005	0.055	-0.029	0.007
ICMA 05444 x BIB-46	0.400	0.871	0.055	0.442	0.015	0.045	0.086	0.049
ICMA 05444 x BIB-58	-1.462	-0.724	-0.762	-0.982*	-0.044	-0.015	0.023	-0.012
ICMA 05444 x BIB-65	-0.554	-0.064	-0.425	-0.348	0.014	-0.007	0.091	0.033
ICMA 06999 x BIB-8	0.507	0.481	-0.458	0.177	0.028	0.057	0.022	0.036
ICMA 06999 x BIB-15	-0.930	2.032**	-0.078	0.341	0.055	0.03	0.085	0.056
ICMA 06999 x BIB-27	-1.154	-1.593*	-1.246	-1.331**	-0.053	-0.053	0.058	-0.016
ICMA 06999 x BIB-46	1.553	0.759	1.148	1.154*	0.047	-0.026	0.010	0.010
ICMA 06999 x BIB-58	0.425	0.197	0.898	0.507	-0.012	-0.043	-0.110	-0.055
ICMA 06999 x BIB-65	-0.401	-1.876*	-0.265	-0.847	-0.065	0.035	-0.065	-0.032

JMSA 20042 x BIB-8	0.823	-0.177	0.220	0.289	-0.117	-0.066	-0.067	-0.084*
JMSA 20042 x BIB-15	1.792*	1.154	0.067	1.004*	0.176*	-0.007	0.088	0.086*
JMSA 20042 x BIB-27	-1.312	-0.938	-0.435	-0.895	-0.142	0.017	-0.680	-0.064
JMSA 20042 x BIB-46	0.595	0.408	1.260	0.754	-0.032	0.041	0.101	0.036
JMSA 20042 x BIB-58	-1.073	0.066	-1.158	-0.721	0.023	-0.05	-0.052	-0.027
JMSA 20042 x BIB-65	-0.825	-0.514	0.046	-0.431	0.093	0.065	-0.001	0.052
SE (s_{ij}) ±	**0.809**	**0.751**	**0.808**	**0.456**	**0.079**	**0.059**	**0.062**	**0.039**
CD 5%	**1.603**	**1.488**	**1.603**	**0.897**	**0.157**	**0.117**	**0.124**	**0.076**
SE (S_{ij}-S_{kl})±	**1.144**	**1.062**	**1.143**	**0.645**	**0.112**	**0.083**	**0.088**	**0.055**
CD 5%	**2.268**	**2.105**	**2.267**	**1.269**	**0.222**	**0.165**	**0.176**	**0.108**
SE (S_{ij}-S_{ik})±	**1.477**	**1.371**	**1.476**	**0.832**	**0.144**	**0.107**	**0.114**	**0.071**
CD 5%	**2.928**	**2.718**	**2.927**	**1.638**	**0.286**	**0.213**	**0.227**	**0.140**

***, ** Significant at 5% and 1% level of significance, respectively.**

Table 4.2.8.d: Estimates of general combining ability (GCA) effects and specific combining ability (SCA) effects for various characters in pearl millet

`	Test weight				Dry stover yield per plant			
	E_1	E_2	E_3	Pooled	E_1	E_2	E_3	Pooled
				GCA Effects				
Lines (Females)								
RMS 6A	-0.198	-0.281	-0.239	-0.240*	-1.066*	-0.380	1.567**	0.041
RMS 21A	-1.143**	-0.543**	-0.533**	-0.740**	-1.072*	0.208	-0.015	-0.293
ICMA 843-22	0.796**	1.107**	1.000**	0.968**	-3.99**	-6.758**	-3.077**	-4.608**
ICMA93333	-0.470*	-0.559**	-0.706**	-0.578**	3.805**	2.124**	2.931**	2.953**
ICMA 97111	1.224**	0.263	0.578**	0.688**	0.212	-0.344	1.133**	0.334
ICMA 04999	-0.359	-0.793**	-1.311**	-0.821**	1.305**	2.716**	0.259	1.427**
ICMA 05444	0.035	-0.476**	0.028	-0.138	4.265**	5.276**	3.713**	4.418**
ICMA 06999	-0.459*	0.524**	0.228	0.098	0.492	2.259**	-1.253**	0.499*
JMSA 20042	0.574**	0.757**	0.956**	0.762**	-3.952**	-5.102**	-5.258**	-4.707**
SE (g_i) ±	**0.204**	**0.169**	**0.124**	**0.097**	**0.478**	**0.396**	**0.300**	**0.230**
CD 5%	**0.405**	**0.336**	**0.246**	**0.192**	**0.942**	**0.785**	**0.596**	**0.452**
SE (g_i-g_j) ±	**0.289**	**0.240**	**0.175**	**0.138**	**0.677**	**0.560**	**0.425**	**0.325**
CD 5%	**0.573**	**0.476**	**0.348**	**0.272**	**1.342**	**1.110**	**0.843**	**0.640**
Testers (Males)								

BIB - 8	-0.530**	-0.189	0.033	-0.228**	-3.009**	-3.173**	-2.692**	-2.958**
BIB - 15	-0.900**	-1.033**	-1.204**	-1.046**	5.724**	5.527**	6.221**	5.824**
BIB - 27	0.004	0.026	-0.122	-0.031	2.395**	3.784**	1.707**	2.629**
BIB - 46	-0.070	0.074	0.333**	0.112	-1.99**	-2.055**	-2.027**	-2.024**
BIB - 58	1.052**	0.730**	0.707**	0.83**	-2.127**	-3.171**	-2.364**	-2.554**
BIB - 65	0.444**	0.393**	0.252*	0.363**	-0.993*	-0.912**	-0.845**	-0.917**
SE (g_j) ±	**0.167**	**0.138**	**0.101**	**0.079**	**0.391**	**0.323**	**0.245**	**0.187**
CD 5%	**0.331**	**0.274**	**0.201**	**0.157**	**0.775**	**0.641**	**0.487**	**0.369**
SE (g_i-g_j) ±	**0.236**	**0.196**	**0.143**	**0.112**	**0.553**	**0.457**	**0.347**	**0.265**
CD 5%	**0.468**	**0.388**	**0.284**	**0.222**	**1.096**	**0.906**	**0.688**	**0.522**
				SCA Effects				
Crosses								
RMS 6A x BIB-8	0.580	0.722	0.906**	0.736**	0.280	3.493**	3.933**	2.569**
RMS 6A x BIB-15	0.083	-1.067*	-1.191**	-0.725**	-4.974**	-6.569**	-5.853**	-5.799**
RMS 6A x BIB-27	-0.287	0.807	0.261	0.260	-3.186**	0.056	1.516*	-0.538
RMS 6A x BIB-46	-0.480	-0.041	0.139	-0.127	3.110**	1.689	0.388	1.729**
RMS 6A x BIB-58	-0.669	-0.696	-0.569	-0.644**	0.392	-1.314	-2.187**	-1.036
RMS 6A x BIB-65	0.772	0.274	0.454	0.500*	4.376**	2.645**	2.202**	3.074**
RMS 21A x BIB-8	0.991	0.883*	0.433	0.769**	1.528	6.292**	2.058**	3.292**
RMS 21A x BIB-15	-0.606	-0.272	0.004	-0.291	-2.932*	-4.465**	-3.727**	-3.708**

RMS 21Ax BIB-27	-0.076	0.169	0.256	0.116	1.860	-1.195	-1.629*	-0.321
RMS 21A x BIB-46	0.798	-0.146	-0.433	0.073	1.875	0.263	0.793	0.977
RMS 21A x BIB-58	-1.191*	-0.369	-0.007	-0.522*	-2.421*	-0.916	-0.951	-1.429*
RMS 21A x BIB-65	0.083	-0.265	-0.252	-0.144	0.090	0.021	3.456**	1.189*
ICMA 843-22 x BIB-8	0.252	-0.333	0.200	0.040	0.725	2.773**	-0.519	0.993
ICMA 843-22 x BIB-15	0.989	0.611	-0.430	0.390	-1.589	-3.694**	0.599	-1.561**
ICMA 843-22 x BIB-27	-0.048	0.152	-0.111	-0.002	0.941	1.391	0.351	0.894
ICMA 843-22 x BIB-46	-0.174	-0.630	-0.033	-0.279	1.165	0.486	0.524	0.725
ICMA 843-22 x BIB-58	0.204	-0.052	0.393	0.181	-2.128	-0.541	-2.799**	-1.823**
ICMA 843-22 x BIB-65	-1.222*	0.252	-0.019	-0.330	0.886	-0.413	1.845*	0.772
ICMA93333 x BIB-8	-1.448**	-0.300	-0.661*	-0.803**	-6.214**	-7.836**	-5.559**	-6.536**
ICMA93333 x BIB-15	-0.011	-0.022	0.376	0.114	10.104**	10.64**	9.367**	10.037**
ICMA93333 x BIB-27	0.652	-0.281	0.094	0.155	-4.397**	-5.047**	-4.258**	-4.567**
ICMA93333 x BIB-46	-1.607**	0.270	0.706*	-0.210	-4.082**	-4.389**	-3.228**	-3.900**
ICMA93333 x BIB-58	1.104*	0.615	-0.969**	0.250	4.022**	4.77**	5.098**	4.63**
ICMA93333 x BIB-65	1.311*	-0.281	0.454	0.494*	0.567	1.863	-1.420	0.336
ICMA 97111 x BIB-8	0.0524	-0.522	0.222	0.075	2.021	-0.495	0.996	0.840
ICMA 97111 x BIB-15	-0.906	0.122	-0.374	-0.386	0.857	6.339**	-0.613	2.194**
ICMA 97111 x BIB-27	0.191	0.563	0.078	0.277	1.191	-3.803**	0.869	-0.581
ICMA 97111 x BIB-46	0.431	0.248	-0.044	0.212	-0.170	3.719**	-0.142	1.136*

ICMA 97111 x BIB-58	-0.657	0.359	-0.152	-0.150	4.128**	-0.905	3.358**	2.194**
ICMA 97111 x BIB-65	0.417	-0.770	0.270	-0.028	-8.027**	-4.855**	-4.467**	-5.783**
ICMA 04999 x BIB-8	0.241	-0.30	-0.756*	-0.272	0.573	-6.387**	-1.057	-2.29**
ICMA 04999 x BIB-15	0.411	0.511	1.115**	0.679**	2.341*	2.712**	4.226**	3.093**
ICMA 04999 x BIB-27	1.007*	-0.181	0.067	0.298	3.225**	1.615	4.227**	3.022**
ICMA 04999 x BIB-46	0.048	-0.830*	-0.589	-0.457	-4.343**	-2.154*	-1.987**	-2.828**
ICMA 04999 x BIB-58	-1.241*	0.815	0.37	-0.019	-4.685**	-2.443*	-4.833**	-3.987**
ICMA 04999 x BIB-65	-0.467	-0.015	-0.207	-0.23	2.888*	6.657**	-0.575	2.99**
ICMA 05444 x BIB-8	0.113	0.217	-0.428	-0.033	0.914	0.394	0.809	0.706**
ICMA 05444 x BIB-15	-0.117	0.494	1.076**	0.485*	3.608**	0.313	3.281**	2.401**
ICMA 05444 x BIB-27	-0.754	-0.398	-0.406	-0.519*	-6.284**	-2.032*	-5.322**	-4.546**
ICMA 05444 x BIB-46	0.587	0.32	-0.128	0.26	3.206**	4.314**	3.01**	3.51**
ICMA 05444 x BIB-58	0.931	-1.335**	0.531	0.043	3.161**	4.222**	4.157**	3.847**
ICMA 05444 x BIB-65	-0.761	0.702	-0.646*	-0.235	-4.605**	-7.211**	-5.935**	-5.917**
ICMA 06999 x BIB-8	-0.759	0.017	-0.094	-0.279	0.68	0.008	0.715	0.468
ICMA 06999 x BIB-15	-0.056	-0.506	-0.357	-0.306	-2.406*	-2.781**	-0.635	-1.941**
ICMA 06999 x BIB-27	0.174	-0.131	-0.106	-0.021	3.726**	2.603**	-0.607	1.907**
ICMA 06999 x BIB-46	0.615	0.520	0.206	0.447	0.829	-1.992*	0.946	-0.072
ICMA 06999 x BIB-58	0.993	0.698	0.531	0.741**	-2.634*	0.329	-1.601*	-1.302*
ICMA 06999 x BIB-65	-0.967	-0.598	-0.180	-0.581*	-0.196	1.832	1.182	0.940

JMSA 20042 x BIB-8	-0.493	-0.383	0.178	-0.233	-0.507	1.758	-1.375	-0.041
JMSA 20042 x BIB-15	0.211	0.128	-0.219	0.040	-5.011**	-2.494*	-6.645**	-4.716**
JMSA 20042 x BIB-27	-0.859	-0.698	-0.133	-0.564*	2.924*	6.412**	4.853**	4.73**
JMSA 20042 x BIB-46	-0.219	0.287	0.178	0.082	-1.591	-1.936*	-0.304	-1.277*
JMSA 20042 x BIB-58	0.526	-0.035	-0.130	0.120	0.164	-3.203**	-0.243	-1.094
JMSA 20042 x BIB-65	0.833	0.702	0.126	0.554*	4.021**	-0.538	3.713**	2.398**
SE (s_{ij}) ±	**0.501**	**0.415**	**0.304**	**0.239**	**1.173**	**0.970**	**0.736**	**0.563**
CD 5%	**0.993**	**0.824**	**0.603**	**0.471**	**2.325**	**1.923**	**1.461**	**1.109**
SE (S_{ij}-S_{kl})±	**0.708**	**0.588**	**0.430**	**0.338**	**1.659**	**1.371**	**1.042**	**0.797**
CD 5%	**1.404**	**1.166**	**0.853**	**0.666**	**3.289**	**2.72**	**2.066**	**1.568**
SE (S_{ij}-S_{ik})±	**0.914**	**0.759**	**0.555**	**0.437**	**2.141**	**1.771**	**1.345**	**1.029**
CD 5%	**1.813**	**1.505**	**1.101**	**0.860**	**4.246**	**3.511**	**2.667**	**2.025**

***, ** Significant at 5% and 1% level of significance, respectively.**

Table 4.2.8.e: Estimates of general combining ability (GCA) effects and specific combining ability (SCA) effects for various characters in pearl millet

`	Grain yield per plant				Harvest index			
	E_1	E_2	E_3	Pooled	E_1	E_2	E_3	Pooled
				GCA Effects				
Lines (Females)								
RMS 6A	0.566*	0.651**	2.684**	1.300**	1.731**	0.996*	2.760**	1.829**
RMS 21A	-2.385*	1.435**	0.809**	-0.047	-4.113**	1.841**	1.134**	-0.379
ICMA 843-22	-0.480	2.747**	-0.491	0.592**	1.418**	7.828**	0.775	3.34**
ICMA93333	-3.413**	-1.348**	-0.616*	-1.792**	-7.991**	-3.221**	-1.944**	-4.385**
ICMA 97111	3.163**	0.881**	0.897**	1.647**	5.913**	1.703**	0.703	2.773**
ICMA 04999	5.204**	-2.924**	-1.811**	0.157	7.404**	-5.575**	-2.754**	-0.308
ICMA 05444	-2.590**	-4.870**	-1.683**	-3.048**	-6.597**	-9.738**	-4.195**	-6.844**
ICMA 06999	-0.136	2.804**	1.644**	1.437**	-0.248	2.314**	2.784**	1.617**
JMSA 20042	0.072	0.623*	-1.434**	-0.246	2.483**	3.851**	0.737	2.357**
SE (g_i) ±	**0.282**	**0.238**	**0.258**	**0.150**	**0.529**	**0.410**	**0.429**	**0.265**
CD 5%	**0.559**	**0.473**	**0.511**	**0.295**	**1.049**	**0.814**	**0.850**	**0.521**
SE (g_i-g_j) ±	**0.399**	**0.337**	**0.365**	**0.212**	**0.748**	**0.581**	**0.606**	**0.375**
CD 5%	**0.791**	**0.669**	**0.723**	**0.418**	**1.483**	**1.152**	**1.203**	**0.737**
Testers (Males)								

BIB - 8	0.462*	1.814**	0.461*	0.912**	2.481**	4.246**	2.078**	2.935**
BIB - 15	-0.426	-0.94**	0.113	-0.418**	-3.408**	-3.611**	-2.465**	-3.161**
BIB - 27	0.775**	1.279**	0.573**	0.876**	-0.199	-0.325	-0.253	-0.259
BIB - 46	0.177	-1.588**	1.431**	0.006	1.597**	-1.249**	3.330**	1.226**
BIB - 58	-2.728**	-3.777**	-3.23**	-3.245**	-4.186**	-3.942**	-3.943**	-4.024**
BIB - 65	1.741**	3.212**	0.652**	1.868**	3.715**	4.881**	1.253**	3.283**
SE (g_j) ±	**0.230**	**0.194**	**0.210**	**0.122**	**0.432**	**0.335**	**0.350**	**0.216**
CD 5%	**0.457**	**0.386**	**0.417**	**0.241**	**0.856**	**0.665**	**0.694**	**0.426**
SE (g_i-g_j) ±	**0.326**	**0.275**	**0.298**	**0.173**	**0.611**	**0.474**	**0.495**	**0.306**
CD 5%	**0.646**	**0.546**	**0.591**	**0.341**	**1.211**	**0.940**	**0.982**	**0.602**
				SCA Effects				
Crosses								
RMS 6A x BIB-8	-0.013	-1.028	1.021	-0.007	0.234	-3.199**	-0.821	-1.262
RMS 6A x BIB-15	-0.922	-2.065**	-3.26**	-2.082**	0.511	-0.034	-1.933	-0.485
RMS 6A x BIB-27	-0.176	1.834**	-0.313	0.448	1.882	2.270*	-1.017	1.045
RMS 6A x BIB-46	0.055	1.898**	-1.250	0.234	-1.755	2.024*	-2.06	-0.597
RMS 6A x BIB-58	0.622	0.775	0.956	0.784*	1.071	2.286*	3.537**	2.298**
RMS 6A x BIB-65	0.433	-1.415*	2.846**	0.622	-1.943	-3.348**	2.294*	-0.999
RMS 21A x BIB-8	0.886	-4.442**	-4.05**	-2.535**	1.170	-9.443**	-7.179**	-5.151**
RMS 21A x BIB-15	-1.583*	0.883	1.711**	0.337	-2.236	2.993**	3.640**	1.466*

RMS 21Ax BIB-27	-0.508	2.458**	1.168	1.039**	-1.083	3.416**	2.622*	1.652*
RMS 21A x BIB-46	-0.478	0.667	-1.178	-0.330	-2.145	1.079	-2.223*	-1.096
RMS 21A x BIB-58	1.352	2.74**	4.199**	2.763**	3.253*	5.036**	7.381**	5.224**
RMS 21A x BIB-65	0.331	-2.306**	-1.85**	-1.275**	1.040	-3.081**	-4.242**	-2.094**
ICMA 843-22 x BIB-8	1.751*	-1.803**	1.064	0.337	3.812**	-3.516**	2.635*	0.977
ICMA 843-22 x BIB-15	0.001	-2.842**	0.683	-0.719	0.292	-2.711**	0.257	-0.721
ICMA 843-22 x BIB-27	2.083**	0.704	2.203**	1.663**	3.626**	-0.413	3.264**	2.159**
ICMA 843-22 x BIB-46	-0.216	5.572**	0.44	1.932**	-0.921	7.961**	0.709	2.583**
ICMA 843-22 x BIB-58	0.681	-2.826**	-2.513**	-1.553**	2.532	-3.361**	-3.397**	-1.409*
ICMA 843-22 x BIB-65	-4.299**	1.194*	-1.876**	-1.661**	-9.341**	2.040*	-3.468**	-3.590**
ICMA93333 x BIB-8	-2.516**	10.251**	-2.343**	1.797**	-4.346**	18.275**	-1.028	4.300**
ICMA93333 x BIB-15	-0.796	2.144**	-2.388**	-0.347	-2.757*	-0.745	-6.413**	-3.305**
ICMA93333 x BIB-27	0.091	-2.996**	1.662**	-0.414	2.392	-1.377	4.281**	1.765**
ICMA93333 x BIB-46	1.942**	-3.772**	1.687**	-0.048	5.274**	-4.413**	3.538**	1.466*
ICMA93333 x BIB-58	0.092	-3.104**	-0.912	-1.308**	-2.341	-7.636**	-3.919**	-4.632**
ICMA93333 x BIB-65	1.186	-2.523**	2.294**	0.319	1.778	-4.104**	3.542**	0.405
ICMA 97111 x BIB-8	1.952**	3.618**	-0.298	1.757**	1.691	4.664**	-0.903	1.817**
ICMA 97111 x BIB-15	-0.167	-2.636**	-1.727**	-1.510**	-1.449	-6.886**	-2.432*	-3.589**
ICMA 97111 x BIB-27	-1.158	0.165	2.814**	0.607	-2.853*	2.013*	3.234**	0.798
ICMA 97111 x BIB-46	-2.447**	-0.685	-0.032	-1.054**	-4.622**	-3.081**	-0.231	-2.645**

ICMA 97111 x BIB-58	0.093	3.328**	1.514*	1.645**	-1.727	5.578**	0.987	1.613*
ICMA 97111 x BIB-65	1.727*	-3.791**	-2.271**	-1.445**	8.960**	-2.289*	-0.655	2.006**
ICMA 04999 x BIB-8	-2.287**	-2.119**	1.339*	-1.022**	-3.009*	0.400	2.681*	0.024
ICMA 04999 x BIB-15	4.535**	4.066**	3.85**	4.15**	4.789**	4.500**	3.175**	4.155**
ICMA 04999 x BIB-27	3.022**	-1.691**	-4.643**	-1.104**	2.508	-2.402*	-8.829**	-2.908**
ICMA 04999 x BIB-46	1.420*	-1.842**	0.170	-0.084	6.032**	-2.692**	1.338	1.559*
ICMA 04999 x BIB-58	-5.904**	1.805**	0.987	-1.037**	-7.499**	3.356**	3.975**	-0.056
ICMA 04999 x BIB-65	-0.785	-0.219	-1.702**	-0.902*	-2.821*	-3.161**	-2.340*	-2.774**
ICMA 05444 x BIB-8	0.869	-1.577**	-2.376**	-1.028**	0.799	-2.716**	-4.339**	-2.085**
ICMA 05444 x BIB-15	-0.592	2.780**	0.175	0.787*	-1.297	4.420**	0.761	0.787
ICMA 05444 x BIB-27	-2.397**	0.214	-2.001**	-1.395**	-2.006	2.073*	-0.473	-0.135
ICMA 05444 x BIB-46	0.470	0.140	0.861	0.490	-1.070	-1.687	-0.604	-1.120
ICMA 05444 x BIB-58	1.479*	-2.988**	0.075	-0.478	1.104	-8.335**	-1.723	-2.985**
ICMA 05444 x BIB-65	0.170	1.431*	3.266**	1.623**	2.469	6.245**	7.900**	5.538**
ICMA 06999 x BIB-8	-0.048	-0.636	5.478**	1.598**	-0.478	-0.772	6.918**	1.889**
ICMA 06999 x BIB-15	-2.876**	-0.937	0.243	-1.19**	-4.721**	0.040	0.184	-1.499*
ICMA 06999 x BIB-27	-1.238	-2.171**	-0.817	-1.409**	-3.555**	-3.696**	-0.552	-2.601**
ICMA 06999 x BIB-46	0.814	-1.88**	-1.610*	-0.892*	1.047	-0.971	-2.646*	-0.857
ICMA 06999 x BIB-58	2.355**	1.549**	-2.162**	0.581	6.077**	2.753**	-2.032	2.266**
ICMA 06999 x BIB-65	0.993	4.075**	-1.132	1.312**	1.631	2.647**	-1.873	0.802

JMSA 20042 x BIB-8	-0.595	-2.264**	0.165	-0.898*	0.127	-3.693**	2.037	-0.510
JMSA 20042 x BIB-15	2.400**	-1.394*	0.713	0.573	6.868**	-1.577	4.283**	3.191**
JMSA 20042 x BIB-27	0.282	1.483*	-0.071	0.565	-0.913	-1.883	-2.530*	-1.775**
JMSA 20042 x BIB-46	-1.560*	-0.099	0.912	-0.249	-1.839	1.780	2.179*	0.707
JMSA 20042 x BIB-58	-0.770	-1.279*	-2.143**	-1.398**	-2.470	0.323	-4.810**	-2.319**
JMSA 20042 x BIB-65	0.243	3.553**	0.425	1.407**	-1.773	5.051**	-1.159	0.706
SE (s_{ij}) ±	**0.691**	**0.584**	**0.632**	**0.368**	**1.296**	**1.006**	**1.051**	**0.649**
CD 5%	**1.371**	**1.158**	**1.253**	**0.724**	**2.569**	**1.995**	**2.083**	**1.278**
SE (S_{ij}-S_{kl})±	**0.978**	**0.826**	**0.894**	**0.520**	**1.833**	**1.423**	**1.486**	**0.918**
CD 5%	**1.939**	**1.638**	**1.772**	**1.024**	**3.634**	**2.822**	**2.947**	**1.807**
SE (S_{ij}-S_{ik})±	**1.262**	**1.067**	**1.154**	**0.672**	**2.366**	**1.837**	**1.919**	**1.186**
CD 5%	**2.503**	**2.115**	**2.288**	**1.322**	**4.691**	**3.643**	**3.804**	**2.333**

***, ** Significant at 5% and 1% level of significance, respectively.**

Among the crosses two crosses viz., ICMA 93333 x BIB-46 and ICMA 04999 x BIB-15 exhibited significantly negative SCA effects in all the three environments as well as over the environments (Table 4.2.8.a).

4.2.2 Days to maturity:

Similar to earliness in flowering, early maturity is desired trait in pearl millet which is reflected by the negative combining ability effects for days to maturity. The results revealed that out of nine lines, five lines in each environment were good general combiner for this trait. The female line RMS 6A had the maximum GCA effects (-1.815**) followed by the line RMS 21A in E_1. The line JMSA 20042 had the maximum GCA effects (-2.574**), (-2.691**) and (-2.23**) in E_2, E_3 and over the environments, respectively. This line was followed by the line RMS 6A in E_2, E_3 and over the environments.

Among the testers (male parent) two testers in each environment were good general combiner for this trait. The tester BIB-65 had the maximum GCA effects (-1.352**), (-1.444**), (-1.765**), (-1.521**) in E_1, E_2, E_3 and over the environments, respectively. This tester was followed by the tester BIB-8 in each environment.

The results revealed that among the lines, RMS 6A, RMS 21A, ICMA 97111, ICMA 843-22 and JMSA 20042, while among the testers, BIB-8 and BIB-65 depicting desirable significantly negative GCA effects in all the environments were good general combiners for days to maturity.

The results further revealed that one cross in E_1, two crosses in E_2, one cross in E_3 and five crosses in over the environments analysis exhibited significant negative SCA effects for days to maturity. The cross ICMA 05444 x BIB-8 had the maximum SCA effects (-1.63**), (-1.259**) and (-1.195**) in E_1, E_2 and over the environments, respectively. While the cross ICMA 04999 x BIB-46 (-1.457**) had the maximum SCA effects in E_3 (Table 4.2.8.a).

4.2.3 Plant height:

Tallness is a preferred trait when pearl millet breeding is aimed at high fodder yield or for dual purpose, which is reflected by the positive combining ability effects.

The results revealed that out of nine lines, two in E_1, two in E_2, four in E_3, and three lines over the environments were desirable for this trait. The female lines had the maximum GCA effects were ICMA 97111 (6.991**) followed by the line ICMA 843-22 in E_1, RMS 21A (8.666**) followed by line ICMA 843-22 in E_2, ICMA 93333 (12.65**) followed by the line RMS 21A in E_3 and RMS 21A (5.946**) followed by the line ICMA 93333 in over the environments.

Among the testers (male parent) one in E_1, two in E_2, three in E_3, and two testers over the environments were desirable for this trait. The tester BIB-27 had the maximum GCA effects (10.814**), (13.207**), (10.312**), (11.444**) in E_1, E_2, E_3 and over the environments, respectively followed by the tester BIB-15.

The results further revealed that two, three, six and four crosses were desirable for this trait in E_1, E_2, E_3 and over the environments, respectively. The cross ICMA 04999 x BIB-15 had the maximum SCA effects (15.236**) followed by ICMA 06999 x BIB-58 in E_1. The cross ICMA93333 x BIB-15 had the maximum SCA effects (16.128**) in E_2 followed by the cross JMSA 20042 x BIB-58 and (10.556**) in over the environments followed by the cross RMS 6A x BIB-46. The cross RMS 6A x BIB-46 had the maximum SCA effects (21.18**) in E_3 followed by ICMA 93333 x BIB-15 (Table 4.2.8.b).

4.2.4 Number of effective tillers per plant:

As more number of effective tillers is desired, positive GCA and SCA effects were considered. The results revealed that out of nine lines, two, three and three lines were desirable for this trait in E_2, E_3 and over the

environments, respectively. The female lines had the maximum GCA effects were ICMA 843-22 (0.359**), (0.120**) and (0.178**) in E_2, E_3 and over the environments, respectively followed by RMS 6A.
Among the testers (male parent) two in E_1, two in E_2 and two testers over the environments were desirable for this trait. The tester BIB-65 had the maximum GCA effects (0.111**), (0.108**), (0.082**) in E_1, E_2 and over the environments, respectively followed by the tester BIB-8, thus were good general combiners for this trait.

The results further revealed that two, 12, six and four crosses were desirable for this trait in E_1, E_2, E_3 and over the environments, respectively. The cross ICMA 843-22 x BIB-46 had the maximum SCA effects (0.292*) followed by ICMA 06999 x BIB-58 in E_1. The cross ICMA 843-22x BIB-46 had the maximum SCA effects (0.337**) followed by the cross ICMA 04999 x BIB-27 in E_2 and (0.193**) in over the environments followed by the cross ICMA 843-22 x BIB-65. The cross ICMA 06999 x BIB-8 had the maximum SCA effects (0.391**) followed by ICMA 93333 x BIB-27 in E_3 (Table 4.2.8.b).

4.2.5 Ear head length:

Longer ear heads are generally preferred, hence positive combining ability effects are desired for this trait. The estimates of GCA effects revealed that out of nine lines (female parent) two, three, two and two lines were desirable for this trait in E_1, E_2, E_3 and over the environments, respectively. The line RMS 21A exhibited maximum GCA effects (3.865**), (0.1.605**), (2.435**) and (2.575**) in E_1, E_2, E_3 and over the environments, respectively. Among the testers (male parent), the tester BIB-27 had the maximum GCA effects (3.830**), (1.742**), (2.958**) and (2.843**) in E_1, E_2, E_3 and over the environments, respectively.

RMS 21A and tester (male parent) BIB-27 exhibited significant and positive GCA effects in all the environments as well as over the environments thus were good general combiners for long ear head.

The estimates of SCA effects revealed that four crosses in $E_{1,}$ six crosses in $E_{2,}$ four crosses in E_3 and five crosses in over the environments had significant positive SCA effects.The cross RMS 6A x BIB-58 had the maximum SCA effects (2.572**) followed by ICMA 843-22 x BIB-27 in $E_{1.}$ The cross ICMA 843-22x BIB-27 had the maximum SCA effects (3.052**) followed by the cross RMS 21A x BIB-58 in E_2 and (1.981**) in over the environments followed by the cross RMS 21A x BIB-58. The cross RMS 6A x BIB-8 had the maximum SCA effects (1.82**) followed by ICMA 97111 x BIB-58 in E_3 (Table 4.2.8.c).

4.2.6 Ear head diameter:

The estimates of GCA effects revealed that out of nine lines (female parent) three, two, two and three lines were desirable for this trait in $E_{1,}$ E_2, E_3 and over the environments, respectively. The line ICMA 97111 exhibited maximum GCA effects (0.217**), (0.113**), (0.102**) and (0.144**) in E_1, E_2, E_3 and over the environments, respectively followed by the line JMSA 20042. Among the testers (male parent), the tester BIB-46 had the maximum GCA effects (0.161**), (0.098**), (0.157**) and (0.138**) in E_1, E_2, E_3 and over the environments, respectively followed by the tester BIB-65. The results revealed that lines (female parent) ICMA 97111, JMSA 20042 and among the testers (male parents) BIB-46, BIB-58, BIB-65 showed desirable significantly positive GCA effects in all the environments as well as over the environments, thus were good general combiners for this trait.

The estimates of SCA effects revealed that two crosses in $E_{1,}$ five crosses in $E_{2,}$ one crosses in E_3 and five crosses in over the environments had desirable significant positive SCA effects. The cross ICMA 843-22 x BIB-27 and JMSA 20042 x BIB-15 had the maximum SCA effects (0.176*) in $E_{1.}$ The cross RMS 21A x BIB-15 had the maximum SCA effects (0.159**) followed by the cross RMS 6A x BIB-46 in E_2 and RMS 21A x BIB-15 (0.133*) in $E_{3.}$ The cross RMS 6A x BIB-58 had the maximum SCA effects (0.101**) followed by the cross RMS 6A x BIB-46 in over the environments (Table 4.2.8.c).

4.2.7 Test weight:

Perusal of the estimates of GCA effects revealed that out of nine lines (female parent) three, three, two and three lines were desirable for this trait in $E_{1,}$ E_2, E_3 and over the environments, respectively. The line ICMA 97111 exhibited maximum GCA effects (1.224**) in E_1 followed by ICMA 843-22 (0.796**). The line ICMA 843-22 exhibited maximum GCA effects (0.1.107**), (1.00**) and (0.968**) in E_2, E_3 and over the environments, respectively followed by the line JMSA 20042. Among the testers (male parent), the tester BIB-58 had the maximum GCA effects (1.052**), (0.730**), (0.707**) and (0.83**) in E_1, E_2, E_3 and over the environments, respectively followed by the tester BIB-65. The results revealed that lines (female parent) ICMA 843-22, JMSA 20042 and among the testers (male parents) BIB-58, BIB-65 showed desirable significantly positive GCA effects in all the environments as well as over the environments, thus were good general combiners for this trait.

The estimates of SCA effects revealed that out of 54 crosses, three crosses in $E_{1,}$ one crosses in $E_{2,}$ three crosses in E_3 and six crosses in over the environments had desirable significant positive SCA effects. The cross ICMA 93333 x BIB-65 had the maximum SCA effects (1.31*) in E_1 followed by the cross ICMA 93333 x BIB-58. The cross RMS 21A x BIB-8 had the maximum SCA effects (0.883*) in E_2 and ICMA 04999 x BIB-15 (1.115**) followed by the cross ICMA 05444 x BIB-15 in $E_{3.}$ The cross RMS 21A x BIB-8 had the maximum SCA effects (0.769**) followed by the cross ICMA 06999 x BIB-58 in over the environments (Table 4.2.8.d).

4.2.8 Dry stover yield per plant:

Dry stover yield per plant is desirable in pearl millet, which is reflected by the significant positive combining ability. The results revealed that out of nine lines, three, four, four and four lines were desirable for this trait in $E_{1,}$ E_2, E_3 and over the environments, respectively. The female lines had the maximum GCA effects were ICMA 05444 (4.265**), (5.276**) (3.713**) and

(4.418**) in E_1, E_2, E_3 and over the environments, respectively followed by ICMA 93333.

Among the testers (male parent) two in E_1, two in E_2 and two testers over the environments were desirable for this trait. The tester BIB-15 had the maximum GCA effects (5.724**), (5.527**), (6.221**) and (5.824**) in E_1, E_2, E_3 and over the environments, respectively followed by the tester BIB-27. The results revealed that parents ICMA 05444, ICMA 93333, BIB-15 and BIB-27 showed desirable significantly positive GCA effects in all the environments as well as over the environments, thus were good general combiners for this trait.

The estimates of SCA effects revealed that 14 crosses in E_1, 13 crosses in E_2, 16 crosses in E_3 and 20 crosses in over the environments had desirable significant positive SCA effects. The cross ICMA 93333 x BIB-15 had the maximum SCA effects (10.104**), (10.64**), (9.367**) and (10.037**) in E_1, E_2, E_3 and over the environments, respectively followed by the cross ICMA 93333 x BIB-58 (Table 4.2.8.d).

Out of 54 crosses seven crosses i.e. RMS 6A x BIB-65, ICMA 93333 x BIB-15, ICMA 93333 x BIB-58, ICMA 04999 x BIB-15, ICMA 05444 x BIB-46, ICMA 05444 x BIB-58 and JMSA 20042 x BIB-27 exhibited desirable significantly positive SCA effects in all the three environments as well as over the environments (Table 4.2.9.d).

4.2.9 Grain yield per plant:

Grain yield per plant is desirable in pearl millet, which is reflected by the significant positive combining ability.

The results revealed that out of nine lines, three in E_1, five in E_2, three in E_3 and four lines in over the environments were desirable for this character. The female lines had the maximum GCA effects were ICMA 04999 (5.204**) followed by the line ICMA 97111 in E_1, ICMA 06999 (2.804**) followed by line ICMA 843-22 in E_2, RMS 6A (2.684**) followed by the line ICMA 06999 in E_3 and ICMA 97111 (1.647**) followed by the line ICMA 06999 in over the environments.

Among the testers (male parent) three in E_1, three in E_2, four in E_3 and three testers over the environments were desirable for this trait. The tester BIB-65 had the maximum GCA effects (1.741**), (3.212**) and (1.868**) in E_1, E_2 and over the environments, respectively followed by the tester BIB-27 in E_1, BIB-8 in E_2 and over the environments. Tester BIB-46 exhibited maximum GCA effects (1.431**) in E_3 followed by the tester BIB-65.

The results revealed that parents RMS 6A, ICMA 97111, BIB-8, BIB-27 and BIB-65 showed desirable significantly positive GCA effects in all the environments as well as over the environments, thus were good general combiners for this trait.

The estimates of SCA effects revealed that 11 crosses in E_1, 17crosses in E_2, 13 crosses in E_3 and 14 crosses in over the environments had desirable significant positive SCA effects. The cross ICMA 04999 x BIB-15 had the maximum SCA effects (4.535**) followed by the cross ICMA 04999 x BIB-27 in E_1. The cross ICMA 93333 x BIB-8 had the maximum SCA effects (10.251**) followed by the cross ICMA 843-22 x BIB-46 in E_2. The cross ICMA 06999 x BIB-8 had the maximum SCA effects (5.478**) followed by the cross RMS 21A x BIB-58 in E_3 and the cross ICMA 04999 x BIB-15 had the maximum SCA effects (4.15**) followed by RMS 21A x BIB-58 in over the environments. The cross ICMA 04999 x BIB-15 exhibited desirable significantly positive SCA effects in all the three environments as well as over the environments (Table 4.2.8.e).

4.2.10 Harvest index:

The results revealed that out of nine lines, five, six, three and five lines were desirable for this trait in E_1, E_2, E_3 and over the environments, respectively. The female lines had the maximum GCA effects were ICMA 04999 (7.404**) followed by the line ICMA 97111 in E_1, ICMA 843-22 (7.828**) followed by line JMSA 20042 in E_2, ICMA 06999 (2.784**) followed by the line

RMS 6A in E_3 and ICMA 843-22 (3.34**) followed by the line ICMA 97111 in over the environments.

Among the testers (male parent) three in E_1, two in E_2, three in E_3 and three testers over the environments were desirable for this trait. The tester BIB-65 had the maximum GCA effects (3.715**), (4.88**) and (3.283**) in E_1, E_2 and over the environments, respectively followed by the tester BIB-8. In E_2 environment tester BIB-46 had the maximum GCA effects (3.33**) followed by the tester BIB-8.

The results revealed that parents RMS 6A, BIB-8 and BIB-65 exhibited desirable significantly positive GCA effects in all the environments as well as over the environments, thus were good general combiners for harvest index.

The estimates of SCA effects revealed that out of 54 crosses, nine, 20, 18 and 18 crosses had desirable significant positive SCA effects for this trait in E_1, E_2, E_3 and over the environments, respectively. The cross ICMA 97111 x BIB-58 had the maximum SCA effects (8.96**) followed by the cross JMSA 20042 x BIB-15 in E_1. The cross ICMA 93333 x BIB-8 had the maximum SCA effects (18.275**) followed by the cross ICMA 843-22 x BIB-46 in E_2. The cross ICMA 05444 x BIB-65 had the maximum SCA effects (7.90**) in E_3 followed by the cross ICMA 06999 x BIB-8 and the cross ICMA 05444 x BIB-65 had the maximum SCA effects (5.538**) in over the environments followed by RMS 21A x BIB-58. The cross RMS 21A x BIB-58 and ICMA 04999 x BIB-15 exhibited desirable significantly positive SCA effects in all the three environments as well as over the environments (Table 4.2.8.e).

4.3 STANDARD HETEROSIS:

Standard heterosis was computed as per cent increase of F_1's over the best check hybrid for grain yield per plant in the trial. HHB-67 Imp. was best check for days to 50% flowering, days to maturity, plant height, number of effective tillers per plant, ear head length, grain yield per plant and dry stover yield per plant. While, for rest of the characters HHB-67 Imp. was at par to the

next best check RHB177. So, in present study HHB-67 Improved was used to compute standard heterosis for all the characters. Standard heterosis was estimated in E_1, E_2, E_3 and over the environments for all the characters. The results obtained are presented in Table 4.3.1.a to 4.3.1.e and are described character wise as below.

4.3.1 Days to 50% flowering

In pearl millet early flowering is desirable. The hybrids possessing negative heterotic effects were, therefore, considered to be superior over late flowering hybrids (Table 4.4.1.a). Standard heterosis ranged from -3.125 (JMSA 20042 x BIB-65) to 23.438 (ICMA 93333 x BIB-15) in E_1, -0.787 (JMSA 20042 x BIB-65) to 26.772 (ICMA 93333 x BIB-15) in E_2 and -0.787 (ICMA 93333 x BIB-15) to 38.583 (ICMA 93333 x BIB-58) in E_3 . While over the environments, standard heterosis ranged from -1.42 (JMSA 20042 x BIB-65) to 26.65 (ICMA 93333 x BIB-58) (Table 4.3.1.a).

Out of 54 crosses, none of the cross exhibited significant negative heterosis for days to 50% flowering. All the crosses were either at par or later in flowering than the best check hybrid HHB-67 Imp (42.44 days).

4.3.2 Days to maturity

The estimates of standard heterosis for days to maturity ranged from -1.493 (JMSA 20042 x BIB-65) to 11.94 (ICMA 93333 x BIB-27) in E_1, -0.943 (JMSA 20042 x BIB-65) to 13.679 (ICMA 93333 x BIB-27) in E_2 and -1.835 (ICMA 93333 x BIB-15) to 11.468 (ICMA 93333 x BIB-27) in E_3 . While over the environments heterosis ranged from -1.43 (JMSA 20042 x BIB-65) to 12.41 (ICMA 93333 x BIB-27) (Table 4.3.1.a).

Out of 54 crosses, none of the cross exhibited significant negative heterosis for days to maturity. Therefore, none of cross was significantly earlier in maturity than the earliest superior check hybrid HHB-67 Improved (71.778 days).

Table 4.3.1.a: Estimates of standard heterosis (SH) over the best check for different characters in pearl millet in E_1, E_2, E_3 and over the environments

Crosses	Days to 50% flowering				Days to maturity			
	E_1	E_2	E_3	Pooled	E_1	E_2	E_3	Pooled
RMS 6A x BIB-8	3.125	2.362	4.724	3.54	0	-0.943	-1.376	-0.71
RMS 6A x BIB-15	9.375*	7.087	7.874**	8.255*	0.498	0.472	0.459	0.43
RMS 6A x BIB-27	8.594*	7.874	5.512*	7.547*	2.488	3.302	3.211*	3.00
RMS 6A x BIB-46	3.906	3.15	0.787	2.83	0.995	1.415	0.917	1.14
RMS 6A x BIB-58	5.469	3.15	2.362	3.77	2.488	3.302	2.752	2.85
RMS 6A x BIB-65	3.125	-0.787	0.787	1.18	-0.995	-0.943	-1.835	-1.28
RMS 21A x BIB-8	1.563	0	0	0.71	-0.995	0	-0.459	-0.43
RMS 21A x BIB-15	7.031	11.024*	11.811**	10.142**	0.995	1.415	0.917	1.14
RMS 21Ax BIB-27	7.031	11.811*	7.087*	8.726*	2.985	3.774*	3.211*	3.28
RMS 21A x BIB-46	2.344	6.299	3.937	4.25	1.493	1.887	0.459	1.28
RMS 21A x BIB-58	3.906	10.236*	10.236**	8.255*	3.483	3.774*	2.752	3.28
RMS 21A x BIB-65	0.781	2.362	4.724	2.83	-0.995	0.943	-1.376	-0.43
ICMA 843-22 x BIB-8	2.344	2.362	3.937	3.07	0.498	1.887	1.376	1.28
ICMA 843-22 x BIB-15	7.031	9.449*	12.598**	9.906*	1.493	1.887	1.376	1.57

ICMA 843-22 x BIB-27	5.469	11.811*	7.087*	8.255*	3.98	5.66**	4.128*	4.565*
ICMA 843-22 x BIB-46	2.344	1.575	3.937	2.83	2.488	2.83	2.752	2.71
ICMA 843-22 x BIB-58	0.781	5.512	4.724	3.77	3.98	5.66**	4.128*	4.565*
ICMA 843-22 x BIB-65	0.781	0	0.787	0.71	-0.995	-0.472	0	-0.43
ICMA93333 x BIB-8	17.969**	24.409**	23.622**	22.17**	7.96**	8.962**	9.174**	8.702**
ICMA93333 x BIB-15	23.438**	26.772**	25.984**	25.472**	9.95**	10.849**	10.092**	10.271**
ICMA93333 x BIB-27	4.688	20.472**	25.984**	17.217**	11.94**	13.679**	11.468**	12.411**
ICMA93333 x BIB-46	2.344	4.724	2.362	3.30	9.453**	10.377**	10.092**	9.986**
ICMA93333 x BIB-58	20.313**	20.472**	38.583**	26.651**	9.453**	12.736**	11.468**	11.27**
ICMA93333 x BIB-65	1.563	2.362	1.575	1.89	6.965**	8.491**	6.881**	7.418**
ICMA 97111 x BIB-8	3.906	3.937	3.15	3.77	-0.995	-0.472	-0.459	-0.57
ICMA 97111 x BIB-15	9.375*	11.811*	13.386**	11.557**	0.995	1.887	1.376	1.43
ICMA 97111 x BIB-27	4.688	10.236*	7.087*	7.547*	3.98	4.717**	4.128*	4.28*
ICMA 97111 x BIB-46	2.344	5.512	3.937	4.01	1.493	2.358	3.67*	2.57
ICMA 97111 x BIB-58	0.781	7.874	2.362	3.77	1.99	3.774*	4.587**	3.57
ICMA 97111 x BIB-65	-0.781	0.787	0	0.00	-0.498	0.943	-0.917	-0.14
ICMA 04999 x BIB-8	5.469	12.598**	13.386**	10.613**	3.483	5.189**	4.587**	4.422*
ICMA 04999 x BIB-15	5.469	8.661	12.598**	8.962*	3.98	6.132**	7.339**	5.849**

ICMA 04999 x BIB-27	7.813*	12.598**	12.598**	11.085**	6.468**	8.019**	8.257**	7.561**
ICMA 04999 x BIB-46	6.25	9.449*	11.811**	9.198*	3.98	5.189**	3.67*	4.28*
ICMA 04999 x BIB-58	7.813*	11.811*	11.024**	10.377**	4.478*	6.132**	6.422**	5.706**
ICMA 04999 x BIB-65	6.25	5.512	8.661**	6.84	2.985	3.302	3.67*	3.28
ICMA 05444 x BIB-8	8.594*	8.661	9.449**	8.962*	3.483	4.245*	4.128*	3.994*
ICMA 05444 x BIB-15	14.063**	12.598**	14.173**	13.679**	6.965**	7.075**	6.881**	6.99**
ICMA 05444 x BIB-27	16.406**	14.961**	14.961**	15.566**	10.448**	10.377**	8.716**	9.843**
ICMA 05444 x BIB-46	13.281**	11.024*	11.811**	12.264**	7.463**	8.491**	7.339**	7.846**
ICMA 05444 x BIB-58	10.156**	13.386**	11.811**	11.792**	8.458**	8.962**	7.339**	8.274**
ICMA 05444 x BIB-65	8.594*	9.449*	10.236**	9.434*	6.468**	5.189**	4.587**	5.421**
ICMA 06999 x BIB-8	7.813*	7.087	5.512*	6.84	5.473*	5.189**	6.422**	5.706**
ICMA 06999 x BIB-15	14.844**	11.811*	13.386**	13.443**	6.965**	7.075**	8.257**	7.418**
ICMA 06999 x BIB-27	9.375*	11.811*	14.961**	12.264**	5.473*	6.604**	10.55**	7.561**
ICMA 06999 x BIB-46	7.031	6.299	6.299*	6.60	4.975*	3.774*	7.798**	5.563**
ICMA 06999 x BIB-58	3.906	10.236*	6.299*	6.84	5.473*	5.189**	8.716**	6.562**
ICMA 06999 x BIB-65	8.594*	3.937	5.512*	6.13	2.985	2.83	5.046**	3.709*
JMSA 20042 x BIB-8	1.563	0	1.575	1.18	1.99	1.415	0	1.14
JMSA 20042 x BIB-15	1.563	3.937	5.512*	3.77	0.498	0.472	0.917	0.71

JMSA 20042 x BIB-27	4.688	6.299	5.512*	5.66	1.99	1.887	2.752	2.28
JMSA 20042 x BIB-46	0.781	-0.787	-0.787	-0.24	0.995	0	-0.459	0.14
JMSA 20042 x BIB-58	1.563	3.15	0	1.65	4.975*	0.472	0.459	1.85
JMSA 20042 x BIB-65	-3.125	-0.787	-0.787	-1.42	-1.493	-0.943	-1.835	-1.43
RHB-177	3.906	3.937	4.724	4.25	1.99	2.83	2.294	2.43
GHB-538	12.5**	12.598**	14.173**	13.208**	7.463**	6.604**	5.505**	6.562**

***, ** Significant at 5% and 1% level of significance, respectively.**

Table 4.3.1.b: Estimates of standard heterosis (SH) over the best check for different characters in pearl millet in E_1, E_2, E_3 and over the environments

Crosses	Plant height				Number of effective tillers / plant			
	E_1	E_2	E_3	Pooled	E_1	E_2	E_3	Pooled
RMS 6A x BIB-8	-11.483	-13.103	-9.485	-11.37	-12.186	-7.524	14.164	0.00
RMS 6A x BIB-15	-13.331	-11.178	-4.948	-9.89	-25.042	3.136	10.292	-6.67
RMS 6A x BIB-27	-3.932	-10.206	-1.485	-5.30	-23.922	-13.231	2.32	-13.33
RMS 6A x BIB-46	-5.466	-15.813	6.557	-5.24	-15.891	-23.706*	35.37*	-6.67
RMS 6A x BIB-58	-6.331	-16.374	-3.711	-9.01	-16.299	-9.916	28.23	0.00
RMS 6A x BIB-65	-6.213	-18.972*	-2.557	-9.48	-3.529	-12.149	17.672	0.00
RMS 21A x BIB-8	-1.966	-16.28	-6.021	-8.25	6.672	-18.395	25.144	0.00
RMS 21A x BIB-15	-9.143	2.523	4.124	-0.82	-26.893	-21.167	35.712*	-6.67
RMS 21Ax BIB-27	3.893	2.299	8.165	4.71	-26.09	-11.088	-7.732	-13.33
RMS 21A x BIB-46	-4.601	-12.897	-9.278	-8.95	-7.03	-19.633	3.454	-6.67
RMS 21A x BIB-58	-4.601	-5.701	6.515	-1.41	-22.972	-3.748	29.152	0.00
RMS 21A x BIB-65	-4.719	-16.187	-10.804*	-10.66	-9.269	-8.109	12.123	0.00
ICMA 843-22 x BIB-8	-1.18	-6.336	-12.825**	-6.66	1.017	10.295	13.694	6.67
ICMA 843-22 x BIB-15	-6.646	-9.009	3.381	-4.24	-27.865	-16.63	14.927	-13.33

ICMA 843-22 x BIB-27	10.657	-1.028	1.938	3.83	-27.261	-4.956	10.252	-6.67
ICMA 843-22 x BIB-46	-6.449	-12.299	-5.691	-8.25	6.674	16.805	15.468	13.33
ICMA 843-22 x BIB-58	-4.68	-13.925	-0.825	-6.66	-18.953	-3.278	23.678	0.00
ICMA 843-22 x BIB-65	-3.893	-7.757	-6.763	-6.13	-7.591	22.118	41.02*	13.33
ICMA93333 x BIB-8	-15.179	-17.103*	-4.371	-12.43	-11.872	3.254	6.627	0.00
ICMA93333 x BIB-15	-6.213	3.178	19.835**	5.36	-18.127	-15.487	-7.325	-13.33
ICMA93333 x BIB-27	2.792	-5.383	9.278	2.00	-21.03	-32.753**	16.237	-13.33
ICMA93333 x BIB-46	-2.045	-13.757	-2.309	-6.18	-10.447	-36.789**	1.859	-13.33
ICMA93333 x BIB-58	-6.567	-18.692*	0.165	-8.66	-6.597	-34.64**	-3.079	-13.33
ICMA93333 x BIB-65	-1.612	-15.14	-1.567	-6.30	-19.858	-2.422	3.723	-6.67
ICMA 97111 x BIB-8	-8.455	-22.299*	-8.99	-13.43	-17.588	-4.734	1.026	-6.67
ICMA 97111 x BIB-15	-0.157	-15.813	1.278	-5.18	-9.439	-34.883**	-3.21	-13.33
ICMA 97111 x BIB-27	5.269	-6.729	4.247	0.77	-21.022	-24.082*	3.968	-13.33
ICMA 97111 x BIB-46	-3.657	-19.626*	-14.515**	-12.66	-15.87	-31.887**	0.792	-20.00
ICMA 97111 x BIB-58	2.753	-14.224	-0.948	-4.36	-31.117	-10.297	-4.636	-13.33
ICMA 97111 x BIB-65	-6.842	-19.813*	-7.464	-11.54	2.014	-20.656	13.292	0.00
ICMA 04999 x BIB-8	-5.132	-21.925*	-19.381**	-15.49	-16.707	-34.204**	8.551	-13.33
ICMA 04999 x BIB-15	-0.472	-12.037	-3.918	-5.60	-17.368	-15.224	3.67	-13.33

ICMA 04999 x BIB-27	-1.652	-12.43	-5.979	-6.77	-24.661	-9.437	-7.388	-13.33
ICMA 04999 x BIB-46	-11.876	-18.729*	-17.196**	-15.96*	-18.26	-35.693**	-7.546	-20.00
ICMA 04999 x BIB-58	-14.55	-16.393	-18.557**	-16.431*	-24.521	-24.952*	2.945	-20.00
ICMA 04999 x BIB-65	-14.117	-22.131*	-20.33**	-18.846*	-8.761	-33.967**	-7.519	-20.00
ICMA 05444 x BIB-8	-11.247	-17.047	-5.237	-11.37	-17.173	-26.804*	-6.521	-20.00
ICMA 05444 x BIB-15	-6.331	-5.776	2.433	-3.36	-17.99	-9.746	-2.018	-13.33
ICMA 05444 x BIB-27	-2.674	-3.832	9.031	0.65	-14.057	-33.082**	-2.999	-20.00
ICMA 05444 x BIB-46	-14.353	-13.626	-6.433	-11.54	-15.36	-36.994**	7.932	-20.00
ICMA 05444 x BIB-58	-11.876	-14.729	-1.278	-9.48	-16.015	-33.345**	26.137	-13.33
ICMA 05444 x BIB-65	-8.238	-14.598	-9.567	-10.84	-13.112	-21.573	10.523	-6.67
ICMA 06999 x BIB-8	-11.62	-17.72*	-14.928**	-14.78	-17.72	-17.248	47.29**	0.00
ICMA 06999 x BIB-15	-19.544*	-1.346	1.938	-6.36	-18.43	-26.402*	-2.136	-13.33
ICMA 06999 x BIB-27	-8.455	-5.121	-0.371	-4.71	-18.34	-31.708**	5.918	-13.33
ICMA 06999 x BIB-46	-5.859	-20.28*	-15.34**	-13.90	-20.16	-36.409**	2.019	-20.00
ICMA 06999 x BIB-58	-1.219	-18.019*	-3.299	-7.72	0.397	-20.5	1.657	-6.67
ICMA 06999 x BIB-65	-10.539	-21.533*	-17.773**	-16.667*	-6.95	-20.021	4.097	-6.67
JMSA 20042 x BIB-8	-12.505	-18.71*	-10.928*	-14.13	-4.973	-16.442	9.654	-6.67
JMSA 20042 x BIB-15	-5.348	-16.093	-1.773	-7.95	-22.244	-26.503*	19.573	-13.33

JMSA 20042 x BIB-27	-2.241	-4.019	-6.309	-4.12	-21.145	-26.741*	-6.117	-20.00
JMSA 20042 x BIB-46	-6.528	-20.224*	-10.144*	-12.43	-25.892	-21.96	25.595	-13.33
JMSA 20042 x BIB-58	-8.14	-4.523	-3.381	-5.36	-27.331	-19.705	12.018	-13.33
JMSA 20042 x BIB-65	-7.983	-10.112	-5.567	-7.95	-14.318	-2.666	11.663	0.00
RHB-177	-5.82	-10.766	-1.526	-6.18	-13.418	-21.873	13.551	-6.67
GHB-538	-10.696	-11.103	-1.485	-7.89	-27.11	-18.944	-9.343	-20.00

***, ** Significant at 5% and 1% level of significance, respectively.**

Table 4.3.1.c: Estimates of standard heterosis (SH) over the best check for different characters in pearl millet in E_1, E_2, E_3 and over the environments

Crosses	Ear head length				Ear head diameter			
	E_1	E_2	E_3	Pooled	E_1	E_2	E_3	Pooled
RMS 6A x BIB-8	-16.333*	-8.748	-12.152	-12.74	-4.13	2.516	5.741	0.00
RMS 6A x BIB-15	-23.781**	-25.903**	-28.74**	-26.255**	-21.964**	-15.263*	-13.73*	-16.667*
RMS 6A x BIB-27	-3.984	-8.037	-5.906	-6.18	-18.878**	-8.43	-11.604	-16.667*
RMS 6A x BIB-46	-19.154**	-21.397**	-17.979*	-19.691**	5.04	10.438	8.628	4.17
RMS 6A x BIB-58	-5.419	-24.822**	-19.685*	-16.602*	0.006	7.95	5.945	4.17
RMS 6A x BIB-65	-20.02**	-16.838*	-19.685*	-18.919*	1.072	0.68	7.534	0.00
RMS 21A x BIB-8	3.563	-13.544	-2.257	-3.86	-6.788	-0.965	1.17	-4.17
RMS 21A x BIB-15	-8.439	-5.059	-4.409	-6.18	-7.458	8.935	1.682	0.00
RMS 21Ax BIB-27	19.005**	-4.901	16.535*	10.43	-21.277**	-1.433	-9.874	-12.50
RMS 21A x BIB-46	-3.217	-7.773	-2.887	-4.63	-6.392	-0.189	3.019	-4.17
RMS 21A x BIB-58	11.309	5.375	3.281	6.56	-3.049	6.484	8.89	4.17
RMS 21A x BIB-65	0.569	-0.079	-8.268	-2.70	-6.711	3.57	3.344	0.00
ICMA 843-22 x BIB-8	-15.64*	-13.188	-14.173	-14.29	-2.35	2.355	10.49	0.00
ICMA 843-22 x BIB-15	-23.088**	-15.942*	-13.386	-17.761*	-0.499	7.307	4.283	0.00

ICMA 843-22 x BIB-27	8.735	7.681	2.625	6.18	-8.117	-7.818	-5.82	-8.33
ICMA 843-22 x BIB-46	-22.791**	-18.34*	-16.404*	-19.305**	0.508	11.425	7.381	4.17
ICMA 843-22 x BIB-58	-16.06*	-13.544	-13.648	-14.672*	-3.109	7.005	5.894	0.00
ICMA 843-22 x BIB-65	-15.442*	-14.282*	-12.861	-14.29	-3.887	8.827	12.042*	4.17
ICMA93333 x BIB-8	-25.489**	-13.465	-12.336	-17.375*	-12.646*	-0.795	8.523	-4.17
ICMA93333 x BIB-15	-18.065*	-7.589	-11.942	-12.74	-11.423	1.675	0.919	-4.17
ICMA93333 x BIB-27	-6.533	3.794	-1.969	-1.93	-22.877**	-16.047**	-13.705*	-20.833**
ICMA93333 x BIB-46	-15.961*	-3.294	-12.682	-10.81	-6.414	-4.918	10.406	-4.17
ICMA93333 x BIB-58	-19.599**	-5.402	-20.472**	-15.444*	-5.698	-3.249	0.269	-4.17
ICMA93333 x BIB-65	-13.734	-12.727	-6.299	-11.20	-1.42	-2.521	4.803	0.00
ICMA 97111 x BIB-8	-21.505**	-8.353	-8.005	-12.74	2.042	10.545	8.243	4.17
ICMA 97111 x BIB-15	-14.279*	-23.188**	-13.78	-16.988*	5.527	6.371	10.66	4.17
ICMA 97111 x BIB-27	6.088	0.922	1.05	2.70	-9.689	-7.885	-5.894	-8.33
ICMA 97111 x BIB-46	-9.503	-15.955*	-13.255	-12.74	19.443**	16.606**	14.841*	16.667*
ICMA 97111 x BIB-58	-10.938	-7.668	-2.231	-6.95	14.623*	10.023	11.771	8.33
ICMA 97111 x BIB-65	-10.344	-12.003	-9.843	-10.81	8.679	10.336	8.905	8.33
ICMA 04999 x BIB-8	-2.821	-12.095	-14.829	-9.65	3.705	10.08	4.113	4.17
ICMA 04999 x BIB-15	-14.254*	-15.099*	-8.399	-12.74	4.652	4.981	4.939	4.17

ICMA 04999 x BIB-27	9.478	-7.088	0.525	1.16	-4.295	-6.083	-9.51	-8.33
ICMA 04999 x BIB-46	-6.706	-4.69	-16.535*	-9.27	10.573	4.524	8.794	4.17
ICMA 04999 x BIB-58	-9.8	-13.412	-9.711	-11.20	1.765	5.054	5.693	4.17
ICMA 04999 x BIB-65	-9.255	-12.727	-8.661	-10.43	7.575	10.912	11.42	8.33
ICMA 05444 x BIB-8	-10.542	-1.686	-10.131	-7.72	-1.098	1.334	-0.732	-4.17
ICMA 05444 x BIB-15	-15.491*	-7.721	-7.349	-10.43	-4.985	-2.189	-1.043	-4.17
ICMA 05444 x BIB-27	9.503	0.343	14.173	8.11	-15.689**	-7.234	-11.881*	-12.50
ICMA 05444 x BIB-46	-9.428	-0.791	-6.562	-5.79	4.752	6.774	12.961*	4.17
ICMA 05444 x BIB-58	-14.749*	-6.746	-9.186	-10.43	-1.212	2.425	5.473	0.00
ICMA 05444 x BIB-65	-14.13	-6.983	-8.136	-10.04	1.991	3.875	11.129	4.17
ICMA 06999 x BIB-8	-9.577	-14.73*	-15.486*	-13.13	-3.491	6.526	5.97	0.00
ICMA 06999 x BIB-15	-19.253**	-11.173	-15.879*	-15.444*	-2.37	3.706	5.583	0.00
ICMA 06999 x BIB-27	0.965	-15.415*	-4.987	-6.56	-18.975**	-9.682	-7.251	-12.50
ICMA 06999 x BIB-46	-4.974	-13.307	-9.449	-9.27	4.897	6.001	10.587	4.17
ICMA 06999 x BIB-58	-7.572	-15.178*	-9.843	-10.81	-1.027	3.3	0.563	0.00
ICMA 06999 x BIB-65	-13.388	-26.219**	-14.698	-18.147*	-2.658	7.967	5.329	0.00
JMSA 20042 x BIB-8	-13.017	-15.889*	-11.549	-13.51	-4.278	5.181	4.763	0.00
JMSA 20042 x BIB-15	-13.759	-13.202	-14.042	-13.90	8.006	6.055	8.673	4.17

JMSA 20042 x BIB-27	-4.232	-11.383	-0.525	-5.41	-17.463**	-2.927	-10.033	-12.50
JMSA 20042 x BIB-46	-13.14	-13.254	-7.743	-11.58	6.928	12.626*	17.086**	8.33
JMSA 20042 x BIB-58	-17.743*	-14.256*	-16.667*	-16.216*	5.821	6.774	5.597	4.17
JMSA 20042 x BIB-65	-19.574**	-19.394**	-12.205	-16.988*	9.657	12.855*	10.68	8.33
RHB-177	-2.796	-6.719	-3.15	-4.25	11.388	13.371*	14.072*	12.50
GHB-538	-18.362*	-12.833	-14.173	-15.444*	-1.574	2.189	10.126	0.00

***, ** Significant at 5% and 1% level of significance, respectively.**

Table 4.3.1.d: Estimates of standard heterosis (SH) over the best check for different characters in pearl millet in E_1, E_2, E_3 and over the environments

Crosses	Test weight				Dry Stover yield per plant			
	E_1	E_2	E_3	Pooled	E_1	E_2	E_3	Pooled
RMS 6A x BIB-8	-12.955	-3.321	1.064	-4.49	-17.14*	-4.627	2.348	-5.96
RMS 6A x BIB-15	-23.482	-32.472**	-34.397**	-30.337**	-6.84	-8.17	0.078	-4.88
RMS 6A x BIB-27	-17.004	0	-7.447	-7.87	-11.406	4.525	7.501	0.81
RMS 6A x BIB-46	-20.243	-8.856	-3.901	-11.24	-5.747	-6.413	-5.136	-5.69
RMS 6A x BIB-58	-8.907	-8.856	-7.447	-8.99	-14.198	-17.123**	-12.706**	-14.634*
RMS 6A x BIB-65	1.215	-1.845	-1.418	-1.12	0.953	-0.954	2.65	0.81
RMS 21A x BIB-8	-19.433	-4.428	-7.092	-10.11	-13.467	4.177	-6.639	-4.88
RMS 21A x BIB-15	-43.32**	-26.568*	-24.823**	-31.461**	-0.815	-1.171	1.493	0.00
RMS 21Ax BIB-27	-25.911	-9.963	-10.638	-15.73	3.515	2.8	-4.788	0.27
RMS 21A x BIB-46	-16.194	-12.915	-13.121	-14.61	-9.425	-8.592	-8.195	-8.67
RMS 21A x BIB-58	-26.721	-8.118	-4.61	-12.36	-22.549**	-14.56*	-13.605**	-16.531*
RMS 21A x BIB-65	-18.623	-10.701	-12.057	-13.48	-11.756	-6.249	1.795	-5.15
ICMA 843-22 x BIB-8	-4.858	0.369	6.738	1.12	-24.485**	-23.085**	-21.294**	-22.764**
ICMA 843-22 x BIB-15	-0.405	1.476	-13.121	-4.49	-5.477	-17.279**	4.777	-5.96

ICMA 843-22 x BIB-27	-2.024	8.118	1.773	2.25	-7.846	-8.588	-7.6	-8.13
ICMA 843-22 x BIB-46	-4.453	0	7.447	1.12	-20.165*	-26.126**	-16.855**	-21.138**
ICMA 843-22 x BIB-58	13.765	13.653	15.957*	14.61	-30.319**	-31.7**	-26.367**	-29.539**
ICMA 843-22 x BIB-65	-10.931	13.284	6.738	3.37	-18.039*	-25.491**	-10.351*	-17.886**
ICMA93333 x BIB-8	-40.891**	-17.712	-20.567**	-25.843*	-21.947*	-27.575**	-18.779**	-22.764**
ICMA93333 x BIB-15	-27.935	-23.985*	-22.695**	-24.719*	52.22**	43.088**	43.181**	45.799**
ICMA93333 x BIB-27	-8.907	-15.129	-14.184	-13.48	-0.57	-2.233	-3.962	-2.44
ICMA93333 x BIB-46	-37.247*	-8.487	-2.837	-15.73	-12.622	-15.707*	-10.99*	-13.008*
ICMA93333 x BIB-58	9.312	2.583	-16.667*	-2.25	10.967	5.207	9.77*	8.67
ICMA93333 x BIB-65	4.453	-11.07	-6.383	-4.49	4.094	3.524	-3.221	1.36
ICMA 97111 x BIB-8	3.644	-11.07	2.482	-2.25	-8.207	-14.904*	-6.414	-10.03
ICMA 97111 x BIB-15	-18.219	-13.284	-17.021*	-15.73	14.202	25.489**	12.571**	17.615**
ICMA 97111 x BIB-27	6.073	3.321	-0.709	2.25	5.336	-5.413	4.689	1.36
ICMA 97111 x BIB-46	8.097	0.369	2.837	3.37	-11.678	-1.04	-7.643	-6.50
ICMA 97111 x BIB-58	8.502	8.856	5.674	7.87	0.642	-15.966**	0.577	-5.15
ICMA 97111 x BIB-65	14.17	-7.38	5.319	3.37	-31.988**	-20.363**	-15.813**	-22.222**
ICMA 04999 x BIB-8	-19.028	-20.295	-28.014**	-22.47	-9.253	-22.268**	-14.022**	-15.447*
ICMA 04999 x BIB-15	-21.457	-20.664	-21.277**	-21.35	21.835*	24.014**	22.874**	23.035**

ICMA 04999 x BIB-27	-3.239	-16.605	-20.922**	-14.61	14.595	16.631**	11.145*	14.092*
ICMA 04999 x BIB-46	-15.789	-23.247*	-23.05**	-21.35	-20.793*	-8.353	-14.71**	-14.363*
ICMA 04999 x BIB-58	-17.814	2.214	-8.865	-7.87	-22.21**	-12.007	-22.984**	-18.97**
ICMA 04999 x BIB-65	-15.789	-10.701	-19.858*	-15.73	3.568	17.529**	-7.968	4.34
ICMA 05444 x BIB-8	-15.789	-11.07	-10.284	-12.36	0.519	2.022	-0.195	0.81
ICMA 05444 x BIB-15	-23.077	-17.343	-7.447	-15.73	34.351**	24.432**	29.397**	29.268**
ICMA 05444 x BIB-27	-19.838	-15.498	-11.702	-15.73	-4.796	13.802*	-4.694	1.63
ICMA 05444 x BIB-46	-4.453	-7.011	-3.901	-5.62	10.319	15.12*	7.257	10.84
ICMA 05444 x BIB-58	13.36	-18.081	7.092	0.00	9.782	11.977	9.36*	10.30
ICMA 05444 x BIB-65	-14.575	0.738	-10.284	-7.87	-9.854	-11.876	-12.92**	-11.65
ICMA 06999 x BIB-8	-32.389*	-2.214	-4.61	-12.36	-11.347	-6.827	-13.344**	-10.57
ICMA 06999 x BIB-15	-28.34	-17.343	-20.567**	-22.47	5.372	8.542	6.311	6.78
ICMA 06999 x BIB-27	-14.575	-1.476	-6.383	-7.87	13.669	18.01**	-5.345	8.67
ICMA 06999 x BIB-46	-10.121	6.273	1.773	0.00	-7.891	-9.123	-11.016*	-9.49
ICMA 06999 x BIB-58	8.097	15.498	9.22	11.24	-18.547*	-5.99	-18.512**	-14.092*
ICMA 06999 x BIB-65	-23.077	-2.583	-3.191	-8.99	-7.972	3.795	-7.33	-3.52
JMSA 20042 x BIB-8	-16.599	-4.059	6.028	-4.49	-28.018**	-21.416**	-29.183**	-26.016**
JMSA 20042 x BIB-15	-12.551	-7.749	-11.348	-10.11	-15.497	-9.852	-19.715**	-14.905*

JMSA 20042 x BIB-27	-14.575	-5.166	1.064	-5.62	-1.862	8.776	-1.564	1.90
JMSA 20042 x BIB-46	-7.692	6.273	9.22	3.37	-28.211**	-28.116**	-24.672**	-26.829**
JMSA 20042 x BIB-58	14.98	9.963	9.929	11.24	-23.42**	-34.312**	-25.391**	-27.913**
JMSA 20042 x BIB-65	11.336	14.391	7.801	11.24	-8.644	-21.508**	-11.162*	-14.092*
RHB-177	3.644	5.904	0.355	3.37	-23.563**	-25.587**	-14.807**	-21.138**
GHB-538	-19.028	-1.845	-5.319	-8.99	-1.916	10.425	-0.619	2.71

***, ** Significant at 5% and 1% level of significance, respectively.**

Table 4.3.1.e: Estimates of standard heterosis (SH) over the best check for different characters in pearl millet in E_1, E_2, E_3 and over the environments

Crosses	Grain yield per plant				Harvest index			
	E_1	E_2	E_3	Pooled	E_1	E_2	E_3	Pooled
RMS 6A x BIB-8	-12.64	0.661	51.571**	11.45	4.106	3.962	33.146**	13.08
RMS 6A x BIB-15	-28.023	-23.288*	11.994	-14.50	-17.774	-12.131	8.887	-7.69
RMS 6A x BIB-27	-11.355	15.362	41.125**	14.50	0.085	7.043	22.309*	9.62
RMS 6A x BIB-46	-14.498	-2.34	40.446**	6.87	-7.098	3.03	33.202**	8.85
RMS 6A x BIB-58	-34.513*	-23.263*	19.459	-13.74	-18.622	-5.309	26.015*	0.00
RMS 6A x BIB-65	2.128	7.051	68.821**	23.664*	0.426	5.628	42.969**	15.39
RMS 21A x BIB-8	-30.208*	-15.946	-7.824	-18.32	-15.028	-14.556	-1.102	-10.39
RMS 21A x BIB-15	-58.947**	0.29	38.47**	-6.11	-51.262**	1.15	25.822*	-8.46
RMS 21Ax BIB-27	-39.465**	24.258**	37.761**	9.16	-34.257**	13.871	30.946**	3.46
RMS 21A x BIB-46	-44.333**	-5.16	25.031	-8.40	-31.399*	2.686	25.528*	-1.54
RMS 21A x BIB-58	-53.531**	-5.899	31.154*	-9.16	-32.899**	7.021	35.529**	2.69
RMS 21A x BIB-65	-24.009	6.378	12.619	-0.76	-10.728	9.442	7.957	2.69
ICMA 843-22 x BIB-8	-6.496	9.014	24.788	9.16	16.83	26.307**	39.456**	27.308*

ICMA 843-22 x BIB-15	-29.08*	-14.952	18.562	-9.16	-19.849	2.123	9.763	-2.69
ICMA 843-22 x BIB-27	-0.97	21.466*	35.489**	18.32	5.661	21.274*	32.157**	19.62
ICMA 843-22 x BIB-46	-25.775	34.11**	27.746*	13.74	-5.067	46.827**	36.563**	26.923*
ICMA 843-22 x BIB-58	-42.966**	-32.766**	-37.37**	-37.405**	-14.148	-1.247	-12.245	-8.46
ICMA 843-22 x BIB-65	-47.343**	36.77**	1.28	0.76	-29.635*	47.543**	9.736	11.15
ICMA93333 x BIB-8	-68.133**	59.281**	-5.422	1.53	-51.644**	63.151**	12.079	10.39
ICMA93333 x BIB-15	-61.011**	-9.327	-8.781	-24.427*	-68.408**	-29.031**	-30.511**	-42.308**
ICMA93333 x BIB-27	-43.137**	-27.777**	29.795*	-15.27	-35.825**	-19.93*	24.855*	-11.54
ICMA93333 x BIB-46	-32.409*	-50.789**	37.34**	-19.08	-17.594	-33.512**	37.037**	-6.92
ICMA93333 x BIB-58	-73.114**	-60.395**	-24.746	-53.435**	-69.819**	-53.803**	-26.15*	-50.769**
ICMA93333 x BIB-65	-25.489	-12.576	35.873**	-2.29	-22.967	-11.427	28.143*	-3.08
ICMA 97111 x BIB-8	26.417	31.467**	25.005	27.481*	26.084*	33.357**	23.971*	28.462**
ICMA 97111 x BIB-15	0.676	-25.439**	9.808	-7.63	-9.113	-33.203**	-2.082	-15.77
ICMA 97111 x BIB-27	2.472	6.274	52.579**	18.32	-2.073	8.586	31.716**	12.31
ICMA 97111 x BIB-46	-13.68	-17.202	35.578**	-0.76	-1.971	-12.052	32.219**	4.62
ICMA 97111 x BIB-58	-16.804	-5.685	8.94	-4.58	-13.229	8.408	6.248	0.77
ICMA 97111 x BIB-65	35.441*	-6.504	9.769	10.69	59.231**	11.689	21.495	30.385**
ICMA 04999 x BIB-8	7.599	-28.812**	15.846	-4.58	13.577	-6.232	24.512*	9.62

ICMA 04999 x BIB-15	58.398**	-7.135	34.357**	24.427*	21.016	-19.116*	7.144	1.92
ICMA 04999 x BIB-27	55.733**	-29.488**	-34.349**	-6.11	24.638*	-31.519**	-34.858**	-13.85
ICMA 04999 x BIB-46	36.89*	-48.551**	14.146	-4.58	45.37**	-35.682**	24.121*	8.85
ICMA 04999 x BIB-58	-50.671**	-39.336**	-18.723	-36.641**	-29.916*	-24.177**	4.237	-17.31
ICMA 04999 x BIB-65	31.405*	-7.979	-8.525	3.05	19.118	-16.268	-0.561	0.39
ICMA 05444 x BIB-8	-32.112*	-37.682**	-14.824	-29.008*	-26.157*	-31.198**	-11.779	-23.462*
ICMA 05444 x BIB-15	-52.223**	-27.557**	4.019	-25.954*	-57.287**	-33.669**	-15.925	-36.154**
ICMA 05444 x BIB-27	-57.384**	-29.747**	-10.659	-32.824**	-47.538**	-30.449**	-5.199	-28.462**
ICMA 05444 x BIB-46	-37.968*	-48.323**	21.151	-24.427*	-36.889**	-46.512**	9.612	-26.538*
ICMA 05444 x BIB-58	-54.192**	-81.91**	-25.432	-57.252**	-50.96**	-78.551**	-26.389*	-53.846**
ICMA 05444 x BIB-65	-27.144	-9.848	35.064**	-1.53	-14.842	1.716	37.183**	6.92
ICMA 06999 x BIB-8	-18.956	16.739	80.8**	25.191*	-6.386	16.806*	66.45**	24.231*
ICMA 06999 x BIB-15	-50.76**	-2.559	33.061*	-6.87	-45.882**	-7.355	18.071	-12.31
ICMA 06999 x BIB-27	-26.461	3.664	27.921*	1.53	-28.825*	-8.899	24.406*	-5.39
ICMA 06999 x BIB-46	-14.018	-12.61	28.476*	-0.76	-3.888	-2.723	30.791**	6.92
ICMA 06999 x BIB-58	-25.684	-4.774	-16.106	-14.50	-6.823	0.812	2.227	-1.15
ICMA 06999 x BIB-65	0.912	55.33**	25.903	29.771*	6.646	30.713**	25.2*	21.538*
JMSA 20042 x BIB-8	-21.855	-7.322	9.033	-6.87	6.618	12.06	36.73**	17.69

JMSA 20042 x BIB-15	-3.812	-19.226*	10.755	-6.11	9.937	-7.629	26.873*	8.46
JMSA 20042 x BIB-27	-11.664	12.969	7.974	3.82	-7.88	2.593	7.14	0.77
JMSA 20042 x BIB-46	-32.551*	-15.133	23.712	-9.16	-4.49	11.986	42.706**	15.77
JMSA 20042 x BIB-58	-50.658**	-36.418**	-42.271**	-42.748**	-29.496*	-2.25	-18.47	-15.77
JMSA 20042 x BIB-65	-3.734	38.255**	12.896	17.56	4.019	44.231**	19.481	23.846*
RHB-177	-23.215	-14.748	32.109*	-3.82	0.47	9.833	37.287**	15.00
GHB-538	-48.404**	-12.846	10.296	-16.79	-39.654**	-15.96	8.26	-16.54

***, ** Significant at 5% and 1% level of significance, respectively.**

4.3.3 Plant height

The standard heterosis for plant height ranged from -19.544 (ICMA 06999 x BIB-15) to 10.657 (ICMA 843-22 x BIB-27) in E_1, -22.299 (ICMA 97111 x BIB-8) to 13.679 (ICMA 93333 x BIB-27) in E_2 and -19.38(ICMA 04999 x BIB-8) to 19.835 (ICMA 93333 x BIB-15) in E_3 .While over the environments heterosis ranged from -18.84 (ICMA 04999 x BIB-65) to 5.36 (ICMA 93333 x BIB-15) (Table 4.3.1.b).

It was observed that out of 54 crosses, the cross ICMA 93333 x BIB-15 (19.835%) in E_3 exhibited significant positive heterosis over superior check hybrid HHB-67 Improved (159.33 cm).

4.3.4 Number of effective tillers per plant

Higher number of effective tillers per plant is considered as a desirable trait. The estimates of standard heterosis ranged from -27.865 (ICMA 843-22 x BIB-15) to 6.674 (ICMA 843-22 x BIB-46) in E_1, -36.99 (ICMA 05444 x BIB-46) to 22.118 (ICMA 843-22 x BIB-65) in E_2 and -7.73 (RMS21A x BIB-27) to 47.29 (ICMA 06999 x BIB-8) in E_3. While over the environments range was from -20.0 (ICMA 97111 x BIB-46, ICMA 04999 x BIB-46, ICMA 04999 x BIB-58, ICMA 04999 x BIB-65, ICMA 05444 x BIB-8, ICMA 05444 x BIB-27, ICMA 05444 x BIB-46, ICMA 0699 x BIB-46 and JMSA 20042 x BIB-27) to 13.33 (ICMA 843-22 x BIB-46 and ICMA 843-22 x BIB-65) (Table 4.3.1.b).

Out of 54 crosses, 4 crosses RMS 6A x BIB-46 (35.37%), RMS 21A x BIB-15 (35.71%), ICMA 843-22 x BIB-65 (41.02%), and ICMA 06999 x BIB-8 (47.29%) in E_3 showed positively significant standard heterosis over superior check hybrid HHB-67 Imp. (Mean value 1.51).

4.3.5 Ear head length

The estimates of standard heterosis for ear head length ranged from -23.78 (RMS 6A x BIB-15) to 19.0 (RMS 21A x BIB-27) in E_1, -26.22 (ICMA 06999 x BIB-65) to 7.68 (ICMA 843-22 x BIB-27) in E_2 and -28.74 (RMS 6A x BIB-15) to 16.535 (RMS21Ax BIB-27) in E_3. While over the environments,

heterosis range was from -26.25 (RMS 6A x BIB-15) to 10.43 (RMS 21A x BIB-27) (Table 4.3.1.c).

Out of 54 crosses, the cross RMS 21A x BIB-27 in E_1 (19.00%) and E_3 (16.53%) exhibited desirable significant positive heterosis for this trait over superior check hybrid HHB-67 Improved (25.88 cm).

4.3.6 Ear head diameter

The magnitude of standard heterosis for ear head diameter ranged from -22.877 (ICMA 93333 x BIB-27) to 19.44 (ICMA 97111 x BIB-46) in E_1, -16.047 (ICMA 93333 x BIB-27) to 16.606 (ICMA 97111 x BIB-46) in E_2 and -13.73(RMS 6A x BIB-15) to 17.086 (JMSA 20042 x BIB-46) in E_3 , while over the environments range was from -20.83 (ICMA 93333 x BIB-27) to 16.67 (ICMA 97111x BIB-46) (Table 4.3.1.c).

Out of 54 crosses, two crosses viz., ICMA 97111 x BIB-58 (14.62%), ICMA 97111 x BIB-46 (19.44%) in E_1, three crosses JMSA 20042 x BIB-46 (12.63%), ICMA 97111 x BIB-46 (16.60%) and JMSA 20042 x BIB-65 (12.85%) in E_2, three crosses ICMA 05444 x BIB-46 (12.96%), ICMA 97111 x BIB-46 (14.84%), ICMA 843-22 X BIB-65 (12.04%) and JMSA 20042 x BIB-46 (17.08%) in E_3 showed significant positive standard heterosis. The cross ICMA 97111 x BIB-46 exhibited desirable significant positive standard heterosis in each environment as well as over the environments (16.66%) for this trait.

4.3.7 Test weight

The estimates of standard heterosis for test weight ranged from -43.32 (RMS 21A x BIB-15) to 14.98 (JMSA 20042 x BIB-58) in E_1, -32.47 (RMS 6A x BIB-15) to 15.498 (ICMA 97111 x BIB-46) in E_2 and -34.397(RMS 6A x BIB-15) to 15.957 (ICMA 843-22 x BIB-58) in E_3. On the basis of data pooled over three environments heterosis ranged from -31.461 (RMS 21A x BIB-15) to 14.61 (ICMA 843-22 x BIB-58) (Table 4.3.1.d).

Further, it was observed that out of 54 crosses, one cross ICMA 843-22 x BIB-58 (15.95%) in E_3 exhibited significant positive standard heterosis for this trait over HHB-67 Improved (8.889 g).

4.3.8 Dry stover yield per plant

The magnitude of standard heterosis for dry stover yield per plant ranged from -31.988 (ICMA 97111 x BIB-65) to 52.22 (ICMA 93333 x BIB-15) in E_1, -34.312 (JMSA 20042 x BIB-58) to 43.088 (ICMA 93333 x BIB-15) in E_2, -29.183 (JMSA 20042 x BIB-8) to 43.181 (ICMA 93333 x BIB-15) in E_3 and -29.53 (ICMA 843-22 x BIB-58) to 45.799 (ICMA 93333 x BIB-15) over the environments (Table 4.3.1.d).

The results revealed that out of 54 crosses, three crosses in E_1, six crosses in E_2, seven crosses in E_3, and five crosses over the environments showed significant positive standard heterosis for this trait. The cross ICMA 93333 x BIB-15 (52.22%) depicted the maximum standard heterosis followed by ICMA 05444 x BIB-46 (35.35%) in E_1. The cross ICMA 93333 x BIB-15 (43.08%) had the maximum standard heterosis followed by ICMA 97111 x BIB-15 (25.48%) in E_2. The cross ICMA 93333 x BIB-15 (43.18%) had the maximum standard heterosis followed by ICMA 05444 x BIB-15 (29.39%) in E_3. The cross ICMA 93333 x BIB-15 (45.79%) followed by ICMA 05444 x BIB-15 (29.26%) depicted the maximum standard heterosis over the environments.

The results further revealed that three crosses viz.,ICMA 93333 x BIB-15, ICMA 04999 x BIB-15, and ICMA 05444 x BIB-15 exhibited consistent significant positive heterosis over superior check hybrid HHB-67 Imp. in each environment as well as over the environments.

4.3.9 Grain yield per plant

The estimates of standard heterosis ranged from -73.114 (ICMA 93333 x BIB-58) to 58.398 (ICMA 04999 x BIB-15) in E_1, -81.9 (ICMA 05444 x BIB-58) to 59.281(ICMA 93333 x BIB-8) in E_2 , -42.27 (JMSA 20042 x BIB-58) to 80.80 (ICMA 06999 x BIB-8) in E_3 , while over the environments it ranged

from -57.252 (ICMA 05444 x BIB-58) to 29.77 (ICMA 06999 x BIB-65) (Table 4.3.1.e).

Out of 54 crosses, five crosses in E_1, eight crosses in E_2, twenty crosses in E_3 and five crosses over the environments exhibited significantly positive standard heterosis for grain yield per plant. The cross ICMA 04999 x BIB-15 (58.39%) had the maximum standard heterosis followed by ICMA 05444 x BIB-27 (55.73%) in E_1. The cross ICMA 93333 x BIB-8 (59.28%) had the maximum standard heterosis followed by ICMA 06999 x BIB-65 (55.33%) in E_2. The cross ICMA 06999 x BIB-8 (80.8%) had the maximum standard heterosis followed by RMS 6A x BIB-65 (68.82%) in E_3 .The cross ICMA 06999 x BIB-65 (29.77%) followed by ICMA 97111 x BIB-8 (27.48%) exhibited the maximum standard heterosis in over the environments over HHB-67 Imp. (13.068 g).

4.3.9 Harvest index

The magnitude of standard heterosis ranged from -69.819 (ICMA 93333 x BIB-58) to 59.231 (ICMA 97111 x BIB-65) in E_1, -78.55 (ICMA 05444 x BIB-58) to 63.151(ICMA 93333 x BIB-8) in E_2 , -34.858 (JMSA 04999 x BIB-27) to 66.45 (ICMA 06999 x BIB-8) in E_3. While on the basis of mean data pooled over three environments it ranged from -53.846 (ICMA 05444 x BIB-58) to 30.385 (ICMA 97111 x BIB-65) (Table 4.3.1.e).

The results further revealed that out of 54 crosses, 3, 9, 28, and 7 crosses showed significant positive standard heterosis in E_1, E_2, E_3 and over the environments, respectively. The cross ICMA 97111 x BIB-65 (59.23%) had the maximum standard heterosis followed by ICMA 97111 x BIB-8 (26.08%) in E_1. The cross ICMA 93333 x BIB-8 (63.15%) depicted the maximum standard heterosis followed by ICMA 843-22 x BIB-65 (47.54%) in E_2. The cross ICMA 06999 x BIB-8 (66.45%) had the maximum standard heterosis followed by JMSA 20042 x BIB-46 (42.70%) in E_3. However, the cross ICMA 97111 x BIB-65 (30.38%) had the maximum standard heterosis over the environments followed by ICMA 97111 x BIB-8 (28.46%).

It was also observed that the cross ICMA 97111 x BIB-8 exhibited consistent significant positive heterotic effect over superior check hybrid HHB-67 Imp. in all the environments as well as over the environments. Mean value of superior check hybrid HHB-67 Imp. was 26.04% for this trait.

4.4 PHENOTYPIC STABILITY ANALYSIS

(A) Pooled Analysis

The nature and extent of genotype (G) x environment (E) interactions were studied as per model proposed by Eberhart and Russell (1966). Pooled analysis of variance for phenotypic stability for grain yield and its components is presented in Table 4.4.1 The differences between genotypes were found to be significant for all the characters except number of effective tillers per plant. Similarly, the environments also exhibited significant differences among themselves. Significant G x E interaction was also observed for all the characters indicating non-linear effect of environment on the genotypes. Partitioning of the variance due to E + (G x E) indicated that environment linear contributed maximum to the G x E interaction. The mean squares due to G x E (linear) were significant for all the characters except number of effective tillers per plant, ear head diameter and dry stover yield per plant indicating that the variation in the performance of genotypes was due to the regression of genotypes on environments and hence predictable in nature. The mean squares due to pooled deviation (non-linear) were significant for all the characters except days to maturity, ear head diameter and test weight indicating role of unpredictable causes affecting stability.

(B) Mean performance and stability parameters

In the present investigation, model proposed by Eberhart and Russell (1966) was used for analysis of G x E interactions. It considered both linear (b_i) and non-linear (S^2d_i) components of G x E interaction for the prediction of performance of individual genotypes (parental line/hybrid). The stability parameters, such as regression coefficient (b_i) and deviation from regression

(S^2d_i) along with mean performance of genotypes for various characters were computed to assess the stability and suitability of performance over the different environments. The parameters are presented in Table 4.4.2.a to 4.4.2.c. The linear regression coefficient (b_i) was considered as a measure of responsiveness and deviation from regression (S^2d_i) as measure of stability.

The high mean performances of parents and crosses were decided on the basis of general mean. The character wise results are as under:

The stability analysis was done following the model of Eberhart & Russell (1966). According to this model, a stable genotype is one whose regression coefficient (b_i) equals to unity (b_i =1.0) and deviation from regression (S^2d_i) is zero. The desirability of a genotype is judged on the basis of these stability criteria together with the mean value of the character. The linear regression coefficient (b_i) was considered as a measure of responsiveness. A high value of regression coefficient (b_i) means the genotype is more responsive, such genotype may therefore, be recommended for highly favourable environments. The value of regression coefficient (b_i) around unity indicates its wider adaptability. If however regression coefficient (b_i) is low, the genotype may be grown only in poor environmental conditions.

Deviation from regression (S^2d_i) was considered as a measure of stability. If S^2d_i is significantly deviated from zero, will invalidate the linear prediction and non significant S^2d_i means the performance of a genotype for a given environment may be predicted. The mean performance, linear sensitivity coefficient (b_i) and non-linear sensitivity index (S^2d_i) for the present study are presented character wise in Tables 4.4.2.a, 4.4.2.b and 4.4.2.c.

4.4.1 Days to 50% flowering

Analysis of variance indicated that both linear and non-linear components of G x E interaction were significant for this trait (Table 4.4.1).

The means of genotypes ranged from 41.778 (JMSA 20042 x BIB-65) to 53.667 days (ICMA 93333 x BIB-58) and regression coefficient value (b_i) ranged from –3.94 (ICMA 06999 x BIB-65) to 17.59 (ICMA 93333 x BIB-27).

Table 4.4.1: ANOVA for stability for grain yield and its components

Source of variation	d.f.	Days to 50% flowering	Days to maturity	Plant height	Number of effective tillers / plant	Ear head length	Ear head diameter	Test weight	Dry Stover yield / plant	Grain yield / plant	Harvest index
Replication / Environment	6	1.015	0.820*	42.904	0.023	1.303	0.008	0.382	2.713	0.624	0.879
Genotypes(G)	56	19.500**	17.791**	259.422**	0.045	11.085**	0.093**	2.624**	85.322**	19.048**	72.156**
Env. + (G x E)	114	1.295*	10.242**	74.617	0.035	2.447**	0.015**	1.019**	12.724**	17.669**	35.954**
Environments (E)	2	3.698*	557.148**	298.797**	0.456**	42.329**	0.478**	34.909**	458.940**	458.797**	574.125**
Genotypes x Env.	112	1.252*	0.476*	70.614*	0.027*	1.735**	0.007*	0.413**	4.756*	9.792**	26.344*
Environments (Linear)	1	7.396**	1114.296**	597.595**	0.912**	84.657**	0.956**	69.818**	917.880**	917.594**	1148.249**
Genotypes x Env. (Linear)	56	1.711**	0.590*	88.402*	0.021	2.444**	0.008	0.590**	2.982	11.957*	34.652**
Pooled deviation	57	0.779**	0.354	51.899**	0.033**	1.008**	0.005	0.233	6.416**	7.493**	17.720**
Pooled error	336	0.439	0.282	30.270	0.010	0.601	0.005	0.174	0.940	0.402	1.265
Total	170	7.292	12.729	135.494	0.038	5.293	0.041	1.548	36.639	18.123	47.879

***, ** Significant at 5% and 1% level of significance, respectively.**

Table 4.4.2.a: Estimates of stability parameters for various characters in pearl millet

Genotypes	Days to 50% flowering			Days to maturity			Plant height		
	Mean	b_i	S^2d_i	Mean	b_i	S^2d_i	Mean	b_i	S^2d_i
RMS 6A x BIB-8	43.889	0.23	0.06	69.556	0.76	-0.27	150.456	0.46	4.79
RMS 6A x BIB-15	45.889	-2.33	-0.19	70.444	0.92	-0.26	153.000	-1.85	0.15
RMS 6A x BIB-27	45.556	-3.11	-0.30	72.222	1.04*	-0.29	160.756	0.82	-30.43
RMS 6A x BIB-46	43.556	-3.11	-0.30	70.889	0.93	-0.28	160.889	-1.76	182.57**
RMS 6A x BIB-58	44.000	-3.44	-0.43	72.111	0.99	-0.26	154.533	1.08	6.00
RMS 6A x BIB-65	42.889	-3.22	0.28	69.222	0.83	-0.25	153.678	1.00	86.36
RMS 21A x BIB-8	42.667	-2.16	-0.39	69.778	0.99	-0.26	155.811	3.54	3.26
RMS 21A x BIB-15	46.667	3.44	-0.43	70.889	0.93	-0.28	168.400	-4.15	204.04**
RMS 21Ax BIB-27	46.111	0.27	1.84*	72.444	0.99	-0.26	177.811	-0.08	2.30
RMS 21A x BIB-46	44.222	1.22	0.32	71.000	0.84	-0.07	154.578	3.17	-21.34
RMS 21A x BIB-58	45.889	5.05	-0.13	72.444	0.89	-0.21	167.367	-2.30*	-30.23
RMS 21A x BIB-65	43.556	2.39	-0.23	69.778	0.92	0.88*	151.733	3.88*	-30.41
ICMA 843-22 x BIB-8	43.667	0.39	-0.25	71.000	1.05	-0.22	158.500	5.05	164.99*
ICMA 843-22 x BIB-15	46.556	3.67	-0.12	71.222	0.93	-0.28	162.556	-1.88	-27.95
ICMA 843-22 x BIB-27	45.889	1.71	2.36*	73.333	1.02	0.22	176.300	4.86	-18.62
ICMA 843-22 x BIB-46	43.556	0.23	0.06	72.000	0.98	-0.28	155.822	1.27	-28.07
ICMA 843-22 x BIB-58	44.000	3.05	-0.10	73.333	1.02	0.22	158.478	0.65	3.11
ICMA 843-22 x BIB-65	42.667	-0.89	-0.33	69.778	1.02	-0.22	159.389	2.23	31.13

ICMA93333 x BIB-8	51.778	4.49	0.12	76.222	1.14	-0.28	148.744	-2.24	-23.67
ICMA93333 x BIB-15	53.222	1.61	-0.27	77.333	1.05	-0.22	178.911	-7.82*	-28.99
ICMA93333 x BIB-27	49.667	17.59*	-0.38	78.778	1.03	0.68	173.222	-0.18	2.29
ICMA93333 x BIB-46	43.778	-0.23	0.06	77.111	1.09	-0.28	159.267	2.15	-1.13
ICMA93333 x BIB-58	53.667	12.06	18.22**	78.000	1.30	0.47	155.111	0.00	129.1*
ICMA93333 x BIB-65	43.222	-0.56	-0.42	75.333	1.02	0.22	159.089	2.22	37.26
ICMA 97111 x BIB-8	44.000	-1.28	-0.44	69.667	0.98	-0.28	146.967	2.36	49.59
ICMA 97111 x BIB-15	47.333	2.55	-0.41	71.111	0.99	-0.26	161.044	2.00	121.26*
ICMA 97111 x BIB-27	45.556	2.10	1.05	73.111	0.99	-0.26	171.111	2.49	-11.67
ICMA 97111 x BIB-46	44.111	1.05	-0.07	71.889	1.17	0.00	148.289	5.75	-24.66
ICMA 97111 x BIB-58	44.000	1.88	3.32**	72.556	1.24	-0.25	162.433	3.72	57.60
ICMA 97111 x BIB-65	42.444	0.17	-0.38	70.000	0.91	0.37	150.178	2.32	24.92
ICMA 04999 x BIB-8	46.889	6.32	-0.23	73.222	1.11	-0.17	143.467	6.85*	-29.86
ICMA 04999 x BIB-15	46.222	4.94	0.01	74.222	1.35	-0.21	160.311	3.13	-25.43
ICMA 04999 x BIB-27	47.111	3.61	-0.28	75.444	1.20**	-0.29	158.300	3.31*	-30.25
ICMA 04999 x BIB-46	46.333	3.83	-0.35	73.111	0.96	0.11	142.733	3.16	-7.22
ICMA 04999 x BIB-58	46.778	2.33	-0.19	74.111	1.20**	-0.29	141.878	2.28	80.27
ICMA 04999 x BIB-65	45.333	0.78	0.36	72.444	1.02	-0.22	137.756	3.51	-16.84
ICMA 05444 x BIB-8	46.222	-0.17	-0.38	72.889	1.04*	-0.29	150.533	-0.39	-18.21
ICMA 05444 x BIB-15	48.222	-1.05	-0.07	75.000	0.98	-0.28	164.144	-1.75	-16.71
ICMA 05444 x BIB-27	49.000	-2.16	-0.39	77.000	0.84	-0.07	170.922	-2.45	-29.70
ICMA 05444 x BIB-46	47.556	-2.33	-0.19	75.556	1.00	-0.09	150.167	-1.59	-16.14

ICMA 05444 x BIB-58	47.444	1.05	-0.07	75.889	0.90	0.01	153.689	-2.06	-19.06
ICMA 05444 x BIB-65	46.444	0.56	-0.42	73.889	0.76	-0.27	151.356	1.93	-24.49
ICMA 06999 x BIB-8	45.333	-2.55	-0.41	74.111	1.06	0.21	144.700	2.48	-13.11
ICMA 06999 x BIB-15	48.111	-2.49	0.15	75.333	1.11	0.10	159.044	-7.35	234.54**
ICMA 06999 x BIB-27	47.556	3.67	-0.12	75.444	1.51	2.11**	161.822	-1.81	34.00
ICMA 06999 x BIB-46	45.222	-1.44	-0.42	74.000	1.21	3.60**	146.211	5.17	-27.74
ICMA 06999 x BIB-58	45.333	2.27	1.77*	74.667	1.28	2.34**	156.667	3.17	90.47*
ICMA 06999 x BIB-65	45.000	-3.94	0.43	72.667	1.15	0.86*	141.511	4.13*	-29.95
JMSA 20042 x BIB-8	42.889	-1.05	-0.07	70.889	0.72	-0.20	145.767	0.99	-30.37
JMSA 20042 x BIB-15	44.000	2.55	-0.41	70.556	0.96	-0.17	156.300	0.86	29.85
JMSA 20042 x BIB-27	44.778	0.17	-0.38	71.667	1.01	-0.01	162.789	2.42	114.98*
JMSA 20042 x BIB-46	42.333	-2.16	-0.39	70.222	0.76	-0.27	148.667	3.31	3.46
JMSA 20042 x BIB-58	43.111	-1.50	0.22	71.444	0.39	0.56	160.733	-0.82	98.95*
JMSA 20042 x BIB-65	41.778	1.44	-0.42	69.111	0.89	-0.21	156.322	0.41	-3.00
HHB-67 Improved	42.444	-0.72	-0.44	70.111	0.92	-0.26	169.845	1.05	97.09*
RHB-177	44.222	-0.17	-0.38	71.778	0.99	-0.26	159.333	0.11*	-30.46
GHB-538	48.000	0.39	-0.25	74.667	0.77	-0.28	156.400	-1.84	-28.38
population mean	**45.573**			**72.842**			**156.944**		
SE(Mean)	0.6243			0.4209			5.1		
b_i mean	1			1			1		
SE(b_i)	2.451			0.1346			2.2		

***, ** Significant at 5% and 1% level of significance, respectively.**

Table 4.4.2.b: Estimates of stability parameters for various characters in pearl millet

Genotypes	Number of tillers / plant			Ear head length			Ear head diameter		
	Mean	b_i	S^2d_i	Mean	b_i	S^2d_i	Mean	b_i	S^2d_i
RMS 6A x BIB-8	1.456	1.06	0.00	22.647	-0.22	-0.37	2.387	1.39	0.00
RMS 6A x BIB-15	1.426	0.40	0.11**	19.127	1.27	0.17	1.954	1.22	0.00
RMS 6A x BIB-27	1.310	0.77	0.01	24.344	1.57*	-0.61	2.049	1.39	0.00
RMS 6A x BIB-46	1.426	-0.99	0.02	20.833	1.06	-0.49	2.542	0.81	0.00
RMS 6A x BIB-58	1.473	-0.30	-0.01	21.633	3.94*	-0.54	2.463	1.17	0.00
RMS 6A x BIB-65	1.492	1.51	-0.01	20.996	0.44	-0.24	2.428	0.65	0.01
RMS 21A x BIB-8	1.546	1.75	0.06*	24.867	3.39	0.53	2.302	1.17	0.00
RMS 21A x BIB-15	1.380	-1.90	-0.01	24.322	0.37	-0.61	2.380	1.95	0.02*
RMS 21Ax BIB-27	1.270	1.34	0.04*	28.573	4.21	6.64**	2.099	2.34	0.02*
RMS 21A x BIB-46	1.376	2.09	0.00	24.691	1.54	-0.38	2.324	1.33	0.00
RMS 21A x BIB-58	1.473	-0.83	0.02	27.627	2.23	0.45	2.450	1.75	0.00
RMS 21A x BIB-65	1.460	1.48	-0.01	25.224	1.52	3.15*	2.356	1.65	0.00
ICMA 843-22 x BIB-8	1.627	2.52	0.04*	22.163	0.52	-0.53	2.434	1.55	0.01
ICMA 843-22 x BIB-15	1.318	-0.47	0.00	21.329	-0.48	-0.13	2.441	1.04	0.00
ICMA 843-22 x BIB-27	1.369	0.09	0.06*	27.534	1.53	1.23	2.181	0.35	0.00
ICMA 843-22 x BIB-46	1.701	2.99	0.05*	20.898	-0.01	-0.43	2.506	1.42	0.00
ICMA 843-22 x BIB-58	1.477	-0.11	0.02	22.140	0.47	-0.60	2.431	1.53	0.00
ICMA 843-22 x BIB-65	1.749	0.06	0.11**	22.200	0.63	-0.60	2.489	2.32	0.00

ICMA93333 x BIB-8	1.487	1.80	0.06*	21.411	-1.24	-0.16	2.314	2.69	0.01
ICMA93333 x BIB-15	1.293	1.93	0.00	22.607	-0.67	-0.34	2.286	1.99	0.00
ICMA93333 x BIB-27	1.272	-0.23	0.02	25.447	-0.46	0.10	1.940	1.34	0.00
ICMA93333 x BIB-46	1.253	1.64	0.07**	23.096	-0.78	1.40	2.348	1.66	0.05**
ICMA93333 x BIB-58	1.270	2.37	0.06**	21.931	-0.82	5.47**	2.286	0.78	0.00
ICMA93333 x BIB-65	1.399	1.22	0.06*	23.040	0.45	0.63	2.362	0.61	0.01
ICMA 97111 x BIB-8	1.388	1.55	0.04*	22.567	-1.35	-0.29	2.518	1.20	0.00
ICMA 97111 x BIB-15	1.251	2.10	0.05*	21.476	1.94	0.78	2.532	0.63	0.00
ICMA 97111 x BIB-27	1.272	0.76	-0.01	26.593	1.95	-0.33	2.169	0.58	0.00
ICMA 97111 x BIB-46	1.246	1.30	0.02	22.559	1.88*	-0.61	2.753	-0.40	0.00
ICMA 97111 x BIB-58	1.260	0.69	0.07*	24.062	0.15	0.45	2.639	-0.37	0.00
ICMA 97111 x BIB-65	1.459	2.15	0.03*	23.106	1.11	-0.60	2.572	0.28	0.00
ICMA 04999 x BIB-8	1.260	0.68	0.04*	23.351	2.66	1.08	2.494	0.60	0.01
ICMA 04999 x BIB-15	1.342	1.24	-0.01	22.616	0.74	0.53	2.467	0.21	0.00
ICMA 04999 x BIB-27	1.290	1.48	0.05*	26.178	3.52	-0.49	2.197	-0.42	0.00
ICMA 04999 x BIB-46	1.180	1.62	0.02	23.482	1.17	5.68**	2.541	-0.38	0.00
ICMA 04999 x BIB-58	1.243	0.53*	-0.01	23.047	1.37	-0.52	2.451	0.71*	0.00
ICMA 04999 x BIB-65	1.243	2.48	0.04*	23.242	1.34	-0.46	2.587	0.69	0.00
ICMA 05444 x BIB-8	1.241	1.80	-0.01	23.933	-0.14	1.49	2.349	0.34	0.00
ICMA 05444 x BIB-15	1.347	1.64	0.02	23.216	-0.41	-0.54	2.289	0.66	0.00
ICMA 05444 x BIB-27	1.236	1.71	0.02	27.962	2.03	3.34*	2.080	0.98	0.00
ICMA 05444 x BIB-46	1.249	0.78	0.06*	24.411	-0.21	0.25	2.547	0.98	0.00

ICMA 05444 x BIB-58	1.336	-0.48	0.06**	23.209	-0.31	-0.53	2.406	0.93	0.00
ICMA 05444 x BIB-65	1.357	1.02	0.00	23.333	-0.22*	-0.61	2.487	1.05	0.01
ICMA 06999 x BIB-8	1.497	-1.86	0.00	22.467	1.82	-0.17	2.426	1.58	0.00
ICMA 06999 x BIB-15	1.251	1.40	-0.01	21.864	-0.27	-0.09	2.409	1.23	0.00
ICMA 06999 x BIB-27	1.253	0.74	0.01	24.244	3.28	0.27	2.071	1.70	0.00
ICMA 06999 x BIB-46	1.203	0.78	0.03	23.511	2.19*	-0.61	2.522	0.70	0.00
ICMA 06999 x BIB-58	1.406	2.84	0.01	23.087	1.98	-0.44	2.377	0.56	0.00
ICMA 06999 x BIB-65	1.377	2.06	0.00	21.222	2.50	1.31	2.437	1.47	0.00
JMSA 20042 x BIB-8	1.429	1.87	0.00	22.393	1.19	-0.38	2.399	1.52	0.00
JMSA 20042 x BIB-15	1.314	-0.47	0.00	22.342	0.85	-0.48	2.531	0.07	0.00
JMSA 20042 x BIB-27	1.219	1.42	-0.01	24.496	1.69	1.75	2.116	1.66	0.02*
JMSA 20042 x BIB-46	1.340	-1.12	-0.01	22.927	0.68	0.14	2.641	1.38	0.00
JMSA 20042 x BIB-58	1.293	-0.25	-0.01	21.673	0.39	-0.35	2.498	0.21	0.00
JMSA 20042 x BIB-65	1.461	1.15	0.02	21.453	0.49	0.92	2.613	0.47	0.00
HHB-67 Improved	1.511	3.22	0.01	25.880	1.04	-0.54	2.353	0.16*	0.00
RHB-177	1.367	0.76	0.00	24.796	1.50	-0.55	2.659	0.53*	0.00
GHB-538	1.216	1.24	0.01	21.949	0.01	-0.58	2.438	1.39	0.01
population mean	**1.362**			**23.357**			**2.392**		
SE(Mean)	0.1284			0.7101			0.0516		
b_i mean	1			1			1.000		
SE(b_i)	1.4359			0.824			0.5632		

***, ** Significant at 5% and 1% level of significance, respectively.**

Table 4.4.2.c: Estimates of stability parameters for various characters in pearl millet

Genotypes	Test weight			Dry stover yield / plant			Grain yield / plant			Harvest index		
	Mean	b_i	S^2d_i	Mean	b_i	S^2d_i	Mean	b_i	S^2d_i	Mean	b_i	S^2d_i
RMS 6A x BIB-8	8.467	1.51	-0.13	34.681	2.03	3.6*	14.621	1.28	4.21**	29.352	0.68	0.07
RMS 6A x BIB-15	6.189	-0.11	-0.17	35.095	1.09	4.69*	11.215	0.82	1.12	24.032	0.79	-0.95
RMS 6A x BIB-27	8.189	1.43	0.13	37.161	2.20	0.17	15.039	1.46	-0.33	28.465	0.83	0.14
RMS 6A x BIB-46	7.944	1.60	-0.13	34.775	0.89	-0.76	13.956	1.17	1.79*	28.308	1.16	1.98
RMS 6A x BIB-58	8.144	0.76	-0.15	31.480	0.75	0.71	11.255	1.03	3.61**	25.953	1.30	4.84*
RMS 6A x BIB-65	8.822	0.58	-0.15	37.228	0.95	0.24	16.205	1.21	7.55**	29.963	1.04	6.49*
RMS 21A x BIB-8	8.000	1.50	-0.11	35.071	1.80	6.47**	10.745	0.85	1.12	23.255	0.45	-0.39
RMS 21A x BIB-15	6.122	1.63*	-0.18	36.852	1.02	-0.25	12.288	2.25	2.65**	23.775	3.02	5.79*
RMS 21Ax BIB-27	7.544	1.60	-0.15	37.044	0.65	2.95*	14.283	2.28	0.62	26.864	2.76*	-0.90
RMS 21A x BIB-46	7.644	0.85	-0.18	33.689	0.94	-0.92	12.045	1.68	0.33	25.600	2.16	0.97
RMS 21A x BIB-58	7.767	1.96*	-0.18	30.753	1.40	-0.79	11.887	1.93	2.23*	26.670	2.52	5.45*
RMS 21A x BIB-65	7.678	1.09	-0.17	35.008	1.57	4.68*	12.961	1.34	2.57**	26.659	1.22	12.8**
ICMA 843-22 x BIB-8	8.978	1.36	-0.02	28.456	0.90	-0.61	14.257	1.08	0.98	33.102	0.97	3.68*
ICMA 843-22 x BIB-15	8.511	0.21	0.41	34.684	0.80	36.28**	11.870	1.07	0.62	25.308	1.40	1.76
ICMA 843-22 x BIB-27	9.133	1.13	-0.02	33.944	0.86	-0.83	15.546	1.30	1.99*	31.091	1.21	3.47
ICMA 843-22 x BIB-46	9.000	1.36	0.04	29.122	0.64	5.81**	14.946	2.07	9.25**	32.999	2.66	28.79**
ICMA 843-22 x BIB-58	10.178	0.96	-0.12	26.044	0.76	1.42	8.210	0.56	3.59**	23.758	0.73	27.36**
ICMA 843-22 x BIB-65	9.200	2.00	0.17	30.277	0.76	16.8**	13.215	2.41	28.73**	28.883	3.45	87.51**

ICMA93333 x BIB-8	6.589	1.87	-0.03	28.489	0.63	5.15*	13.332	3.31	62.14**	28.700	5.03	116.6**
ICMA93333 x BIB-15	6.689	0.87	-0.17	53.844	0.74	-0.95	9.858	1.70	1.81*	14.999	1.98	0.76
ICMA93333 x BIB-27	7.744	0.32	-0.13	36.044	0.75	-0.83	11.084	1.23	11.96**	22.971	1.56	29.96**
ICMA93333 x BIB-46	7.522	2.66*	-0.18	32.059	0.77	0.94	10.581	0.57	39.45**	24.157	0.41	87.88**
ICMA93333 x BIB-58	8.700	-0.50	0.67*	40.058	0.78	0.83	6.070	0.81	5.17**	12.809	1.24	13.47**
ICMA93333 x BIB-65	8.478	-0.04	0.14	37.402	0.70	2.07	12.810	1.18	4.73**	25.153	1.31	15.77**
ICMA 97111 x BIB-8	8.733	0.42	0.95*	33.246	0.67	4.77*	16.732	0.77	14.95**	33.375	0.59	43.14**
ICMA 97111 x BIB-15	7.456	0.78	-0.14	43.382	1.49	10.14**	12.134	0.08	0.23	21.872	-0.49	2.61
ICMA 97111 x BIB-27	9.133	0.43	-0.17	37.411	0.54	7.00**	15.545	1.05	1.66*	29.162	1.11	-1.15
ICMA 97111 x BIB-46	9.211	0.41	-0.06	34.475	1.43	1.67	13.014	0.80	5.91**	27.204	0.39	15.49**
ICMA 97111 x BIB-58	9.567	0.70	-0.17	35.002	0.28	19.68**	12.462	0.89	0.53	26.212	1.27	12.94**
ICMA 97111 x BIB-65	9.222	0.00	1.04**	28.663	1.73	1.11	14.485	-0.34	2.29*	33.911	-1.72	20.28**
ICMA 04999 x BIB-8	6.878	0.17	-0.05	31.208	0.15	4.19*	12.461	-0.10	2.04*	28.500	-0.22	-0.23
ICMA 04999 x BIB-15	7.011	0.62*	-0.18	45.373	1.29	-0.95	16.304	-0.69*	-0.34	26.535	-1.25**	-1.24
ICMA 04999 x BIB-27	7.644	-0.36**	-0.18	42.107	1.05	0.88	12.343	-1.66	12.73**	22.375	-2.42	30.86**
ICMA 04999 x BIB-46	7.033	0.15	-0.14	31.605	1.49	1.44	12.494	-1.20	8.08**	28.327	-2.72	22.3**
ICMA 04999 x BIB-58	8.189	1.46	0.47	29.915	1.13	7.15**	8.290	0.76	-0.21	21.462	0.86	4.37*
ICMA 04999 x BIB-65	7.511	0.56	0.08	38.530	1.13	45.24**	13.537	-0.43	9.01**	26.050	-1.17	2.58
ICMA 05444 x BIB-8	7.800	0.99	-0.17	37.196	0.99	-0.74	9.252	0.39	-0.29	19.856	0.23	-0.93
ICMA 05444 x BIB-15	7.500	1.42	0.15	47.672	0.69	1.12	9.737	1.23	1.37*	16.632	1.51	1.21
ICMA 05444 x BIB-27	7.511	1.07	-0.12	37.530	1.67	22.38**	8.848	1.18	-0.30	18.612	1.32	5.12*
ICMA 05444 x BIB-46	8.433	0.69	-0.09	40.934	1.14	3.02*	9.864	0.61	21.76**	19.112	0.47	56.73**

ICMA 05444 x BIB-58	8.933	-0.10	3.61**	40.740	1.12	-0.64	5.645	-0.08	16.76**	11.998	-0.50	53.69**
ICMA 05444 x BIB-65	8.189	1.17	0.37	32.614	0.66	-0.93	12.858	1.26	3.39**	27.827	1.53	8.21**
ICMA 06999 x BIB-8	7.789	2.43	0.02	33.039	0.96	1.77	16.362	2.00	10.24**	32.291	2.06	27.02**
ICMA 06999 x BIB-15	6.944	1.13	-0.12	39.412	1.17	-0.76	12.245	1.95	1.61*	22.806	2.37	5.21*
ICMA 06999 x BIB-27	8.244	1.30	-0.05	40.065	0.55	38.46**	13.319	1.47*	-0.40	24.607	1.62	9.29**
ICMA 06999 x BIB-46	8.856	1.58	-0.04	33.432	0.71	-0.79	12.967	0.84	1.63*	27.836	0.78	3.82*
ICMA 06999 x BIB-58	9.867	1.03	-0.06	31.673	1.29	9.6**	11.188	0.91	9.57**	25.709	0.66	10.37**
ICMA 06999 x BIB-65	8.078	1.93	-0.13	35.552	1.38	7.21**	17.033	1.87	33.34**	31.552	1.40	25.31**
JMSA 20042 x BIB-8	8.500	1.94	0.08	27.260	0.91	3.04*	12.183	0.98	0.11	30.632	0.90	-1.20
JMSA 20042 x BIB-15	7.956	0.82	-0.15	31.367	0.88	5.66**	12.324	0.32	-0.29	28.237	-0.07	2.13
JMSA 20042 x BIB-27	8.367	1.56	-0.07	37.618	1.38	6.03**	13.609	1.14	8.56**	26.173	0.84	6.56*
JMSA 20042 x BIB-46	9.156	1.77	-0.17	26.958	0.82	0.11	11.926	1.19	1.98*	30.140	1.49	2.02
JMSA 20042 x BIB-58	9.911	0.53	-0.15	26.611	0.21	5.08*	7.526	0.63	3.4**	21.864	1.31	30.67**
JMSA 20042 x BIB-65	9.878	0.75	-0.08	31.741	0.25	7.18**	15.444	1.52	26.62**	32.196	1.92	70.73**
HHB-67 Improved	8.889	0.76	-0.17	36.903	0.95	-0.96	13.068	0.54	6.36**	26.040	0.29	14.38**
RHB-177	9.178	0.68	-0.12	29.071	0.97	8.35**	12.637	1.05	4.04**	29.934	1.11	-0.25
GHB-538	8.144	1.61	-0.07	37.944	1.49	7.01**	10.907	1.50	-0.27	21.740	1.65	2.92
population mean	**8.227**			**35.009**			**12.404**			**25.853**		
SE(Mean)	0.3413			1.791			1.9356			2.9765		
b_i mean	1.000			1.000			1.000			1.000		
SE(b_i)	0.4361			0.6312			0.6822			0.9379		

***, ** Significant at 5% and 1% level of significance, respectively.**

The estimate of S^2d_i significantly differed from zero for five genotypes. Therefore, these five genotypes were considered as instable (Table 4.4.2.a). Joint consideration of mean performance of genotypes pooled over three environments and stability parameters it was revealed that out of 52 stable genotypes, 24 genotypes, JMSA 20042 x BIB-65, JMSA 20042 x BIB-46, HHB-67 Improved, ICMA 97111 x BIB-65, RMS 21A x BIB-8, ICMA 843-22 x BIB-65, RMS 6A x BIB-65, JMSA 20042 x BIB-8, JMSA 20042 x BIB-58, ICMA93333 x BIB-65, RMS 6A x BIB-46, ICMA 843-22 x BIB-46, RMS 21A x BIB-65, ICMA 843-22 x BIB-8, ICMA93333 x BIB-46, RMS 6A x BIB-8, RMS 6A x BIB-58, ICMA 97111 x BIB-8, JMSA 20042 x BIB-15, ICMA 843-22 x BIB-58, ICMA 97111 x BIB-46, RHB-177, RMS 21A x BIB-46 and JMSA 20042 x BIB-27 had mean lower than population mean (45.573-0.624 = 44.948), regression coefficient equivalent to unity and S^2d_i equivalent to zero. This exhibited average stability and wider adaptability, therefore, most stable and desirable for earliness.

4.4.2 Days to maturity

Analysis of variance indicated that the linear component of G x E interaction was significant and non-linear component for this trait was non-significant (Table 4.4.1).

Among the genotypes, the means ranged from 69.111 (JMSA 20042 x BIB-65) to 78.778 days (ICMA93333 x BIB-27) and regression coefficient value (b_i) ranged from 0.39 (JMSA20042 x BIB-58) to 1.51 (ICMA06999 x BIB-27). Out of 57 genotypes, five genotypes significantly deviated from zero indicating their unpredictable behaviour and instability in performance (Table 4.4.2.a).

On the basis of mean and regression coefficient, 24 genotypes Viz, JMSA 20042 x BIB-65, RMS 6A x BIB-65, RMS 6A x BIB-8, ICMA 97111 x BIB-8, RMS 21A x BIB-8, ICMA 843-22 x BIB-65, ICMA 97111 x BIB-65, HHB - 67 Improved, JMSA 20042 x BIB-46, RMS 6A x BIB-15, JMSA 20042 x BIB-5, RMS 6A x BIB-46, RMS 21A x BIB-15, JMSA 20042 x BIB-8, RMS 21A x BIB-46, ICMA 843-22 x BIB-8, ICMA 97111 x BIB-15, ICMA 843-22 x BIB-15,

JMSA 20042 x BIB-58, JMSA 20042 x BIB-27, RHB-177, ICMA 97111 x BIB - 46, ICMA 843-22 x BIB-46, RMS 6A x BIB-58 had mean lower than population mean (72.84 – 0.42 = 72.42), regression coefficient equivalent to unity and S^2d_i equivalent to zero, hence exhibiting wider adaptability. One genotype (RMS 6A x BIB-27) had mean values lower than population mean and regression coefficient higher than unity, exhibiting below average stability, therefore, suitable for better environmental condition only.

4.4.3 Plant height

Analysis of variance indicated that both linear and non-linear components of G x E interaction were significant for this trait (Table 4.4.1).

The mean performance of genotypes ranged from 137.756 cm (ICMA 04999 x BIB-65) to 178.911 (ICMA 93333 x BIB-15). Ten genotypes out of 57 significantly deviated from zero ($S^2d_i \neq 0$). Therefore, these genotypes were considered as instable.

On the basis of mean performance and b_i values it was revealed that out of 47 stable genotypes, eight genotypes Viz., RMS 21A x BIB-27, ICMA 843-22 x BIB-27, ICMA 93333 x BIB-27, ICMA 97111 x BIB-27, ICMA 05444 x BIB-27, ICMA 05444 x BIB-15, ICMA 843-22 x BIB-15, ICMA 97111 x BIB-58 had higher plant height mean values as compared to the population mean (156.94 + 5.1 = 162.04 cm), regression coefficient equivalent to unity and S^2d_i equivalent to zero. These genotypes exhibited average stability and therefore most stable for tallness and considered as suitable for wider adaptability. Two genotypes Viz., ICMA93333 x BIB-15, RMS 21A x BIB-58 exhibited above average stability as these genotypes had higher mean values as compared to the population mean, regression coefficient less than unity and therefore, were suitable for poor conditions (Table 4.4.2.a).

4.4.4 Number of effective tillers per plant

The linear component of G x E interactions was non-significant and non-linear component for number of effective tillers per plant was significant (Table 4.4.1).

Amongst the genotypes, the mean ranged from 1.18 (ICMA 04999 x BIB-46) to 1.749 (ICMA 843-22 x BIB-65). The non-linear component (S^2d_i) significantly deviated from zero for 20 genotypes revealing their instability for this character (Table 4.4.2.b). Joint consideration of mean performance of genotypes pooled over three environments and b_i values, it was revealed that out of 37 stable genotypes three genotypes Viz., HHB-67 Improved, ICMA 06999 x BIB-8 , RMS 6A x BIB-65 had higher number of effective tillers per plant than population mean (1.36 + 0.13 = 1.49), regression coefficient equivalent to unity and S^2d_i equivalent to zero. These genotypes exhibited average stability therefore, considered as suitable for wider adaptability.

4.4.5 Ear head length

Analysis of variance indicated that both linear and non-linear components of G x E interaction were significant for ear head length (Table 4.4.1).

Amongst the genotypes, means ranged from 19.127 (RMS 6A x BIB-46) to 28.573 (RMS 21A x BIB-27). Non-linear component (S^2d_i) significantly deviated from zero in five genotypes, exhibiting their instability (Table 4.4.2.b). Joint consideration of mean performance of genotypes pooled over three environments and stability parameters it was found that out of 52 stable genotypes, nine genotypes exhibited higher ear head length mean values as compared to population mean (23.36 + 0.71 = 24.07 cm), b_i was unity and $S^2d_i \approx 0$. These genotypes were RMS 21A x BIB-58, ICMA 843-22 x BIB-27, ICMA 97111 x BIB-27, ICMA 04999 x BIB-27, HHB-67 Improved, ICMA93333 x BIB-27, RMS 21A x BIB-8, RHB-177 and RMS 21A x BIB-46. Hence, these genotypes were considered suitable for wider adaptability.

4.4.6 Ear head diameter

Both linear as well as non-linear components of G x E interactions were non -significant for this trait (Table 4.4.1).

Amongst the genotypes, means ranged from 1.94 (ICMA 93333 x BIB-27) to 2.753 (ICMA 97111 x BIB-46). On the basis of non-linear component (S^2d_i) four genotypes out of 57 evaluated genotypes were significantly deviated from zero ($S^2d_i \neq 0$) and remaining 53 genotypes exhibited $S^2d_i \approx 0$.Therefore, these genotypes were considered as instable and stable, respectively (Table 4.4.2.b). Joint consideration of mean performance of genotypes pooled over three environments and b_i values, it was revealed that out of 53 stable genotypes, 22 genotypes exhibited higher ear head diameter mean values as compared to the population mean (2.39 + 0.05 = 2.44 cm), b_i was unity and $S^2_{di} \approx 0$. These genotypes were ICMA 97111 x BIB-46, JMSA 20042 x BIB-46, ICMA 97111 x BIB-58, JMSA 20042 x BIB-65, ICMA 04999 x BIB-65, ICMA 97111 x BIB-65, ICMA 05444 x BIB-46, RMS 6A x BIB-46, ICMA 04999 x BIB-46, ICMA 97111 x BIB-15, JMSA 20042 x BIB-15, ICMA 06999 x BIB-46, ICMA 97111 x BIB-8, ICMA 843-22 x BIB-46, JMSA 20042 x BIB-58, ICMA 04999 x BIB-8, ICMA 843-22 x BIB-65, ICMA 05444 x BIB-65, ICMA 04999 x BIB -15, RMS 6A x BIB-58, RMS 21A x BIB-58 and ICMA 843-22 x BIB-15. Therefore, these genotypes were considered as suitable for widely adapted. Two genotypes Viz., RHB-177, ICMA 04999 x BIB-58 had mean values higher than population mean, regression coefficient was less than unity and $S^2d_i \approx 0$, exhibited above average stability. Hence, these genotypes were considered suitable for poor environmental conditions.

4.4.7 Test weight

Analysis of variance indicated that the linear component of G x E interaction was significant and non-linear component for test weight was non-significant (Table 4.4.1).

The mean performance of crosses ranged from 6.122 (RMS 21A x BIB-15) to 10.178 (ICMA 843-22 x BIB-58). Among the 57 genotypes, non-linear component (S^2d_i) significantly deviated from zero in four genotypes, exhibiting their instability (Table 4.4.2.c). On the basis of mean performance of genotypes pooled over three environments and stability parameters it was found that out of 53 stable genotypes, 15 genotypes exhibited higher test

weight than population mean (8.227 + 0.341= 8.568 g), b_i was unity and $S^2d_i \approx 0$. These genotypes were ICMA 843-22 x BIB-58, JMSA 20042 x BIB-58, JMSA 20042 x BIB-65, ICMA 06999 x BIB-58, ICMA 97111 x BIB-58, ICMA 97111 x BIB-46, ICMA 843-22 x BIB-65, RHB-177, JMSA 20042 x BIB-46, ICMA 97111 x BIB-27, ICMA 843-22 x BIB-27, ICMA 843-22 x BIB-46, ICMA 843-22 x BIB-8, HHB-67 Improved and ICMA 06999 x BIB-46. Therefore, these genotypes were considered suitable for wider adaptability.

4.4.8 Dry Stover yield per plant

The linear component of G x E interactions was non-significant and non-linear component for dry stover yield per plant was significant (Table 4.4.1).

Amongst the genotypes, the mean ranged from 26.044 (ICMA 843-22 x BIB-58) to 53.844 (ICMA 93333 x BIB-15). The non-linear component (S^2d_i) significantly deviated from zero for 28 genotypes revealing their instability for this character (Table 4.4.2.c). On the basis of mean performance of genotypes pooled over three environments and regression coefficient (b_i), it was revealed that out of 29 stable genotypes 13 genotypes Viz., ICMA 93333 x BIB-15, ICMA 05444 x BIB-15, ICMA 04999 x BIB-15, ICMA 04999 x BIB-27, ICMA 05444 x BIB-58, ICMA93333 x BIB-58, ICMA 06999 x BIB-15, ICMA93333 x BIB-65, RMS 6A x BIB-65, ICMA 05444 x BIB-8, RMS 6A x BIB-27, HHB-67 Improved, RMS 21A x BIB-15 had higher mean values than population mean (35.01 + 1.79 = 36.80 g), regression coefficient equivalent to unity and S^2d_i equivalent to zero. These genotypes exhibited average stability therefore, considered suitable for wider adaptability.

4.4.9 Grain yield per plant

Both linear as well as non-linear components of G x E interactions were significant for grain yield per plant (Table 4.4.1).

The mean performance of genotypes ranged from 5.46 g (ICMA 05444 x BIB-58) to 17.033 g (ICMA06999 x BIB-65). 40 Genotypes out of 57 significantly deviated from zero ($S^2d_i \neq 0$). Therefore, these genotypes were

considered as instable. On the basis of mean performance and regression coefficient (b_i), it was revealed that out of 17 stable genotypes, one genotypes Viz., RMS 6A x BIB - 27 had higher mean value as compared to the population mean (12.40 + 1.94 = 14.34 g), regression coefficient equivalent to unity and S^2d_i equivalent to zero. This genotype exhibited average stability, therefore, is the most stable for grain yield per plant and considered as suitable for wider adaptability. One genotypes Viz., ICMA 04999 x BIB - 15 had higher mean value as compared to the population mean, regression coefficient less than unity, exhibiting above average stability. Therefore, was suitable for poor environmental conditions (Table 4.4.2.c).

4.4.9 Harvest index

Analysis of variance indicated that both linear and non-linear components of G x E interaction were significant for this trait (Table 4.4.1).

Amongst the genotypes, the mean ranged from 11.998 (ICMA 05444x BIB-58) to 33.911 (ICMA 97111 x BIB-65). The non-linear component (S^2d_i) significantly deviated from zero for 35 genotypes revealing their instability for this character (Table 4.4.2.c). Joint consideration of mean performance of genotypes pooled over three environments and regression coefficient (b_i), it was revealed that out of 22 stable genotypes, six genotypes Viz., ICMA 843-22 x BIB-27, JMSA 20042 x BIB-8, JMSA 20042 x BIB-46, RHB-177, RMS 6A x BIB-8, ICMA 97111 x BIB-27 had higher mean values than population mean (25.85 + 2.98 = 28.83), regression coefficient equivalent to unity and S^2d_i equivalent to zero, exhibited average stability, therefore, considered as suitable for wider adaptability.

5. DISCUSSION

Pearl millet [*Pennisetum glaucum* (L.) R. Br.] is a most drought tolerant crop among all cultivated food grain crops. It is widely cultivated across the arid and semi arid tropics of Africa and Asia. It is highly cross pollinated crop with the advantages of huge genetic variability, protogyny and availability of efficient cytoplasmic genetic male sterility system. These characteristics offer great possibilities of crop improvement through commercial exploitation of heterosis. Heterosis in pearl millet has resulted in a substantial improvement in the productivity in relatively better environment. There is, however, still need to improve yield potential in harsh environment. Hence, it is imperative to follow a precise and directed breeding programme to exploit heterosis in harsh environment of western Rajasthan. In India, Rajasthan is having the largest area and production in the country. However, its productivity is very low. The average yield of pearl millet in North-Western part of Rajasthan is very low ranging from 3 to 4 q/ha. Due to unavailability of the high yielding hybrids for moisture stress condition, the productivity of pearl millet in North-Western Rajasthan is quite low. Such harsh situations require development of such genotypes which can give higher grain as well as fodder yield under moisture stress conditions. This is important as about 90 per cent of total area under pearl millet is rainfed.

The main objective in any plant breeding programme is to evolve promising and desirable varieties, possessing high yield potential. Sufficient success has been achieved by genetic manipulation in the improvement of cereals and it is now possible to augment the grain yield potential of pearl millet as well. Success of plant breeding programme is largely dependent on the extent of genetic variability present in the population. The genetic facts are inferred from phenotypic observations.

One of the major objectives of any plant breeding programme is to improve the yield potential of the crop under consideration. However, yield is a complex character with low heritability. To achieve this objective, basic information on nature and extent of genetic variation, combining ability,

heterosis and G x E interaction is required to design effective breeding programme.

Pearl millet is largely cultivated under rain fed conditions. In arid region of Rajasthan sowing of pearl millet in the beginning of July is considered to be normal. Farmers generally sow their crop at the onset of Monsoon from middle of June to end of July, which varies from location to location and year to year. Pearl millet faces drought at critical stages which affects its productivity to a great extent in North-Western Rajasthan. Continuous low rainfall pattern at critical stages occurred in North-Western Rajasthan. In the present investigation, therefore, the information has been obtained from the three different environments created by different number of irrigations with recommended dose of fertilizers on the basis of irrigations at critical stages (pre flowering, flowering and grain filling) which is expected to be useful in planning of breeding strategies to develop suitable hybrids for such an harsh environment with unique adaptation.

The crop breeders are interested in discovering potential combinations both for developing hybrids and to develop varieties by obtaining useful segregants. The *per se* performance of the parents is not always a good indication of their superior combining ability. Basic information on combining ability of parents, nature and extent of genetic variation and inheritance pattern of desired character etc. are very essential to design a fruitful breeding programme. Heterosis has been exploited effectively in pearl millet in relatively better environments. The most important aspect for the commercial exploitation of heterosis is to study the extent of heterosis present for agriculturally important traits with harsh arid environment.

For stabilizing the production, it is important that a variety has consistency in yield across the environments. A population of organisms has immediate fitness when its individuals are morphologically and physiologically equipped for growth and reproduction in a constant environment. Since, no environment is constant; all organisms attempt to cope with environmental heterogeneity through individual and population adaptability (Cook and Johnson, 1968). In out breeding species, high degree of stability is generally a

property of heterozygotes, while in self fertilizing crops the situation is not clear. Individual genotypes highly resistant to one or more classes of environmental stress may exist in both autogamons and allogamons species (Pederson, 1968).

The evaluation of genotypes x environmental interaction gives an idea of the stability or buffering ability of the population under study. Eberhart and Russell (1966) provided a model for estimation of stability parameters. In this model b_i (regression co-efficient) is the parameter of response and s^2d_i is the parameter of stability. This model being relatively simple is widely used for stability analysis. An ideal variety performs fairly well under average or poor environments and also responds favourably under better environments.

In the present investigation, the objective of the research was to identify suitable parents and stable desirable hybrid combinations using line x tester mating design. The experimental material comprised of 54 pearl millet hybrids generated by 9 male sterile lines (female lines) crossed with 6 genetically diverse restorer lines (male parents) in line x tester mating design. These 54 pearl millet hybrids along with three standard check hybrids were raised during *kharif*, 2015 at Agriculture Research Station, Bikaner. The material was evaluated in randomized block design with three replications in three different environments. The three different environments were created by manipulating different irrigation levels and fertilizer doses. Environment E_1, E_2 and E_3 were provided one, two and three irrigations, respectively. In each environment, the fertilizer doses of NPK were given as per the recommendations. The genotypes were evaluated to obtain information on various parameters of heterosis, combining ability and G x E interaction. Data were recorded on various morphological characters *viz.* days to 50% flowering, days to maturity, plant height (cm), number of effective tillers per plant, ear head length (cm), ear head diameter (cm), test weight (g), harvest index (%), dry stover yield per plant (g) and grain yield per plant (g).The data recorded on various characters were subjected to statistical analysis as per the standard procedure. The results thus obtained have been discussed with respect to the pertinent literature under the following heads:

(A) Analysis of variances

(B) Combining ability variances, effects and gene action

(C) Standard heterosis

(D) Phenotypic stability analysis

5.1 ANALYSIS OF VARIANCES

The pooled analysis of variance exhibited significant mean squares due to environments indicating appreciable variation among the environments selected for this investigation. Highly significant differences among crosses were observed for all the characters studied (Table 4.1.4). The experimental material possesses enough variability for the study planned. The crosses x environment interaction were significant for all the characters, indicating existence of diffrential responses of crosses to the varying environments. This is in conformity with the general belief that the genotypes x environment interactions are common in crop plant species (Allard and Bradshaw, 1964).

In view of significant crosses x environment interactions for all characters, the analysis of variance for individual environment was done for all the characters. The analysis of variance for individual environment indicated significant differences among crosses for all the traits indicating the sufficient variability for the traits studied (Table 4.1.1 to 4.1.3).

5.2 COMBINING ABILITY VARIANCES, EFFECTS AND GENE ACTION

Constant efforts are being made to improve yield and yield contributing characters through hybridization in pearl millet. Proper selection of parents is very crucial in any planned hybridization programme. Certain parents nick well, whereas other which appear equally good but produce poor progenies in combinations. Eventually, the lines, which produce good progenies on crossing, are of immense value to the plant breeder. In a crop improvement

programme, much of the success depends upon isolation of valuable gene combinations as determined in the form of lines with high combining ability.

The concept of general and specific combining ability as a measure of gene action was proposed by Sprague and Tatum (1942). The resulting total genetic variance is partitioned into the variance due to general combining ability and specific combining ability. The general combining ability is an average performance of a line in hybrid combination and can be recognized as a measure of additive gene action. On the other hand, specific combining ability is the deviation from expectation on the basis of average performance of lines involved and can be regarded as a measure of non-additive gene action. The line x tester analysis as proposed by Kempthorne (1957) is a powerful tool to discriminate good as well as poor combiners and choose appropriate parental material in breeding programme. Therefore, combining ability analysis was carried-out in the present study with a view to obtain useful information for selection of better parents and crosses for their further use in breeding programme. The information regarding nature and magnitude of gene action could also be obtained, which is useful in deciding breeding methodology aiming at exploitable fixable (additive) and non-fixable (non-additive) genetic variances.

In the present study, combining ability indicated that mean squares due to crosses were significant for all the traits in each environment as well as over the environments (Table 4.1.1 to 4.1.4) which revealed the sufficient diversity among the crosses. Partitioning of these mean squares into lines, testers and line x tester interaction revealed that the mean squares due to line, tester and line x tester were found to be significant for most of the traits in each environment as well as over the environments (Table 4.2.1 to 4.2.4) which indicated the differences among the parental lines used for the present study. Crosses x environment interaction were found highly significant for all the characters indicating the differential responses of the genotypes to the environments for all the traits. Significant mean squares due to L x E, T x E, (L x T) x E indicated their sensitivity to the environment and for this reason; estimates based over the environments might be biased.

The analysis of variance for combining ability in individual environments indicated that both GCA and SCA variances were highly significant for all the traits in all the three environments except GCA variances for days to maturity (E_3), number of effective tillers per plant (E_1,E_2 and E_3), test weight (E_2,E_3). While non significant SCA variances for days to maturity (E_1), plant height (E_2 and E_3) and number of effective tillers per plant (E_1). This indicated that these characters were controlled by additive as well as non-additive gene action. The present findings are in close agreement with the earlier reports of Yadav *et al.* (2002a), Patel *et al.* (2008b), Chotaliya *et al.* (2010), Chouhan *et al.* (2010a), Bhadalia *et al.* (2014) and Singh, P. *et al.* (2014).

Pooled analysis of variance for combining ability indicated that variances due to GCA and SCA were highly significant for all the characters except grain yield per plant, harvest index. Variances due to SCA were highly significant for all the characters except plant height, number of effective tillers per plant, grain yield per plant and harvest index. This showed that both the additive and non-additive gene action were involved in the governing of the characters expression. The magnitude of GCA variances was higher than SCA variances for all the characters except dry stover yield per plant indicating the preponderance of additive gene action in the inheritance of these attributes. Similar results were reported by Mohan *et al.*(1999), Yadav *et al.*(2002a), Chauhan *et al.* (2010a), Chotaliya *et al.* (2010), Jethva *et al.* (2011), Parmar *et al.(*2013), Yadav and Nijhawan (1994), Yadav *et al.*(2000).

Heritability(ns) was higher (>50%) for days to 50% flowering, days to maturity, plant height, ear head length, ear head diameter, test weight and dry stover yield / plant that means these characters were largely governed by additive genes and selection for improvement would be rewarding. While, the characters, number of effective tillers per plant, grain yield per plant and harvest index exhibited low heritability means preponderance of non- additive genes and heterosis breeding may be useful (Table 4.2.6).

Proportional contribution of line, tester and their interaction to total variance (%) is presented in Table 4.2.7. The Maximum contribution of lines to total variance was through days to maturity (78.78%) followed by days to 50%

flowering. The maximum contribution of tester to total variance was through ear head diameter (60.91%) followed by plant height while dry stover yield per plant (35.43%) displayed maximum contribution to total variance in line x tester.

From the present results it was evident that the additive and non-additive gene action was responsible in governing the characters. Therefore, recurrent selection or mass selection with concurrent random mating may also be adopted for population improvement to exploit additive gene action in the present material and heterosis breeding may be adopted to exploit non-additive gene action for improving these traits in pearl millet.

5.2.1 General Combining Ability (GCA) effects:

An understanding of the genetic control of the characters is the basic requirement for the purposeful management of the available genetic variability. Selection of the parents for hybridization is an important aspect in the crop improvement programme and the performance of varieties in a trial may give an idea of their relative superiority. Therefore, in any sound breeding programme, the proper choice of parents based on their combining ability is a pre-requisite. The choice of the most suitable breeding method would depend mainly on the combining ability behavior vis-à-vis nature of gene action involved in the control of the traits of interest to the breeder. The agronomic and quality characters which are of economic importance are generally controlled by a large number of genes, each having small individual effects resulting thereby in continuous variation. Comprehensive analysis of the combining ability involved in the inheritance of quantitative characters and in the phenomenon of heterosis is necessary for the evaluation of various possible breeding procedures (Allard, 1960).

Nature and magnitude of combining ability effects provide an idea about relative role of fixable and non-fixable gene effects in the inheritance of different characters. This in turn, helps in identifying suitable parents for crossing programme. The data on GCA effects indicated that the GCA effects

varied significantly for different characters. The high GCA effects in desirable direction for yield and its components indicated that such lines would combine well with other lines to produce superior progeny. The magnitude and direction of estimates of GCA and SCA effects in most of the cases for grain yield per plant also frequently changed from environment to environment, complicating the problem of identification of promising parents and crosses.

The best performing genotypes on the basis of GCA effects has been given In Table 5.2.1. In the present investigation, the GCA estimates of the parents were inconsistent for most of the characters in the three environments. This might be attributed to the presence of GCA x environment interaction. Thus, it is suggested that environment specific breeding for these characters would be effective. However, it was possible to identify some parents which exhibited consistent desirable GCA estimates across the environments.

A close examination of GCA effects of the parents revealed that none of the parents was found to be consistently good general combiner for all the characters. However, a number of parents (lines and testers) showed superior GCA performance for various characters in each environments as well as over the environments. Amongst the female lines, good general combiners were RMS 6A, ICMA 843-22, ICMA 97111, ICMA 04999 and ICMA 06999 for grain yield and yield attributing characters. While lines viz., JMSA 20042, RMS 6A, ICMA 843-22, ICMA 97111 and RMS 21A were found good general combiner for days to 50% flowering and days to maturity (Table 4.2.9.a to 4.2.9.e).

Amongst the testers, good general combiners were BIB-8, BIB-27 and BIB-65 for grain yield and its attributing characters. Not only this, these were found good general combiner for days to 50% flowering and days to maturity also (Table 4.2.9.a to 4.2.9.e). Tyagi *et al.*(1975), Maciel *et al.*(1987), Harer *et al.*(1990), Navale *et al.* (1991), Karad and Harer (2005), Sahane *et al.*(1997a), Mohan *et al.*(1999), Madhusudhana and Govila (2001), Lakshmana *et al.*(2003), Pethani *et al.* (2004), Lakshmana *et al.* (2011) and Singh *et al.*(2014) also observed various lines and testers having good combining ability behavior for yield and its attributing characters.

In general, it was observed that parents with high *per se* performance also had desirable high general combining ability effects. Since GCA effects are attributed to additive and additive x additive gene effects, the above mentioned parents are potential and can be used in hybridization programme for the improvement of respective characters (Griffing, 1956a and Sprague, 1966). Also these parents may be used in a multiple crossing programme to synthesize a dynamic population with accumulation of the most of the favourable genes (Griffing, 1956a).

5.2.2 Specific Combining Ability (SCA) effects:

Analysis of specific combining ability is an important aspect for judging the specific combinations in order to exploit them through heterosis breeding programme. The good specific cross combinations were selected based on their SCA effects. Variance due to specific combining ability represents dominance and epistatis and it is non-fixable (Griffing 1956 a and b) and is related to heterosis. In the present study, estimates of SCA effects revealed that none of cross combination was good for all the characters over all the environments, obviously due to the effect of environments on phenotypic expression.

Estimates of SCA effects further revealed that cross combination, ICMA 04999 x BIB-15 showed consistent positive and significant SCA effects for grain yield per plant in each environment as well as over the environments. Not only this, this cross also exhibited significant SCA effects for days to flowering, plant height, number of effective tillers per plant, test weight, dry stover yield per plant and harvest index.

Table 5.2.1: The best performing genotypes on the basis of GCA and SCA effects in pearl millet

S. No.	Characters	Env.	Parents		Crosses
			lines	Testers	
1	Days to 50% flowering	E_1	JMSA 20042	BIB-65	ICMA93333 x BIB-27
			ICMA 843-22	BIB-46	ICMA93333 x BIB-46
			ICMA 97111		ICMA93333 x BIB-65
		E_2	JMSA 20042	BIB-65	ICMA93333 x BIB-46
			RMS 6A	BIB-46	RMS 21A x BIB-8
			ICMA 843-22		ICMA04999 x BIB-15
		E_3	JMSA 20042	BIB-65	ICMA93333 x BIB-46
			RMS 6A	BIB-46	RMS 21A x BIB-8
			ICMA 97111		ICMA93333 x BIB-65
		Pooled	JMSA 20042	BIB-65	ICMA93333 x BIB-46
			RMS 6A	BIB-46	ICMA93333 x BIB-65
			ICMA 843-22		ICMA04999 x BIB-15
2	Days to maturity	E_1	RMS 6A	BIB-65	ICMA 05444 x BIB-8
			RMS 21A	BIB-8	
			ICMA 97111		
		E_2	RMS 6A	BIB-65	ICMA 05444 x BIB-8
			JMSA 20042	BIB-8	JMSA 20042 x BIB-58
			RMS 21A		
		E_3	JMSA 20042	BIB-65	ICMA04999 x BIB-46
			RMS 6A	BIB-8	
			RMS 21A		
		Pooled	JMSA 20042	BIB-65	ICMA 05444 x BIB-8
			RMS 6A	BIB-8	ICMA 97111 x BIB-8
			RMS 21A		ICMA 06999 x BIB-58
3	Plant height	E_1	ICMA 97111	BIB-27	ICMA04999 x BIB-15
			ICMA 843-22		ICMA06999 x BIB-58
		E_2	RMS 21A	BIB-27	ICMA93333 x BIB-15
			ICMA 843-22	BIB-15	JMSA 20042 x BIB-58
					ICMA06999 x BIB-15
		E_3	ICMA 93333	BIB-15	RMS 6A x BIB-46
			RMS 21A	BIB-27	ICMA93333 x BIB-15
			ICMA 05444		RMS 21A x BIB-58
		Pooled	RMS 21A	BIB-27	ICMA93333 x BIB-15
			ICMA 93333	BIB-15	RMS 6A x BIB-46
			ICMA 843-22		ICMA 04999 x BIB-15

S. No.	Characters	Env.	Parents		Crosses
			lines	Testers	
4	No of effective tillers /plant	E_1		BIB-65	ICMA 843-22 x BIB-46
				BIB-8	ICMA 06999 x BIB-58
					RMS 21A x BIB-8
		E_2	ICMA 843-22	BIB-65	ICMA 843-22 x BIB-46
			RMS 6A	BIB-8	ICMA 04999 x BIB-27
					ICMA93333 x BIB-8
		E_3	ICMA 843-22		ICMA 06999 x BIB-8
			RMS 6A		ICMA93333 x BIB-27
			RMS 21A		RMS 21A x BIB-15
		Pooled	ICMA 843-22	BIB-65	ICMA 843-22 x BIB-46
			RMS 6A	BIB-8	ICMA 843-22 x BIB-65
			RMS 21A		ICMA 04999 x BIB-15
5	Ear head length	E_1	RMS 21A	BIB-27	RMS 6A x BIB-58
			ICMA 04999		ICMA 843-22 x BIB-27
					RMS 21A x BIB-58
		E_2	ICMA 05444	BIB-27	ICMA 843-22 x BIB-27
			RMS 21A		RMS 21A x BIB-58
			ICMA 93333		RMS 6A x BIB-8
		E_3	RMS 21A	BIB-27	RMS 6A x BIB-8
			ICMA 05444		ICMA 97111 x BIB-58
					ICMA 05444 x BIB-27
		Pooled	RMS 21A	BIB-27	ICMA 843-22 x BIB-27
			ICMA 05444		RMS 21A x BIB-58
					RMS 6A x BIB-8
6	Ear head diameter	E_1	ICMA 97111	BIB-46	ICMA 843-22 x BIB-27
			ICMA 04999	BIB-65	JMSA 20042 x BIB-15
			JMSA 20042	BIB-58	
		E_2	ICMA 97111	BIB-46	RMS 21A x BIB-15
			JMSA 20042	BIB-65	RMS 6A x BIB-46
				BIB-58	ICMA 93333 x BIB-15
		E_3	ICMA 97111	BIB-46	RMS 21A x BIB-58
			RMS 6A	BIB-65	
			JMSA 20042	BIB-58	
		Pooled	ICMA 97111	BIB-46	RMS 6A x BIB-58
			JMSA 20042	BIB-65	RMS 6A x BIB-46
			ICMA 04999	BIB-58	JMSA 20042 x BIB-15

S. No.	Characters	Env.	Parents		Crosses
			lines	Testers	
7	Test weight	E_1	ICMA 97111	BIB-58	ICMA93333 x BIB-65
			ICMA 843-22	BIB-65	ICMA93333 x BIB-58
			JMSA 20042		ICMA 04999 x BIB-27
		E_2	ICMA 843-22	BIB-58	RMS 21A x BIB-8
			JMSA 20042	BIB-65	
		E_3	ICMA 843-22	BIB-58	ICMA 04999 x BIB-15
			JMSA 20042	BIB-46	ICMA 05444 x BIB-15
			ICMA 97111	BIB-65	RMS 6A x BIB-8
		Pooled	ICMA 843-22	BIB-58	RMS 21A x BIB-8
			JMSA 20042	BIB-65	ICMA 06999 x BIB-58
			ICMA 97111		RMS 6A x BIB-8
8	Dry stover yield /plant	E_1	ICMA 05444	BIB-15	ICMA93333 x BIB-15
			ICMA 93333	BIB-27	RMS 6A x BIB-65
			ICMA 04999		ICMA93333 x BIB-58
		E_2	ICMA 05444	BIB-15	ICMA93333 x BIB-15
			ICMA 04999	BIB-27	ICMA 04999 x BIB-65
			ICMA 93333		JMSA 20042 x BIB-27
		E_3	ICMA 05444	BIB-15	ICMA93333 x BIB-15
			ICMA 93333	BIB-27	ICMA93333 x BIB-58
			ICMA 97111		JMSA 20042 x BIB-27
		Pooled	ICMA 05444	BIB-15	ICMA93333 x BIB-15
			ICMA 93333	BIB-27	ICMA93333 x BIB-58
			ICMA 04999		JMSA 20042 x BIB-27
9	Grain yield / plant	E_1	ICMA 04999	BIB-65	ICMA 04999 x BIB-15
			ICMA 97111	BIB-27	ICMA 04999 x BIB-27
			RMS 6A	BIB-8	JMSA 20042 x BIB-15
		E_2	ICMA 06999	BIB-65	ICMA93333 x BIB-8
			ICMA 843-22	BIB-8	ICMA 843-22 x BIB-46
			ICMA 97111	BIB-27	ICMA 04999 x BIB-15
		E_3	RMS 6A	BIB-46	ICMA 06999 x BIB-8
			ICMA 06999	BIB-65	RMS 21A x BIB-58
			ICMA 97111	BIB-27	ICMA 04999 x BIB-15
		Pooled	ICMA 97111	BIB-65	ICMA 04999 x BIB-15
			ICMA 06999	BIB-8	RMS 21A x BIB-58
			RMS 6A	BIB-27	ICMA 843-22 x BIB-46

S. No.	Characters	Env.	Parents		Crosses
			lines	Testers	
10	Harvest index	E_1	ICMA 04999	BIB-65	ICMA 97111 x BIB-65
			ICMA 97111	BIB-8	JMSA 20042 x BIB-15
			RMS 6A	BIB-46	ICMA 06999 x BIB-58
		E_2	ICMA 843-22	BIB-65	ICMA93333 x BIB-8
			JMSA 20042	BIB-8	ICMA 843-22 x BIB-46
			ICMA 06999		ICMA 05444 x BIB-65
		E_3	ICMA 06999	BIB-46	ICMA 05444 x BIB-65
			RMS 6A	BIB-8	RMS 21A x BIB-58
			RMS 21A		ICMA 06999 x BIB-8
		Pooled	ICMA 843-22	BIB-65	ICMA 05444 x BIB-65
			ICMA 97111	BIB-8	RMS 21A x BIB-58
			JMSA 20042	BIB-46	ICMA 04999 x BIB-15

Apart from this, some other crosses were identified which posses significant SCA effects for yield and its attributing characters. These crosses were ICMA 06999 x BIB-65, ICMA 97111 x BIB-8, ICMA 06999 x BIB-8, ICMA 843-22 x BIB-46 and ICMA 843-22 x BIB-27 (Table 5.3.1). The present findings supported the results obtained by Kunjir and Patil (1986), Chavan and Nerkar (1994), Naik *et al.* (1996), Karale *et al*. (1998), Lakshmana *et al.* (2003), Yadav *et al.* (2002a), Unnikrishanan *et al.* (2004), Sushir *et al.* (2005), Karad and Harer (2005) and Dhuppe *et al.* (2006), Kumhar and Singhania (2007) and Khandagale *et al.*(2014).

SCA effects are primarily governed by dominance gene effects and cannot be fixed. However, if a cross combination has high SCA effect along with high *per se* performance and at least one good general combiner parent, it is expected that such a cross combination may offer desirable transgressive segregants in the later generations (Jinks and Jones, 1958).

5.3 STANDARD HETEROSIS:

Plant breeders have extensively explored and utilized heterosis in enhancing the yield in a number of crops. The possibility of commercial exploitation of hybrid vigour depends primarily on the magnitude of heterosis and feasibility of hybrid seed production at commercial scale. Pearl millet is a cross pollinated crop and mechanism of cyto-genetic male sterility is available to produce hybrid seed on a commercial scale and therefore, the heterosis *per se* is of economic significance. The extent of heterosis depends on the magnitude of non-additive gene action and wide genetic diversity among parents. Mackey (1976) described that superiority of hybrid over better parent might be either due to dominance or epistasis or over dominance or combined effects of two or more of these phenomenon. In any crop improvement programme, superiority of F_1 over standard check has an economic importance and is now widely used for expression of heterosis. For any hybrid to be acceptable for commercial cultivation, it must have sufficient level of superiority over the standard/best check. Such superiority is referred as standard heterosis. The negative heterosis is important for characters like earliness. Since, higher yields in F_1 may be due to fixable (additive) and non-fixable (non-additive) gene action, the partitioning of the total effect of F_1 progeny into general and specific combining ability effects deciphers the causes of heterosis. In the present study, standard heterosis was estimated for various characters over best check hybrid HHB 67 Improved in the trial, which is a widely cultivated hybrid of pearl millet.

The perusal of Table 4.3.1.a to 4.3.1.e indicated that several crosses performed differently in different environments for various characters. It was expected because of significant F_1 x environment interaction. Among the characters, maximum numbers of crosses with significant desirable standard heterosis were found for dry stover yield /plant, grain yield /plant and Harvest index. Sharma and Shrikant (2006) also reported standard heterosis for grain yield / plant and its component characters taking HHB-67 Improved as standard check.

The genotypes with early flowering and maturity have a special significance in the harsh environment of western Rajasthan. In the present experiment, though none of the cross exhibited desirable significant negative heterosis for days to 50% flowering and days to maturity, however for days to 50% flowering crosses viz., JMSA 20042 x BIB-65, JMSA 20042 x BIB-46, ICMA 97111 x BIB-65, ICMA 843-22 x BIB-65 and for days to maturity crosses JMSA 20042 x BIB-65, RMS 6A x BIB-65, ICMA 97111 x BIB-8, RMS 21A x BIB-8, ICMA 843-22 x BIB-65, RMS 21A x BIB-65 and JMSA 20042 x BIB-46 were found at par to the best check hybrid HHB-67 Imp.

Out of total 54 cross combinations studied, five crosses in E_1, eight crosses in E_2, twenty crosses in E_3 and five crosses over the environments indicated significant positive standard heterosis for grain yield per plant. The best five crosses over the environment were ICMA 97111 x BIB-8, ICMA 06999 x BIB-65, ICMA 06999 x BIB-8, ICMA 04999 x BIB-15 and RMS 6A x BIB-65. These crosses were also found superior for some other yield attributing characters. The crosses ICMA 97111 x BIB-8, ICMA 06999 x BIB-65 and RMS 6A x BIB-65 for harvest index, ICMA 04999 x BIB-15 for dry stover yield per plant and ICMA 06999 x BIB-8 for harvest index and number of effective tillers per plant were found superior. These crosses were considered promising for their use in yield improvement because of having high heterotic effect for yield as well as component characters. Similar results in varying environments for different characters were also reported by Deore *et al*. (1997), Kumhar (2007) Davda *et al.* (2008), Patel *et al.* (2008a), Vetriventhan *et al.*(2008), Vagadiya *et al.* (2010b), Devda *et al.* (2012), Bhadalia *et al*. (2013), Kathale *et al.*(2013), Kumar *et al.* (2013), Lone *et al.* (2013) and Parmar *et al.* (2015).

Crosses ICMA 06999 x BIB-65, ICMA 97111 x BIB-8, ICMA 06999 x BIB-8 showed significant positive standard heterosis for grain yield / plant and harvest index along with significant positive SCA effects and both the parents with high GCA effects. The cross ICMA 04999 x BIB-15 showed significant positive standard heterosis for grain yield / plant and dry stover yield /plant along with significant positive SCA effects for grain yield / plant that indicating potential for exploring hybrid vigour in breeding programme. Similar findings

have been reported by Sharma and Shrikant (2006), Kumhar (2007) and Kumar *et al.* (2013). It was suggested that yield being a complex trait and resulting from multiplicative interactions among various component characters and G x E interactions.

In the present study, comparison of SCA effects of top high yielding crosses and GCA effects of their parents indicated that, these crosses in general, had parents at least one parent with good GCA effects. In other words, two combiners with high GCA effects, except few exceptions, resulted in a combination with high SCA effects (Table 5.3.1). Hence, the presence of at least one good general combiner out of two parents appeared to be desirable for getting the better hybrids. Similar results have been reported by several workers Dass *et al.*(1985), Ahuja *et al.*(1989), Latha and Shanmugasundaram (1999), Talukdar and Praksh Babu, (1999) in pearl millet.

High SCA effects in crosses involving good x poor or good x average general combiners indicate the additive x dominance type of interaction and those crosses involving poor x poor combiners reflect complementary genes with over dominance effects. In present study, high x high combinations gave high SCA effects, similar to the reports of Karale *et al.*(1998) and Latha and Shanmugasundaram (1999), who reported hybrids with high SCA effects resulting from high x high combiners. Such results may be explained by the action of the additive x additive type of gene interaction and contribution of favourable genes by the parents. The results obtained indicated that the involvements of both additive and non-additive gene effects are important for improving grain yield and its component characters. The reports of Pethani and Kapoor (1990 and 1995) also showed that high x poor combinations gave high SCA effects.

Table 5.3.1: Promising crosses with high per se performance for grain yield per plant and their performance in related parameters

Best Crosses	Mean Grain yield / plant	Standard Heterosis	SCA effects	GCA Effects		Significant S.H. for other traits
				P1	P2	
ICMA 06999 x BIB-65	17.033	29.771*	1.312**	1.437**	1.868**	Harvest Index
ICMA 97111 x BIB-8	16.732	27.481*	1.757**	1.647**	0.912**	Harvest Index
ICMA 06999 x BIB-8	16.362	25.191*	1.598**	1.437**	0.912**	Harvest Index
ICMA 04999 x BIB-15	16.304	24.427*	4.15**	0.157	-0.418**	Dry Stover yield/plant
RMS 6A x BIB-65	16.205	23.664*	0.622	1.3**	1.868**	-
ICMA 843-22 x BIB-27	15.546	18.32	1.663**	0.592**	0.876**	-
ICMA 97111 x BIB-27	15.545	18.32	0.607	1.647**	0.876**	-
JMSA 20042 x BIB-65	15.444	17.56	1.407**	-0.246	1.868**	-
RMS 6A x BIB-27	15.039	14.5	0.448	1.3**	0.876**	-
ICMA 843-22 x BIB-46	14.946	13.74	1.932**	0.592**	0.006	Harvest Index

***, ** Significant at 5% and 1% level of significance, respectively.**

5.4 PHENOTYPIC STABILITY ANALYSIS:

One of the major objectives of plant breeding is to develop varieties /hybrids with consistently good performance in different environments, so that unfavourable effects of environments on yield are minimized. Two strategies have been suggested to minimize the extent of G x E interaction. The first is sub-division of highly heterogeneous into small homogenous zones but this may not be much use because genotype x irrigation levels interaction cannot be reduced by stratification of area. The second approach concern with the development of widely adapted varieties that interact less with the environment in which they are grown.

Low yield potential and inconsistent yield performance of the genotypes under varied environmental conditions due to high genotype x environmental interaction is the major factors of low productivity of field crops. Hence the identification of phenotypically stable genotypes is very important for commercial cultivation as well as for genetic improvement of crop varieties. Finlay and Wilkinson (1963) suggested linear regression (b_i) as a major of adaption. Eberhart and Russell (1966) emphasized the need for both linear (b_i) and non- linear (s^2d_i) components of genotype x environment interaction for judging phenotypic stability of the genotypes. In the present investigation, an attempt has been made to identify genotypes with high grain yield and stability in performance.

In the present study genotypes x environment interactions were significant for all the characters indicating the influence of environment on the expression of genotypes. Mean squares due to genotype x environment (linear) were significantly higher than the mean squares due to pooled deviations for days to flowering, plant height, ear head length, ear head diameter, test weight, grain yield /plant and harvest index. This indicated that prediction across the environments was possible only for these characters. However, for rest of the characters prediction could still be made considering the values b_i and s^2d_i for individual genotypes.

Pooled deviation also showed significance for most of the characters. It has been stated by Dabholkar (1998) that when the mean square for pooled

deviation is significant but mean square for genotype x environment (linear) is non-significant, variation in the performance of genotypes is entirely unpredictable. On the other hand, significance of mean square for pooled deviations, when mean square for genotypes x environment (linear) is also significant, implies that part of the variability is unpredictable in nature. Similar findings have been reported by Nandanwankar *et al.* (1983), Dahiya *et al.* (1987), Suryavanshi *et al.* (1991), Van Oosterom *et al.* (1996), Shrikant et *al.* (2000), Yahaya *et al.* (2006), Pabale *et al.* (2010) and Abuali *et al. (*2014).

Table 5.4.1: Best stable crosses for different environments

S. No	Characters	Better Environment	Poor environment	Average Environment
1.	Days to 50% flowering	-	-	1. JMSA 20042 x BIB-65 2. JMSA 20042 x BIB-46 3. ICMA 97111 x BIB-65
2.	Days to maturity	1. RMS 6A x BIB-27	-	1. JMSA 20042 x BIB-65 2. RMS 6A x BIB-65 3. RMS 6A x BIB-8
3.	Plant height	-	1. ICMA 93333 x BIB-15 2. RMS 21A x BIB-58	1. RMS 21A x BIB-27 2. ICMA 843-22 x BIB-27 3. ICMA 93333 x BIB-27
4.	Number of effective tillers per plant	-	-	1. ICMA 06999 x BIB-8 2. RMS 6A x BIB-65
5.	Ear head length	-	-	1. RMS 21A x BIB-58 2. ICMA 843-22 x BIB-27 3. ICMA 97111 x BIB-27
6.	Ear head diameter	-	1. ICMA 04999 x BIB-58	1. ICMA 97111 x BIB-46 2. ICMA 04999 x BIB-15 3. ICMA 97111 x BIB-58
7.	Test weight	-	-	1. ICMA 843-22 x BIB-58 2. JMSA 20042 x BIB-58 3. JMSA 20042 x BIB-65
8.	Dry stover yield per plant	-	-	1. ICMA 93333 x BIB-15 2. ICMA 05444 x BIB-15 3. ICMA 04999 x BIB-15
9.	Grain yield per plant	-	1. ICMA 04999 x BIB-15	1. RMS 6A x BIB-27
10.	Harvest Index	-	-	1. ICMA 843-22 x BIB-27 2. JMSA 20042 x BIB-8 3. JMSA 20042 x BIB-46

- Better environment (Below average stability) : mean > μ, $b_i > 1$ and $S^2d_i = 0$
- Poor environment (Above average stability) : mean > μ, $b_i < 1$ and $S^2d_i = 0$
- Average environment (Average stability) : mean > μ, $b_i = 1$ and $S^2d_i = 0$

Among the stable crosses, three best stable crosses were mentioned in table 5.4.1 for consideration of their suitability under different environments.

Joint consideration of mean performance of genotypes pooled over three environments and stability parameters, it was revealed that out of 24 widely adapted genotypes, crosses viz., JMSA 20042 x BIB-65, JMSA 20042 x BIB-46 and ICMA 97111 x BIB-65 were most stable and desirable for earliness, if an average environment is provided. All these hybrids were stable for early flowering across a wide range of environments.

For early maturity, among the crosses one cross viz., RMS 6A x BIB-27 was stable for better environment. It had low mean value than population mean with b_i value greater than unity and S^2d_i equivalent to zero, therefore suitable for better management conditions. The crosses JMSA 20042 x BIB-65, RMS 6A x BIB-65 and RMS 6A x BIB-8, out of 24 widely adapted genotypes found stable for early maturity. These crosses had low mean value than population mean with b_i value equal to unity and S^2d_i equivalent to zero, therefore suitable for average management conditions.

Plant height is one of the important characters in order to get good biomass yield. In the present study, crosses ICMA 93333 x BIB-15 and RMS 21A x BIB-58 were considered for poor environments (higher mean than population mean, b_i <1 and s^2d_i =0). While out of eight widely adapted crosses, three best crosses viz., RMS 21A x BIB-27, ICMA 843-22 x BIB-27 and ICMA 93333 x BIB-27 (higher mean than population mean, b_i=1 and s^2d_i =0), were considered stable for average environments.

In pearl millet, numbers of effective tillers per plant, ear head length, ear head diameter, test weight are considered as important yield contributing characters. Stable and high mean performances of these characters in varying environments can ensure better yield results. Crosses ICMA 06999 x BIB-8 and RMS 6A x BIB-65 for number of effective tillers per plant, RMS 21A x BIB-58, ICMA 843-22 x BIB-27and ICMA 97111 x BIB-27 for ear head length, ICMA 97111 x BIB-46, JMSA 20042 x BIB-46 and ICMA 97111 x BIB-58 for ear head diameter, and ICMA 843-22 x BIB-58, JMSA 20042 x BIB-58 and JMSA 20042 x BIB-65 for test weight were found suitable for average

management conditions (higher mean than population mean, b_i=1 and s^2d_i =0). While, the cross ICMA 04999 x BIB-58 for ear head diameter was considered as suitable for poor management conditions as it had high mean value than population mean with b_i value less than unity and S^2d_i equivalent to zero.

Dry stover yield per plant is a desirable feature for sustainable production of pearl millet in western Rajasthan. In the present investigation, the crosses ICMA 93333 x BIB-15, ICMA 05444 x BIB-15 and ICMA 04999 x BIB-15 had high mean value than population mean with b_i value equal to unity and S^2d_i equivalent to zero. Obviously, were considered suitable for average management conditions.

In the present investigation, prime focus was on improving good grain yield per plant. Crosses having high mean grain yield per plant can be obtained through SCA and heterosis results, but they may not have stable performances across the environments. Through stability estimates we have been able to extract some of the crosses which are not only good in yield performances but also found stable in performances across the environments. For grain yield per plant, among the crosses one cross viz., RMS 6A x BIB-27 was desirable for all the three stability parameters (i.e. higher grain yield/plant than population mean, b_i =1 and s^2d_i =0), therefore, suitable for average management conditions. However, the Cross ICMA 04999 x BIB-15 had higher mean and stable (s^2_{di} =0) for grain yield /plant with b_i value less than unity, exhibiting above average stability, therefore was suitable for poor management conditions. This cross also showed stability for some of the important yield components viz., ear head diameter and dry stover yield /plant under average environmental conditions.

The crosses ICMA 843-22 x BIB-27, JMSA 20042 x BIB-8 and JMSA 20042 x BIB-46 had high mean value than population mean for harvest index with b_i value equal to unity and S^2d_i equivalent to zero, therefore suitable for average management conditions. Similar findings for yield and its attributing characters were reported by Nandanwankar *et al.*(1983), Pethani and kapoor (1985), Dahiya *et al.*(1987), Bidinger *et al.*(1987), Mahalakshmi *et al.*(1987),

Gupta and Ndoye (1991), Van Oosterom *et al.*(1996), Abuali *et al.*(2014) and Ezeaku *et al.*(2014).

Correlation analysis between mean, b_i and s^2d_i *inter se* are presented in Table 5.4.2 In general, the correlation between mean and b_i was found to be significant and positive, indicating that the genotypes with high yield were also having high b_i values making them more suitable for better environments. On the other hand, very low or no correlation between mean & s^2d_i and between b_i & s^2d_i was found which indicated that the mean, b_i and s^2d_i are not directly related, suggesting that selection for stability might be easier. Since the high mean and b_i showed positive association this would warrant more rigorous selection for genotypes which have high mean value as well as stable in performance.

Table 5.4.2: Correlation coefficient between mean and b_i, mean and S^2d_i, b_i and S^2d_i

Characters	**Mean & b_i**	**mean &** S^2d_i	**b_i &** S^2d_i
Days to 50% flowering	0.501**	0.407**	0.405**
Days to maturity	0.430**	0.259*	0.385**
Plant height	-0.42**	0.16	-0.22*
Number of tillers / plant	0.23	0.222*	0.128
Ear head length	0.402**	0.336**	0.185
Ear head diameter	0.343**	-0.142	0.333**
Test weight	-0.89	0.193	-0.3*
Dry stover yield / plant	0.149	0.046	-0.065
Grain yield / plant	0.189	0.118	0.257*
Harvest index	0.066	0.043	0.250*

***, ** Significant at 5% and 1% level of significance, respectively.**

In practical plant breeding, it is usually desired to identify genotypes with higher mean performance, desired linear response and low non-linear sensitivity coefficient. If these three important parameters of adaptation are controlled by different genetic systems then such desired genotypes may be bred through conventional breeding procedures. In the present investigation positive but non-significant association between mean performance and linear response (b_i) for grain yield /plant was observed. This indicated that these two parameters are controlled by different genetic systems.

Implication of the present findings to future pearl millet breeding improvement programme

In arid and semi-arid tropics of the country low and erratic behaviour of rainfall adversely effects the yields in pearl millet. Such harsh situations require development of such genotypes which can give higher grain as well as fodder yield under moisture stress conditions. Hence the breeder is expected to develop varieties that have wider adaptability to varying environments. In the present study, the ANOVA indicated that sufficient variability for the traits was present among the crosses and significant crosses x environment interaction for all the characters, indicated that environments influenced the expression of genotypes significantly.

Because of the presence of significant genotype x environment interaction, the results of three environments were not consistent for most of the characters. The results of the present study also revealed that in general both additive (fixable) and non-additive (unfixable) gene actions are involved in the inheritance of the grain yield and its components. It could be concluded that an appreciable progress could therefore be obtained in pearl millet through heterosis breeding and varietal development programmes for these characters. The choice of the breeding material or the method should be based on the information obtained from multi-environment experiments as the genotype x environment interaction was significant. Pearl millet improvement in the country is at a stage where large number of hybrids and a few composites are released for commercial cultivation in relatively better

environment, while only a very few hybrids are released for drought prone areas.

Development of high yielding varieties of pearl millet has led to increased productivity and stability largely in the regions with relatively better environments, while regions like Western Rajasthan, with arid and semi arid environment, still suffers from low productivity due to moisture stress. Hence, it needs identification of genotypes with stability in performance under the fluctuating environments.

Combining ability of the parents and their *per se* performance showed that the tester BIB-8, BIB-27 and BIB-65 were found to be better general combiner for grain yield per plant in each environment as well as over the environments. For rest of the characters tester BIB-8 was found to be desirable for days to flowering, days to maturity, number of effective tillers per plant and harvest index; BIB-27 for plant height, ear head length, dry stover yield per plant; BIB-65 for days to flowering, days to maturity, number of effective tillers per plant, ear head diameter, test weight and harvest index. Therefore, these can be used for the development of synthetic populations.

Amongst the female lines, good general combiners were RMS 6A, ICMA 843-22, ICMA 97111, ICMA 04999 and ICMA 06999 for grain yield and yield attributing characters. While lines viz., JMSA 20042, RMS 6A, ICMA 843-22, ICMA 97111 and RMS 21A were found good general combiner for days to 50% flowering and days to maturity. MS line ICMA 06999 also good general combiner for grain yield per plant in E_2, E_3 and over the environments. For rest of the characters line RMS 6A was also found to be desirable for days to flowering, days to maturity, number of effective tillers per plant and harvest index; MS line ICMA 97111 for days to flowering, days to maturity, ear head diameter, harvest index and MS line ICMA 06999 for harvest index and dry stover yield per plant. The B line of the above mentioned male sterile line can be used in hybridization programme for the improvement of respective trait and development of new B lines.

Among the crosses based on the per se performance of grain yield per plant and SCA effects the combination ICMA 04999 x BIB-15 (4.15) was the

best specific combination for grain yield per plant in each environment as well as over the environments with some other yield attributing traits. It was followed by combinations, ICMA 06999 x BIB-65, ICMA 97111 x BIB-8, ICMA 06999 x BIB-8, ICMA 843-22 x BIB-46 and ICMA 843-22 x BIB-27 (Table 5.3.1).

The possibility of commercial exploitation of hybrid vigour depends primarily on the magnitude of heterosis and feasibility of hybrid seed production at commercial SCAle. Present study indicated that crosses ICMA 97111 x BIB-8, ICMA 06999 x BIB-65, ICMA 06999 x BIB-8, ICMA 04999 x BIB-15, RMS 6A x BIB-65 having significant standard heterosis in more than one environment with some other yield attributing characters. These crosses were considered promising for their use for yield improvement because of having high heterotic effect for yield as well as some other component characters.

Crosses ICMA 06999 x BIB-65, ICMA 97111 x BIB-8, ICMA 06999 x BIB-8 showed significant positive standard heterosis for grain yield / plant and harvest index with high per se performance, highly significant positive SCA effects and were having both the parents with high GCA effects for grain yield /plant. The cross ICMA 04999 x BIB-15 showed significant positive standard heterosis for grain yield / plant and dry stover yield /plant along with high significant positive SCA effects for grain yield / plant that indicating potential for exploring hybrid vigour in breeding programme.

In the present study genotypes x environment interactions were significant for all the characters indicating the influence of environment on the expression of genotypes. Joint consideration of mean performance and stability parameters for grain yield per plant revealed that one cross viz., RMS 6A x BIB-27 was desirable for all the three stability parameters, suitable for average management conditions and cross ICMA 04999 x BIB-15 was suitable for poor management conditions. This cross showed stability for some of the important yield components e.g. ear head diameter and dry stover yield /plant.

It is concluded from present investigations that, one cross viz., ICMA 04999 x BIB-15 had high per se performance, high standard heterosis, high significant SCA effect and showed stability for grain yield /plant (s^2d_i =0 and b_i = less than unity). Hence, suitable for poor management conditions and thus could be included in multilocational testing programme to identify the suitability as commercial hybrid in arid and semi arid regions of Rajasthan.

6. SUMMARY

The present study was under taken with the objectives of assessing the magnitude of combining ability, variances, effects and gene action for grain yield and its contributing characters, standard heterosis and to identify phenotypically stable crosses suitable for arid zone in pearl millet [*Pennisetum glaucum* (L.) R. Br.]. Nine MS lines were crossed with six restorer lines in line x tester mating design to develop 54 F_1 hybrids. The 54 F_1 hybrids and three commercial hybrid checks were evaluated in Randomized Block Design with three replications under three different environments created by different irrigation levels with different recommended doses of fertilizers during *Kharif,* 2015 at Agriculture Research Station Beechhwal, Bikaner. Observations were recorded on ten characters viz., days to 50 percent flowering, days to maturity, plant height, number of effective tillers per plant, ear head length, ear head diameter, test weight, grain yield per plant, dry stover yield per plant and harvest index. Combining ability variances, effects and gene action for grain yield and its contributing characters, standard heterosis were estimated. The stability parameters were also computed using the model proposed by Eberhart and Russell (1966). The important findings and conclusions are summarized as follows:-

1. Pooled analysis of data revealed significant difference among the crosses for all the characters studied. Significant differences among the environments were also observed indicating the influence of environments on the characters expression. The crosses x environment interaction were significant for all the characters, indicating existence of differential responses of crosses to the varying environments and thereafter further statistical analysis was done environment wise. The analysis of variance for individual environment indicated significant differences among crosses for all the traits indicating the sufficient variability for the traits studied.
2. Combining ability indicated that mean squares due to crosses were significant for all the traits in each environment as well as over the environments which revealed the sufficient diversity among the crosses.

Partitioning of these mean squares into lines, testers and line x tester revealed that the mean squares due to line, tester and line x tester were found to be significant for most of the traits in each environment as well as over the environments which indicated the differences among the parental lines used for the present study. Crosses x environment interaction were found highly significant for all the characters indicating the differential responses of the genotypes to the environments for all the traits.

3. The analysis of variance for combining ability in individual environments indicated that both GCA and SCA variances were highly significant for all the traits in all the three environments except GCA variances for days to maturity (E_3), number of effective tillers per plant (E_1, E_2 and E_3), test weight (E_2,E_3). While non significant SCA variances for days to maturity (E_1), plant height (E_2 and E_3) and number of effective tillers per plant (E_1). This indicated that these characters were controlled by additive as well as non-additive gene action. The magnitude of GCA variances was higher than SCA variances for all the characters except dry stover yield per plant indicating the preponderance of additive gene action in the inheritance of the attributes.

4. Pooled analysis of variance for combining ability indicated that variances due to GCA and SCA were highly significant for all the characters except grain yield per plant, harvest index. Variances due to SCA were highly significant for all the characters except plant height, number of effective tillers per plant, grain yield per plant and harvest index. This showed that both the additive and non-additive gene action was involved in the governing of the characters expression. The magnitude of GCA variances was higher than SCA variances for all the characters except dry stover yield per plant indicating the preponderance of additive gene action in the inheritance of these attributes.

5. From the present results it was evident that the additive and non additive gene action was responsible in governing the characters. Therefore, recurrent selection or mass selection with concurrent random mating may also be adopted for population improvement to

exploit additive gene action in the present material and heterosis breeding may be adopted to exploit non-additive gene action.

6. A close examination of GCA effects of the parents revealed that none of the parents was found to be consistently good general combiner for all the characters. However, a number of parents (lines and testers) showed superior GCA performance for various characters in each environment as well as over the environments. Amongst the female lines, good general combiners were RMS 6A, ICMA 843-22, ICMA 97111, ICMA 04999 and ICMA 06999 for grain yield and yield attributing characters. While lines viz., JMSA 20042, RMS 6A, ICMA 843-22, ICMA 97111 and RMS 21A were found good general combiner for days to 50% flowering and days to maturity. Amongst the testers, good general combiners were BIB-8, BIB-27 and BIB-65 for grain yield and its attributing characters. Apart from this, these were found good general combiner for days to 50% flowering and days to maturity also. Therefore, these good general combiner parents for grain yield and other yield contributing characters can be used in hybridization programme for the improvement of respective characters. Also these parents may be used in a multiple crossing programme to synthesize a dynamic population with accumulation of the most of the favourable genes.

7. Estimates of SCA effects further revealed that cross combination viz., ICMA 04999 x BIB-15 showed consistent positive and significant SCA effects for grain yield per plant in each environment as well as over the environments. This cross also exhibited significant SCA effects for days to flowering, plant height, number of effective tillers per plant, test weight, dry stover yield per plant and harvest index. Apart from these, some other crosses were identified which posses significant SCA effects for grain yield and its attributing characters. These crosses were ICMA 06999 x BIB-65, ICMA 97111 x BIB-8, ICMA 06999 x BIB-8, ICMA 843-22 x BIB-46 and ICMA 843-22 x BIB-27. However, if a cross combination has high SCA effect along with *per se* performance with at least one good general combiner parent for a particular trait, it is

expected that such a cross combination may offer desirable transgressive segregates in the later generations.

8. Based on the standard heterosis, the best five crosses ICMA 97111 x BIB-8, ICMA 06999 x BIB-65, ICMA 06999 x BIB-8, ICMA 04999 x BIB-15 and RMS 6A x BIB-65 were identified superior over best check HHB 67 improved for grain yield per plant with some other yield attributing characters. The crosses ICMA 97111 x BIB-8, ICMA 06999 x BIB-65 and RMS 6A x BIB-65 for harvest index, ICMA 04999 x BIB-15 for dry stover yield per plant and ICMA 06999 x BIB-8 for harvest index and number of effective tillers per plant were found superior. These crosses were considered promising for their use in yield improvement because of having high heterotic effect for yield as well as component characters.

9. When comparison was made between combining ability and standard 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 and L x L.

10. Crosses ICMA 06999 x BIB-65, ICMA 97111 x BIB-8 and ICMA 06999 x BIB-8 showed significant positive standard heterosis for grain yield / plant and harvest index with high per se performance, highly significant positive SCA effects and were having both the parents with high GCA effects for grain yield /plant. The cross ICMA 04999 x BIB-15 showed significant positive standard heterosis for grain yield / plant and dry stover yield /plant along with high significant positive SCA effects for grain yield / plant that indicating potential for exploring hybrid vigour in breeding programme.

11. In the present study genotypes x environment interactions were significant for all the characters indicating the influence of environment on the expression of genotypes. Mean squares due to genotype x environment (linear) were significantly higher than the mean squares due to pooled deviations for days to flowering, plant height, ear head length, ear head diameter, test weight, grain yield /plant and harvest index. This indicated that prediction across the environments was possible only for these characters. However, for rest of the characters

prediction could still be made considering the values b_i and s^2d_i for individual genotypes.

12. Joint consideration of mean performance of genotypes pooled over three environments and stability parameters it was revealed that for grain yield per plant among the crosses one cross viz., RMS 6A x BIB-27 was desirable for all the three stability parameters (i.e. higher grain yield/plant than population mean, b_i =1 and s^2d_i =0) therefore, suitable for average management conditions. However, the Cross ICMA 04999 x BIB-15 had higher mean and stable (s^2d_i =0) for grain yield /plant with b_i value less than unity, exhibiting above average stability, therefore was suitable for poor management conditions. This cross also showed stability for some of the important yield components e.g. ear head diameter and dry stover yield /plant under average agronomical conditions.

13. In present investigation, the Cross ICMA 04999 x BIB-15 exhibited higher mean and stability (s^2d_i =0) for grain yield /plant with b_i value less than unity, exhibiting above average stability, therefore was suitable for poor management conditions. This cross also showed stability for some of the important yield components e.g. Ear head diameter and dry stover yield /plant under average agronomical conditions. Thus it is suggested that this cross may be tested in multilocational trials for their suitability for commercial cultivation in arid and semi- arid regions of Rajasthan.

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Genetics and Phenotypic Stability Studies in Pearl Millet [*Pennisetum glaucum* (L.) R. Br.]

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ABSTARCT**

Nine Male Sterile lines (Female) and six genetically diverse restorer lines (Male pollinator) of Pearl millet [*Pennisetum glaucum* (L.) R. Br.] were crossed into Line X Tester design to develop 54 hybrids during *Summer*, 2015 at ICRISAT, Hyderabad. These hybrids along with three standard checks were evaluated in RBD with three replications under three different environments created by different irrigation numbers (E_1, E_2 and E_3) with different recommended dose of fertilizers during *Kharif,* 2015 at Agriculture Research Station Beechhwal, Bikaner. Observations were recorded on ten characters viz., days to 50 percent flowering, days to maturity, plant height, number of effective tillers per plant, ear head length, ear head diameter, test weight, grain yield per plant, dry stover yield per plant and harvest index. Combining ability, variances, effects and gene action for seed yield and its contributing characters, standard heterosis and phenotypic stability parameters were also computed.

Pooled analysis of data revealed that significant difference among the crosses for all the characters studied. The crosses x environment interaction were significant for all the characters, indicating existence of diffrential responses of crosses to the varying environments and thereafter further statistical analysis was done environment wise. The analysis of variance for individual environment indicated significant differences among crosses for all the traits indicating the sufficient variability for the traits studied

The estimate of GCA and SCA variances were significant for most of the traits in all the environments indicating the importance of both additive and non-additive gene effects in the inheritance of these characters. However the magnitude of GCA variances was higher than SCA variances for all the characters except dry stover yield per plant indicating the preponderance of additive gene action in the inheritance of the attributes. On the basis of GCA effects parents RMS 6A, ICMA 843-22, ICMA 97111, ICMA 04999, ICMA 06999, BIB-8, BIB-27 and BIB-65 were better general combiners for grain yield per plant and other yield contributing characters in all the environments as well as over the environments. Crosse ICMA 04999 x BIB-15 showed consistent positive and significant SCA effects for grain yield per plant in each environment as well as over the environments.

Cross combinations ICMA 06999 x BIB-65, ICMA 97111 x BIB-8, ICMA 06999 x BIB-8 and ICMA 04999 x BIB-15 showed significant positive standard heterosis for grain yield / plant with high per se performance, highly significant

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positive SCA effects and were having both the parents with high GCA effects for grain yield /plant.

The joint regression analysis indicated the importance of unpredictable components along with predictable components of G x E interaction. Crosses RMS 6A x BIB-27 and ICMA 04999 x BIB-15 had higher grain yield per plant and showed stability for better management conditions and poor management conditions, respectively.

In present investigation, the cross Viz., ICMA 04999 x BIB-15 having high per se performance with high standard heterosis and stability for grain yield /plant (S^2d_i=0 and b_i = less than unity) with suitability for poor management conditions thus, it is suggested that this cross may be tested in multlocational trials for their suitability for commercial cultivation in arid and semi- arid regions of Rajasthan.

बाजरा [*पेनिसेटम ग्लॉकम* (एल.) आर. बीआर.] की आनुवांशिकी एवं प्रारुपीय स्थायित्वता का अध्ययन

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अनुक्षेपण

बाजरा [*पेनिसेटम ग्लॉकम* (एल.) आर. बीआर.] की नौ मादा जीन प्रारूपों को छः नर जीन प्रारूपों से पंक्ति X परीक्षक पद्वती द्वारा ग्रीष्म ऋतु 2015 मे अर्ध शुष्क प्रदेशो के लिये अन्तराष्ट्रीय फसल शोध संस्थान, हैदराबाद पर संकरित कर नये संकर तैयार किये गये। परिणामित 54 संकरो को तीन मानक संकरो के साथ यादृच्छित खण्ड अभिकल्पना में तीन पुनरार्वतन सहित, तीन अलग–अलग वातावरणो जो की सिंचाई की संख्या के आधार पर तैयार किये गये थे, के अर्न्तगत कृषि अनुसंधान केन्द्र, बीछवाल, बीकानेर पर खरीफ 2015 में बोये गये। वर्तमान अध्ययन हेतु दस विभिन्न लक्षणो जैसे– पुष्पन अवधि, परिपक्वता अवधि, पौधो की ऊचाँई, प्रभावी कल्लो की संख्या, सिटटे की लम्बाई, सिटटे की मोटाई, एक हजार दानो का भार, दानो की उपज, शुष्क चारे की उपज एवं उपज सूचक के लिये आंकडे एकत्रित किये गये। संयोजी क्षमता विभिन्नताये, प्रभाव, जीन क्रिया, मानक संकर ओज एवं प्रारूपीय स्थायित्व के मापको का अध्ययन किया गया।

विभिन्नताओ के एक साथ विश्लेषण से ज्ञात हुआ की सभी संकर एंव संकर X वातावरण सम्बन्ध सभी लक्षणो के लिये सार्थक पाये गये। इसलिये आगे प्रत्येक वातावरण के लिये विश्लेषण पृथक रूप से किया गया। संकरो ने प्रत्येक वातावरण में सभी लक्षणो के लिये सार्थक विभिन्नता दर्शायी।

सामान्य संयोजी क्षमता, प्रभाव एवं विशिष्ट संयोजी क्षमता, प्रभावो के लिये भिन्नता के विश्लेषण सभी वातावरण में दोनो योज्य एवं अयोज्य जीन प्रारूपों के महत्तव वाले लक्षणो की वंशागति में सार्थक पाये गये। यधपि शुष्क चारा प्रति पौधे के अलावा सभी लक्षणो के लिये योज्य जीन क्रिया की प्रबलता अंकित की गई।

सामान्य संयोजी क्षमता प्रभावो के आधार पर आर.एम.एस.–6ए, आई.सी.एम.ए.–843–22, आई.सी.एम.ए.–97111, आई.सी.एम.ए.–04999, आई.सी.एम.ए.–06999 (मादा जनक) एवं बी.आई.बी.–8, बी.आई.बी.–27, बी.आई.बी.–65 (नर जनक) विभिन्न लक्षणो के लिये सभी वातावरणो में अच्छे सामान्य संयोजक पाये गये। संकर आई.सी.एम.ए.–04999 X बी.आई.बी.–15 ने सभी वातावरणो में सार्थक विशिष्ट संयोजी क्षमता प्रदर्शित की।

संकर, आई.सी.एम.ए.–06999 X बी.आई.बी.–65, आई.सी.एम.ए.–97111 X बी.आई.बी.–8, आई.सी.एम.ए.–06999 X बी.आई.बी.–8 एवं आई.सी.एम.ए.–04999 X बी.आई.बी.–15 दानो की उपज के लिये तुलनात्मक निष्पादन, उच्च मानक संकर ओज

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* विद्या वाचस्पति छात्र, पादप प्रजनन एवं आनुवांशिकी विभाग, कृषि महाविद्यालय, बीकानेर, स्वामी केशवानन्द राजस्थान कृषि विश्वविद्यालय, बीकानेर।

** पादप प्रजनन व आनुवांशिकी में विद्या वाचस्पति की आंशिक आवश्यकता की पूर्ति के संदर्भ में प्रस्तुत शोध ग्रन्थ डॉ. पी.सी. गुप्ता, आचार्य, पादप प्रजनन एवं आनुवांशिकी विभाग, कृषि अनुसंधान केन्द्र, बीकानेर, स्वामी केशवानन्द राजस्थान कृषि विश्वविद्यालय, बीकानेर के निर्देशन में प्रस्तुति की गई।

एवं विशिष्ट संयोजन क्षमता हेतु सार्थक होने के साथ–साथ इन संकरो के दोनो जनको का सामान्य संयोजी प्रभाव भी उच्च पाया गया।

प्रारूपीय स्थायित्व परीक्षण ने दर्शाया की जीन प्रारूप X वातावरण पारस्परिक क्रियाओ में अनुमानित एवं गैर अनुमानित घटको का महत्तव है। आर.एम.एस.–6ए X बी.आई.बी.–27 एवं आई.सी.एम.ए.–04999 X बी.आई.बी.–15 संकरो में दानो की अधिक उपज के साथ–साथ क्रमशः अच्छे कृषि प्रबन्धन एवं कुप्रबन्धन वाले वातावरणो के लिये स्थायित्व भी पाया गया।

अतः संकर आई.सी.एम.ए.–04999 X बी.आई.बी.–15 को वृहद वातावरण परीक्षणो में परीक्षण करना चाहिये जिससे इसकी राजस्थान के अर्ध शुष्क क्षेत्रो के लिये वाणिज्यक उत्पादन की सार्थकता का पता लगाया जा सके।

Appendix-I

Appendix-I: Mean performance of different hybrids for yield and its contributing traits in pearl millet

S.No.	Crosses	Days to 50% flowering			Days to maturity			Plant height (cm.)		
		E_1	E_2	E_3	E_1	E_2	E_3	E_1	E_2	E_3
1	RMS 6A x BIB - 8	44.00	43.33	44.33	67.00	70.00	71.67	150.07	154.97	146.33
2	RMS 6A x BIB - 15	46.67	45.33	45.67	67.33	71.00	73.00	146.93	158.40	153.67
3	RMS 6A x BIB - 27	46.33	45.67	44.67	68.67	73.00	75.00	162.87	160.13	159.27
4	RMS 6A x BIB - 46	44.33	43.67	42.67	67.67	71.67	73.33	160.27	150.13	172.27
5	RMS 6A x BIB - 58	45.00	43.67	43.33	68.67	73.00	74.67	158.80	149.13	155.67
6	RMS 6A x BIB - 65	44.00	42.00	42.67	66.33	70.00	71.33	159.00	144.50	157.53
7	RMS 21A x BIB - 8	43.33	42.33	42.33	66.33	70.67	72.33	166.20	149.30	151.93
8	RMS 21A x BIB - 15	45.67	47.00	47.33	67.67	71.67	73.33	154.03	182.83	168.33
9	RMS 21Ax BIB - 27	45.67	47.33	45.33	69.00	73.33	75.00	176.13	182.43	174.87
10	RMS 21A x BIB - 46	43.67	45.00	44.00	68.00	72.00	73.00	161.73	155.33	146.67
11	RMS 21A x BIB - 58	44.33	46.67	46.67	69.33	73.33	74.67	161.73	168.17	172.20
12	RMS 21A x BIB - 65	43.00	43.33	44.33	66.33	71.33	71.67	161.53	149.47	144.20
13	ICMA 843-22 x BIB - 8	43.67	43.33	44.00	67.33	72.00	73.67	167.53	167.03	140.93

14	ICMA 843-22 x BIB - 15	45.67	46.33	47.67	68.00	72.00	73.67	158.27	162.27	167.13
15	ICMA 843-22 x BIB - 27	45.00	47.33	45.33	69.67	74.67	75.67	187.60	176.50	164.80
16	ICMA 843-22 x BIB - 46	43.67	43.00	44.00	68.67	72.67	74.67	158.60	156.40	152.47
17	ICMA 843-22 x BIB - 58	43.00	44.67	44.33	69.67	74.67	75.67	161.60	153.50	160.33
18	ICMA 843-22 x BIB - 65	43.00	42.33	42.67	66.33	70.33	72.67	162.93	164.50	150.73
19	ICMA93333 x BIB - 8	50.33	52.67	52.33	72.33	77.00	79.33	143.80	147.83	154.60
20	ICMA93333 x BIB - 15	52.67	53.67	53.33	73.67	78.33	80.00	159.00	184.00	193.73
21	ICMA93333 x BIB - 27	44.67	51.00	53.33	75.00	80.33	81.00	174.27	168.73	176.67
22	ICMA93333 x BIB - 46	43.67	44.33	43.33	73.33	78.00	80.00	166.07	153.80	157.93
23	ICMA93333 x BIB - 58	51.33	51.00	58.67	73.33	79.67	81.00	158.40	145.00	161.93
24	ICMA93333 x BIB - 65	43.33	43.33	43.00	71.67	76.67	77.67	166.80	151.33	159.13
25	ICMA 97111 x BIB - 8	44.33	44.00	43.67	66.33	70.33	72.33	155.20	138.57	147.13
26	ICMA 97111 x BIB - 15	46.67	47.33	48.00	67.67	72.00	73.67	169.27	150.13	163.73
27	ICMA 97111 x BIB - 27	44.67	46.67	45.33	69.67	74.00	75.67	178.47	166.33	168.53
28	ICMA 97111 x BIB - 46	43.67	44.67	44.00	68.00	72.33	75.33	163.33	143.33	138.20
29	ICMA 97111 x BIB - 58	43.00	45.67	43.33	68.33	73.33	76.00	174.20	152.97	160.13
30	ICMA 97111 x BIB - 65	42.33	42.67	42.33	66.67	71.33	72.00	157.93	143.00	149.60

31	ICMA 04999 x BIB - 8	45.00	47.67	48.00	69.33	74.33	76.00	160.83	139.23	130.33
32	ICMA 04999 x BIB - 15	45.00	46.00	47.67	69.67	75.00	78.00	168.73	156.87	155.33
33	ICMA 04999 x BIB - 27	46.00	47.67	47.67	71.33	76.33	78.67	166.73	156.17	152.00
34	ICMA 04999 x BIB - 46	45.33	46.33	47.33	69.67	74.33	75.33	149.40	144.93	133.87
35	ICMA 04999 x BIB - 58	46.00	47.33	47.00	70.00	75.00	77.33	144.87	149.10	131.67
36	ICMA 04999 x BIB - 65	45.33	44.67	46.00	69.00	73.00	75.33	145.60	138.87	128.80
37	ICMA 05444 x BIB - 8	46.33	46.00	46.33	69.33	73.67	75.67	150.47	147.93	153.20
38	ICMA 05444 x BIB - 15	48.67	47.67	48.33	71.67	75.67	77.67	158.80	168.03	165.60
39	ICMA 05444 x BIB - 27	49.67	48.67	48.67	74.00	78.00	79.00	165.00	171.50	176.27
40	ICMA 05444 x BIB - 46	48.33	47.00	47.33	72.00	76.67	78.00	145.20	154.03	151.27
41	ICMA 05444 x BIB - 58	47.00	48.00	47.33	72.67	77.00	78.00	149.40	152.07	159.60
42	ICMA 05444 x BIB - 65	46.33	46.33	46.67	71.33	74.33	76.00	155.57	152.30	146.20
43	ICMA 06999 x BIB - 8	46.00	45.33	44.67	70.67	74.33	77.33	149.83	146.73	137.53
44	ICMA 06999 x BIB - 15	49.00	47.33	48.00	71.67	75.67	78.67	136.40	175.93	164.80
45	ICMA 06999 x BIB - 27	46.67	47.33	48.67	70.67	75.33	80.33	155.20	169.20	161.07
46	ICMA 06999 x BIB - 46	45.67	45.00	45.00	70.33	73.33	78.33	159.60	142.17	136.87
47	ICMA 06999 x BIB - 58	44.33	46.67	45.00	70.67	74.33	79.00	167.47	146.20	156.33

48	ICMA 06999 x BIB - 65	46.33	44.00	44.67	69.00	72.67	76.33	151.67	139.93	132.93
49	JMSA 20042 x BIB - 8	43.33	42.33	43.00	68.33	71.67	72.67	148.33	144.97	144.00
50	JMSA 20042 x BIB - 15	43.33	44.00	44.67	67.33	71.00	73.33	160.47	149.63	158.80
51	JMSA 20042 x BIB - 27	44.67	45.00	44.67	68.33	72.00	74.67	165.73	171.17	151.47
52	JMSA 20042 x BIB - 46	43.00	42.00	42.00	67.67	70.67	72.33	158.47	142.27	145.27
53	JMSA 20042 x BIB - 58	43.33	43.67	42.33	70.33	71.00	73.00	155.73	170.27	156.20
54	JMSA 20042 x BIB - 65	41.33	42.00	42.00	66.00	70.00	71.33	156.00	160.30	152.67
55	HHB - 67 Improved	42.67	42.33	42.33	67.00	70.67	72.67	169.53	178.33	161.67
56	RHB-177	44.33	44.00	44.33	68.33	72.67	74.33	159.67	159.13	159.20
57	GHB -538	48.00	47.67	48.33	72.00	75.33	76.67	151.40	158.53	159.27

Appendix-I: Cont……

S.No.	Crosses	Number of effective tillers per plant			Ear head length (cm)			Ear head diameter (cm)		
		E_1	E_2	E_3	E_1	E_2	E_3	E_1	E_2	E_3
1	RMS 6A x BIB - 8	1.50	1.54	1.33	22.54	23.09	22.31	2.24	2.42	2.49
2	RMS 6A x BIB - 15	1.28	1.72	1.28	20.53	18.75	18.10	1.82	2.00	2.03
3	RMS 6A x BIB - 27	1.30	1.45	1.19	25.87	23.27	23.90	1.90	2.16	2.08
4	RMS 6A x BIB - 46	1.44	1.27	1.57	21.78	19.89	20.83	2.46	2.61	2.56
5	RMS 6A x BIB - 58	1.43	1.50	1.49	25.48	19.02	20.40	2.34	2.55	2.50
6	RMS 6A x BIB - 65	1.65	1.46	1.37	21.55	21.04	20.40	2.36	2.38	2.54
7	RMS 21A x BIB - 8	1.82	1.36	1.45	27.90	21.87	24.83	2.18	2.34	2.39
8	RMS 21A x BIB - 15	1.25	1.31	1.58	24.67	24.02	24.28	2.16	2.58	2.40
9	RMS 21Ax BIB - 27	1.26	1.48	1.07	32.06	24.06	29.60	1.84	2.33	2.13
10	RMS 21A x BIB - 46	1.59	1.34	1.20	26.07	23.33	24.67	2.19	2.36	2.43
11	RMS 21A x BIB - 58	1.31	1.60	1.50	29.99	26.66	26.23	2.27	2.52	2.57
12	RMS 21A x BIB - 65	1.55	1.53	1.30	27.09	25.28	23.30	2.18	2.45	2.44
13	ICMA 843-22 x BIB - 8	1.72	1.84	1.32	22.73	21.96	21.80	2.28	2.42	2.61
14	ICMA 843-22 x BIB - 15	1.23	1.39	1.33	20.72	21.27	22.00	2.33	2.54	2.46

15	ICMA 843-22 x BIB - 27	1.24	1.58	1.28	29.29	27.24	26.07	2.15	2.18	2.22
16	ICMA 843-22 x BIB - 46	1.82	1.95	1.34	20.80	20.66	21.23	2.35	2.63	2.53
17	ICMA 843-22 x BIB - 58	1.38	1.61	1.44	22.61	21.87	21.93	2.26	2.53	2.50
18	ICMA 843-22 x BIB - 65	1.58	2.03	1.64	22.78	21.69	22.13	2.25	2.57	2.64
19	ICMA93333 x BIB - 8	1.50	1.72	1.24	20.07	21.89	22.27	2.04	2.35	2.56
20	ICMA93333 x BIB - 15	1.40	1.41	1.08	22.07	23.38	22.37	2.07	2.40	2.38
21	ICMA93333 x BIB - 27	1.35	1.12	1.35	25.18	26.26	24.90	1.80	1.98	2.04
22	ICMA93333 x BIB - 46	1.53	1.05	1.18	22.64	24.47	22.18	2.19	2.25	2.60
23	ICMA93333 x BIB - 58	1.59	1.09	1.13	21.66	23.93	20.20	2.20	2.29	2.36
24	ICMA93333 x BIB - 65	1.37	1.63	1.20	23.24	22.08	23.80	2.30	2.30	2.47
25	ICMA 97111 x BIB - 8	1.41	1.59	1.17	21.15	23.19	23.37	2.39	2.61	2.55
26	ICMA 97111 x BIB - 15	1.55	1.08	1.12	23.09	19.43	21.90	2.47	2.51	2.61
27	ICMA 97111 x BIB - 27	1.35	1.26	1.21	28.58	25.53	25.67	2.11	2.18	2.22
28	ICMA 97111 x BIB - 46	1.44	1.13	1.17	24.38	21.26	22.03	2.79	2.76	2.71
29	ICMA 97111 x BIB - 58	1.18	1.49	1.11	23.99	23.36	24.83	2.68	2.60	2.64
30	ICMA 97111 x BIB - 65	1.74	1.32	1.32	24.15	22.26	22.90	2.54	2.61	2.57
31	ICMA 04999 x BIB - 8	1.42	1.10	1.26	26.18	22.24	21.63	2.42	2.60	2.46

32	ICMA 04999 x BIB - 15	1.41	1.41	1.20	23.10	21.48	23.27	2.45	2.48	2.47
33	ICMA 04999 x BIB - 27	1.29	1.51	1.08	29.49	23.51	25.53	2.24	2.22	2.13
34	ICMA 04999 x BIB - 46	1.39	1.07	1.07	25.13	24.11	21.20	2.58	2.47	2.57
35	ICMA 04999 x BIB - 58	1.29	1.25	1.20	24.30	21.91	22.93	2.38	2.48	2.49
36	ICMA 04999 x BIB - 65	1.56	1.10	1.07	24.45	22.08	23.20	2.51	2.62	2.63
37	ICMA 05444 x BIB - 8	1.41	1.22	1.09	24.10	24.87	22.83	2.31	2.40	2.34
38	ICMA 05444 x BIB - 15	1.40	1.50	1.14	22.77	23.35	23.53	2.22	2.31	2.33
39	ICMA 05444 x BIB - 27	1.47	1.11	1.13	29.50	25.39	29.00	1.97	2.19	2.08
40	ICMA 05444 x BIB - 46	1.44	1.05	1.25	24.40	25.10	23.73	2.45	2.52	2.66
41	ICMA 05444 x BIB - 58	1.43	1.11	1.46	22.97	23.59	23.07	2.31	2.42	2.49
42	ICMA 05444 x BIB - 65	1.48	1.31	1.28	23.13	23.53	23.33	2.38	2.46	2.62
43	ICMA 06999 x BIB - 8	1.40	1.38	1.71	24.36	21.57	21.47	2.26	2.52	2.50
44	ICMA 06999 x BIB - 15	1.39	1.23	1.14	21.75	22.47	21.37	2.28	2.45	2.49
45	ICMA 06999 x BIB - 27	1.39	1.14	1.23	27.20	21.40	24.13	1.89	2.14	2.19
46	ICMA 06999 x BIB - 46	1.36	1.06	1.18	25.60	21.93	23.00	2.45	2.51	2.61
47	ICMA 06999 x BIB - 58	1.71	1.32	1.18	24.90	21.46	22.90	2.31	2.44	2.37
48	ICMA 06999 x BIB - 65	1.59	1.33	1.21	23.33	18.67	21.67	2.28	2.55	2.48

49	JMSA 20042 x BIB - 8	1.62	1.39	1.27	23.43	21.28	22.47	2.24	2.49	2.47
50	JMSA 20042 x BIB - 15	1.33	1.22	1.39	23.23	21.96	21.83	2.52	2.51	2.56
51	JMSA 20042 x BIB - 27	1.35	1.22	1.09	25.80	22.42	25.27	1.93	2.29	2.12
52	JMSA 20042 x BIB - 46	1.26	1.30	1.46	23.40	21.95	23.43	2.50	2.66	2.76
53	JMSA 20042 x BIB - 58	1.24	1.34	1.30	22.16	21.69	21.17	2.47	2.52	2.49
54	JMSA 20042 x BIB - 65	1.46	1.62	1.30	21.67	20.39	22.30	2.56	2.67	2.61
55	HHB - 67 Improved	1.71	1.67	1.16	26.94	25.30	25.40	2.34	2.36	2.36
56	RHB-177	1.48	1.30	1.32	26.19	23.60	24.60	2.60	2.68	2.69
57	GHB -538	1.24	1.35	1.05	21.99	22.05	21.80	2.30	2.42	2.60

Appendix-I: Cont……

S. No.	Crosses	Test weight (g)			Dry stover yield per plant (g)			Grain yield per plant (g)			Harvest index (%)		
		E_1	E_2	E_3	E_1	E_2	E_3	E_1	E_2	E_3	E_1	E_2	E_3
1	RMS 6A x BIB - 8	7.17	8.73	9.50	27.99	36.68	39.38	10.20	15.93	17.72	26.71	30.31	31.04
2	RMS 6A x BIB - 15	6.30	6.10	6.17	31.46	35.32	38.51	8.41	12.14	13.10	21.09	25.62	25.38
3	RMS 6A x BIB - 27	6.83	9.03	8.70	29.92	40.20	41.36	10.35	18.26	16.50	25.68	31.21	28.51
4	RMS 6A x BIB - 46	6.57	8.23	9.03	31.83	35.99	36.50	9.99	15.46	16.42	23.83	30.04	31.05
5	RMS 6A x BIB - 58	7.50	8.23	8.70	28.98	31.87	33.59	7.65	12.15	13.97	20.88	27.61	29.38
6	RMS 6A x BIB - 65	8.33	8.87	9.27	34.10	38.09	39.50	11.93	16.95	19.74	25.76	30.80	33.33
7	RMS 21A x BIB - 8	6.63	8.63	8.73	29.23	40.06	35.92	8.15	13.31	10.78	21.80	24.91	23.05
8	RMS 21A x BIB - 15	4.67	6.63	7.07	33.50	38.01	39.05	4.80	15.88	16.19	12.50	29.49	29.33
9	RMS 21Ax BIB - 27	6.10	8.13	8.40	34.96	39.53	36.63	7.07	19.67	16.11	16.87	33.20	30.53
10	RMS 21A x BIB - 46	6.90	7.87	8.17	30.59	35.15	35.32	6.50	15.01	14.62	17.60	29.94	29.26
11	RMS 21A x BIB - 58	6.03	8.30	8.97	26.16	32.86	33.24	5.43	14.90	15.34	17.21	31.20	31.59
12	RMS 21A x BIB - 65	6.70	8.07	8.27	29.80	36.05	39.17	8.88	16.84	13.17	22.90	31.91	25.17
13	ICMA 843-22 x BIB - 8	7.83	9.07	10.03	25.51	29.58	30.28	10.92	17.26	14.59	29.97	36.83	32.51
14	ICMA 843-22 x BIB - 15	8.20	9.17	8.17	31.93	31.81	40.31	8.28	13.46	13.86	20.56	29.77	25.59

15	ICMA 843-22 x BIB - 27	8.07	9.77	9.57	31.13	35.15	35.55	11.57	19.23	15.84	27.11	35.36	30.81
16	ICMA 843-22 x BIB - 46	7.87	9.03	10.10	26.96	28.41	31.99	8.67	21.23	14.94	24.35	42.81	31.83
17	ICMA 843-22 x BIB - 58	9.37	10.27	10.90	23.54	26.27	28.33	6.66	10.64	7.32	22.02	28.79	20.46
18	ICMA 843-22 x BIB - 65	7.33	10.23	10.03	27.68	28.65	34.49	6.15	21.65	11.84	18.05	43.02	25.58
19	ICMA93333 x BIB - 8	4.87	7.43	7.47	26.36	27.85	31.25	3.72	25.21	11.06	12.40	47.57	26.13
20	ICMA93333 x BIB - 15	5.93	6.87	7.27	51.41	55.03	55.09	4.55	14.35	10.67	8.10	20.69	16.20
21	ICMA93333 x BIB - 27	7.50	7.67	8.07	33.58	37.60	36.95	6.64	11.43	15.18	16.46	23.35	29.11
22	ICMA93333 x BIB - 46	5.17	8.27	9.13	29.51	32.42	34.25	7.89	7.79	16.06	21.14	19.39	31.95
23	ICMA93333 x BIB - 58	9.00	9.27	7.83	37.48	40.46	42.24	3.14	6.27	8.80	7.74	13.47	17.22
24	ICMA93333 x BIB - 65	8.60	8.03	8.80	35.16	39.81	37.24	8.70	13.84	15.89	19.76	25.82	29.87
25	ICMA 97111 x BIB - 8	8.53	8.03	9.63	31.00	32.73	36.01	14.77	20.81	14.62	32.34	38.88	28.90
26	ICMA 97111 x BIB - 15	6.73	7.83	7.80	38.57	48.26	43.31	11.76	11.80	12.84	23.32	19.48	22.83
27	ICMA 97111 x BIB - 27	8.73	9.33	9.33	35.58	36.38	40.28	11.97	16.82	17.84	25.12	31.66	30.70
28	ICMA 97111 x BIB - 46	8.90	9.07	9.67	29.83	38.06	35.54	10.08	13.11	15.85	25.15	25.64	30.82
29	ICMA 97111 x BIB - 58	8.93	9.83	9.93	33.99	32.32	38.70	9.72	14.93	12.74	22.26	31.61	24.77
30	ICMA 97111 x BIB - 65	9.40	8.37	9.90	22.97	30.63	32.39	15.82	14.80	12.84	40.85	32.56	28.32
31	ICMA 04999 x BIB - 8	6.67	7.20	6.77	30.65	29.89	33.08	12.57	11.27	13.55	29.14	27.34	29.03

32	ICMA 04999 x BIB - 15	6.47	7.17	7.40	41.15	47.69	47.28	18.50	14.70	15.71	31.04	23.58	24.98
33	ICMA 04999 x BIB - 27	7.97	7.53	7.43	38.70	44.85	42.76	18.19	11.16	7.68	31.97	19.97	15.19
34	ICMA 04999 x BIB - 46	6.93	6.93	7.23	26.75	35.24	32.82	15.99	8.14	13.35	37.29	18.75	28.93
35	ICMA 04999 x BIB - 58	6.77	9.23	8.57	26.27	33.84	29.63	5.76	9.60	9.50	17.98	22.11	24.30
36	ICMA 04999 x BIB - 65	6.93	8.07	7.53	34.98	45.20	35.41	15.35	14.57	10.70	30.56	24.41	23.18
37	ICMA 05444 x BIB - 8	6.93	8.03	8.43	33.95	39.23	38.40	7.93	9.87	9.96	18.94	20.06	20.57
38	ICMA 05444 x BIB - 15	6.33	7.47	8.70	45.38	47.85	49.79	5.58	11.47	12.16	10.96	19.34	19.60
39	ICMA 05444 x BIB - 27	6.60	7.63	8.30	32.16	43.77	36.67	4.98	11.12	10.45	13.46	20.28	22.10
40	ICMA 05444 x BIB - 46	7.87	8.40	9.03	37.26	44.27	41.27	7.25	8.18	14.17	16.19	15.59	25.55
41	ICMA 05444 x BIB - 58	9.33	7.40	10.07	37.08	43.06	42.08	5.35	2.86	8.72	12.58	6.25	17.16
42	ICMA 05444 x BIB - 65	7.03	9.10	8.43	30.45	33.89	33.51	8.51	14.27	15.79	21.85	29.66	31.98
43	ICMA 06999 x BIB - 8	5.57	8.83	8.97	29.94	35.83	33.34	9.47	18.48	21.14	24.02	34.06	38.80
44	ICMA 06999 x BIB - 15	5.90	7.47	7.47	35.59	41.74	40.90	5.75	15.43	15.56	13.88	27.01	27.52
45	ICMA 06999 x BIB - 27	7.03	8.90	8.80	38.39	45.38	36.42	8.59	16.41	14.96	18.26	26.56	29.00
46	ICMA 06999 x BIB - 46	7.40	9.60	9.57	31.11	34.95	34.24	10.04	13.83	15.02	24.66	28.36	30.49
47	ICMA 06999 x BIB - 58	8.90	10.43	10.27	27.51	36.15	31.35	8.68	15.07	9.81	23.90	29.39	23.83
48	ICMA 06999 x BIB - 65	6.33	8.80	9.10	31.08	39.92	35.66	11.79	24.59	14.72	27.36	38.11	29.19

49	JMSA 20042 x BIB - 8	6.87	8.67	9.97	24.31	30.22	27.25	9.13	14.67	12.75	27.35	32.67	31.87
50	JMSA 20042 x BIB - 15	7.20	8.33	8.33	28.54	34.67	30.89	11.24	12.79	12.95	28.20	26.93	29.58
51	JMSA 20042 x BIB - 27	7.03	8.57	9.50	33.15	41.83	37.87	10.32	17.88	12.63	23.63	29.91	24.98
52	JMSA 20042 x BIB - 46	7.60	9.60	10.27	24.25	27.64	28.98	7.88	13.43	14.47	24.50	32.65	33.27
53	JMSA 20042 x BIB - 58	9.47	9.93	10.33	25.87	25.26	28.71	5.76	10.07	6.75	18.09	28.50	19.01
54	JMSA 20042 x BIB - 65	9.17	10.33	10.13	30.86	30.19	34.18	11.24	21.89	13.20	26.68	42.05	27.85
55	HHB - 67 Improved	8.23	9.03	9.40	33.78	38.46	38.48	11.68	15.83	11.69	25.65	29.16	23.31
56	RHB-177	8.53	9.57	9.43	25.82	28.62	32.78	8.97	13.50	15.45	25.77	32.02	32.00
57	GHB -538	6.67	8.87	8.90	33.13	42.47	38.24	6.03	13.80	12.90	15.48	24.50	25.24

Appendix-II

Appendix-II: Weekly mean meteorological observations recorded during *Kharif*, 2015

Standard Week	Duration	Temperature (℃)		R.H. (%)		Total Rainfall (mm.)*	No. of Rainy days*	Wind Velocity (km./hr.)	Evaporation (mm/day)	BSSH
		Max.	Min.	Max.	Min.					
27	02.07.15 - 08.07.15	37.9	27.08	69.8	41.7	0	0	11.9	8.6	6.4
28	09.07.15 - 15.07.15	38.4	25.4	80.4	42.2	10.2	1	9.5	8.8	7.6
29	16.07.15 - 22.07.15	38.9	27.04	74	41.5	8.3	1	9.4	8.6	7.1
30	23.07.15 - 29.07.15	33.6	24.7	88.2	69.4	104.5	4	7.7	5.5	5.8
31	30.07.15 - 05.08.15	33.6	25	89.1	66.7	93.6	4	10.9	5.2	2.6
32	06.08.15 - 12.08.15	37.5	26.2	78.1	54.8	43.3	2	8.4	9	7.6
33	13.08.15 - 19.08.15	35.9	25.4	86.4	55.2	62.5	2	6.7	7.7	6.8
34	20.08.15 - 26.08.15	36.2	25.6	75.2	53	0	0	12.09	8.6	10.1
35	27.08.15 - 02.09.15	37.4	25.2	74.1	49.5	0	0	9.2	9.1	9.9
36	03.09.15 - 09.09.15	37.4	23.4	62.5	39	0	0	8.1	8.7	9.9
37	10.09.15 - 16.09.15	40.2	23.2	59	29.5	0	0	5.02	9.08	9.8
38	17.09.15 - 23.09.15	34.6	23.8	78.1	50	2.2	0	7.2	6.9	5.9
39	24.09.15 - 30.09.15	35.9	22.1	69.2	31.7	0	0	6.7	6.5	8.9
40	01.10.15 - 07.10.15	38	20.4	70.1	39	0	0	5.2	6.5	9.7
41	08.10.15 - 14.10.15	37.7	20	77.5	44.2	0	0	8.1	5.9	9.7
42	15.10.15 - 21.10.15	36.1	19.2	69.4	41	0	0	3.8	5.4	9.4
43	22.10.15 - 28.10.15	32.5	14.3	65.8	30.5	4.2	1	4.2	4.2	9.1

*2.5 mm or more rainfall is considered as a rainy day.

Data taken from Agro-meteorology observatory, Swami Keshwanand Rajasthan Agriculture University, Bikaner





Plate 1 : Generation of breeding material in L x T mating design at ICRISAT farm, Hyderabad





Plate 2 : Evaluation of breeding material at ARS farm, Bichhwal, Bikaner