CHAPTER - II
REVIEW OF LITERATURE

Improvement through plant breeding depends upon the genetic information available from parents and their combination governing qualitative and quantitative characters. The crucial phase in a plant breeding is the choice of parents in developing the important breeding materials from which the breeder ultimately selects the elite genotypes. To derive such genetic model in relation to the material that is proposed to be utilized.

The literature pertaining to the heterosis, gene action, combining ability for grain yield, its components and micronutrients Fe and Zn in pearl millet has been reviewed under the following subheads.

2.1 Estimation of Heterosis

The term heterosis refers to the phenomenon in which the $F_{1}$ obtained by crossing two genetically dissimilar individuals manifest increased or decreased vigour over the mid-parent value. East and Shull (1905) studied the effect of the cross and self-fertilization in maize and finally Shull (1908) coined the term heterosis to represent the increased or decreased vigour of the $F_{1}$ over its better parent or mid-parental values. Fonseca and Patterson (1968) and Mather and Jinks (1971) suggested a new term heterobeltiosis described improvement of heterozygote in comparison with better parent. Generally heterosis refers to superiority of hybrids in one or more characters over its parents. The heterosis over average of parents is termed as mid-parent heterosis, while over better parent referred as heterobeltiosis, which has a practical utility. However, economic heterosis has the most practical utility, which was compared with a standard variety as check. The utilization of hybrid vigour as mean of maximizing the yield of agricultural crops has become one of the most significant technique in plant breeding. Heterosis breeding led to outstanding breakthrough in the productivity of several economically important crops like bajra, maize, castor, sorghum, cotton etc.

Kushwah and Singh (1992) in a diallel analysis using 66 diallel crosses from 12 inbred lines (three each of Indian and African origin and six derived from
indigenous × exotic crosses) of pearl millet, observed heterosis for days to 50 per cent flowering, plant height, leaf length, leaf width, number of nodes on main tiller, length of first inter-node, number of tillers, spike length, spike girth, grain density, 1000-grain weight and grain yield. Plant height, length and width of leaf, number of nodes on main tiller and earliness showed undesirable heterosis. The magnitude of heterosis was highest for grain yield (397.00%) and lowest for days to 50 per cent flowering (-5.00%).

Ouendeba et al. (1993) conducted a study to assess the heterosis among African pearl millet population to explore the application of inter population improvement for the development of high yielding varieties and hybrids. Better parent heterosis for grain yield ranged from 25 to 81 per cent. Six crosses showed significant heterosis and gave 36 to 81 per cent more grain yield over better parent.

Deor et al., (1997) examined comparative expression of heterosis for physiological traits and grain yield in 21 F1 hybrids of pearl millet. Significant average heterosis for grain yield, harvest index and leaf area index was obtained. Grain yield registered 73.38, 63.36 and 28.50 per cent heterosis over mid-parent, superior parent and standard check, respectively.

Yadav (1999) quantified that heterosis was negative for days to flower and of similar magnitude in hybrids grouped by their cytoplasmic source. Manifestation of cytoplasmic effects was higher for heterosis for grain yield and plant height than heterosis for days to flowering and panicle length.

Sheoran et al. (2000) noticed positive and significant heterobeltiosis for plant height, earhead girth, 1000-grain weight and grain yield per plant while negative significant (desirable) for days to flowering. Grain yield followed by earhead girth recorded maximum heterobeltiosis.

Dutt and Bainiwal (2002) reported that both population and heterosis effects were significant for biological yield and harvest index, indicating the importance of both additive and non-additive gene effects in their expression. In heterotic patterns, specific heterosis is the major contributor for these traits.

Singh and Sagar (2001) showed the prevalence of heterobeltiosis in pearl millet for all the characters viz., plant height, number of effective tillers per plant,
earhead length, earhead weight per plant, dry fodder weight per plant and grain yield per plant except for days to maturity in two crosses in one environment.

Presteral and Weltzien (2003) reported that the mean level of mid-parent heterosis was ranged from 0.85% for time to flowering to 6.57% for fodder yield. For grain yield, expression of heterosis for individual population crosses was between -14 and +30 per cent under drought stress and between -9 to +17 per cent in the favourable environment. They showed also that the mean heterosis fodder yield always positive and higher than for grain yield.

Pethani et al. (2004) studied the estimates of heterosis over mid parent and better parent for various traits and indicated high heterotic effects for grain yield and earhead weight. The hybrid MS 2072A x J 2338 expressed the highest heterotic values for grain yield over mid parent (152.92%) and better parent (121.45%).

Dhuppe et al., (2005) derived crosses between six male sterile lines and ten male 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 yield and fodder yield, MS 841A x IPC 274 for ear head length and MS 862A x Zim D only over the better parent for 1000-grain weight. The crosses, which were heterotic for grain yield, also showed heterosis either for one or more characters.

Lakshmana and Guggari (2006) carried out heterosis study in pearl millet using 25 F1 crosses involving five male and five female parents. Fifteen hybrids exhibited significant and positive heterobeltiosis for grain yield. Crosses 88004A x IPC 338 (87.20%), 93333A x IPC 1503 (30.00%), 93333A x IPC 1503 (14.00%) and 88004A x IPC 390 (58.41%) were observed highly heterotic for higher grain yield per plant, earhead length, productive tillers per plant and 1000-grain weight.

Izge et al. (2007) observed higher parent heterosis among the hybrids in almost all the traits. Higher parent heterosis of 85.13 and 114.05 % for yield per plant and total grain yield per hectare, respectively was obtained.

Kumhar (2007) found that 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.
Kumhar and Singhania (2007) observed significant differences among genotypes for all the characters on pooled as well as in individual environments. Mean sum of squares due to parents vs. hybrids were significant for all the characters indicating presence of heterosis. The estimates of $\sigma^2 \text{gca}$ and $\sigma^2 \text{sca}$ variances were significant for most of the characters in both the environments indicating the importance of both additive and non-additive gene actions in the inheritance.

Ghodasara et al. (2008) identified significant heterosis and heterobeltiosis coupled with inbreeding depression for all the characters studied indicating the presence of non-additive gene action.

Patel et al. (2008) reported that five hybrids exhibited higher relative heterosis, heterobeltiosis and standard heterosis for most of the fodder yield attributes, indicating their importance for commercial exploitation of heterosis.

Vetriventhan et al. (2008) recorded that 13 hybrids were highly significant for standard heterosis for grain yield per plant and seven hybrids selected as best crosses since they expressed high standard heterosis over standard hybrid (MBH 163) for many of the traits studied for high grain yield.

Davda et al. (2008) estimated the nature and magnitude of heterosis for grain yield and its attributing trait through line × tester fashion involving 8 CMS lines and 10 pollinators in pearl millet. Ear head girth exhibited the list heterosis. 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.

Chotaliya et al. (2009) in which 10 diverse inbred were crossed in a diallel fashion, excluding reciprocals, to study the magnitude of heterosis and to identify new restore in pearl millet. The high magnitude of heterobeltiosis was found for grain yield per plant, fodder yield per plant, plant height, number of effective tiller per plant, ear head weight and harvest index. The maximum positive heterosis for grain yield per plant was observed to be 194.65 and 153.22 percent over mid and better parent, respectively.

Vagadiya et al. (2010a) estimated the nature and magnitude of heterosis for grain yield and its attributing traits through line × tester fashion involving four CMS lines and 12 restorers in pearl millet. The high level of heterosis was observed for grain yield per plant and ear head length. Maximum positive heterosis for grain yield
per plant over better parent and standard check (GHB 719) was observed to be 105.71 and 11.30 per cent, respectively. The cause of heterosis in grain yield might be due to its component traits, mainly, ear head length, plant height and harvest index.

Govindaraj (2011) carried out an experiment in two sets of line × tester studies, parents were observed having wide range of genetic variability for both grain Fe and Zn concentration and this was also reflected in both sets of hybrids. Over two season, ICMB 93222, 863B, ICMB 95333, ICMB 96333 among seed parents and IPC 774, IPC 616, IPC 1650, IPC 1178, IPC 536 and IPC 735 amongst pollen parents (testers) were found to have >60 mg/kg Zn concentration.

Jethva et al. (2012) carried out a study for grain yield and its attributes in pearl millet through line × 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. It is inferred that the magnitude of heterosis effect was high for grain yield per plant, fodder yield per plant, 1000-seed weight and number of effective tillers per plant; moderate for ear head length and threshing index and low for ear head girth. The hybrids ICMA 95222 × J-2372 and JMSA 101 × 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.

Chaudhry et al., (2012) studied combining ability analysis in a line × tester fashion for grain yield and eight component trait using five male sterile lines and nine restorers in pearl millet during kharif season of 2011-12. Among the 45 crosses, nine displayed significant and positive sca effects for grain yield. Of these, four hybrids viz., JMSA 20091 × J-2433, ICMA 841 × J-2507, JMSA 20081 × J-2495 and JMSA 20081 × J-2430 were the most promising having good combining ability effects in addition to high per se performance, heterobeltiosis and standard heterosis for grain yield. Thus, it was suggested that these four hybrids would be evaluated under multiplication trials along with the standard hybrid for their direct release as high yielding hybrids.

Anilkumar et al., (2013) reported that the four crosses namely ICMA 95222 × CSSC 46-2 (92.05%), ICMA 94555 × G73-107 (77.76%), HMS 13A × CSSC 46-2 (66.76%) and HMS 9A × CSSC 46-2 (55.52%) showed more than 50 per cent heterosis over check HHB 94. Standard heterosis over check HHB 94 for protein
content was exhibited by only two crosses HMS 9A × 1307 and HMS 18A × H77/833-2. These crosses can be further used for the improvement of nutritional quality.

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

Yadav et al. (2013) conducted an experiment at Hisar during kharif season to estimate the extent of heterosis in pearl millet. The material for that study was developed by crossing ten male sterile lines with five diverse pollinator (testers) in line × tester fashion. Out of all crosses only four, namely, ICMA 95222 × CSSC 46-2 (92.05%), ICMA 94555 × G73-107 (77.76%), HMS 13A × CSSC 46-2 (66.76%) and HMS 9A × CSSC 46-2 (55.52%) showed more than 50 per cent heterosis over check HHB 94. Standard heterosis over check HHB 94 for protein content was exhibited by only two crosses HMS9A × 1307 and H 77/833-2. These crosses can be further used for the improvement of nutritional quality.

Kanatti et al. (2014) carried out a line × tester study of 196 hybrids and their 28 parental lines of pearl millet showed large genetic variability for Fe and Zn densities with predominantly additive gene action and no better parent heterosis.

Bachkar et al. (2014) observed high standard heterosis for number of effective tillers per plant, grain yield per plant, ear head girth and number of grains per cm$^2$ while moderate to low heterosis over standard checks was found for plant height (cm), 1000-grain weight (g), ear head length (cm), total number of tillers per plant, fodder yield per plant (g), days to maturity and days to 50% flowering. The highest positive standard heterosis for grain yield per plant was 70.81%. Heterosis for grain yield might have resulted from heterosis for its component traits, mainly number of effective tiller per plant, ear head girth and number of grains per cm$^2$. The crosses viz., MS 99111 A × AIB 214, MS 88004 A × R 451-1, MS 94111 A × IC 1153, MS 88004 A × PPC 7 and MS 88004 A × AIB 214 were promising on the basis of mean performance and standard heterosis.

Kapoor et al., (2014) carried out an experiment for genetic analysis of forage yield and quality traits in pearl millet. A set of 15 CMS lines and 4 populations as testers were crossed in all possible combinations to obtain 60 top cross hybrids. The
hybrids were evaluated for heterosis over two environments viz., water stress and irrigated. Analysis of variance for quality characters revealed significant differences due to genotypes, environmental and significant genotype × environment interaction for all quality traits. Hybrids 220A × Giant bajra, 01555 × NDFB 2 and 408A × GFB 1 exhibited high positive significant heterotic effect over commercial check also suggested the presence of non-additive gene action and dominance for quality traits.

Bhuri, et al. (2015) concluded that the magnitude of heterotic effect was high for grain yield, biological yield, dry fodder yield and harvest index; moderate for days to 50% flowering, days to maturity, productive tillers per plant, plant height, panicle length, panicle girth and test weight and low for protein content in all the three environments. Crosses 26-30 x 31-40, 26-30 x 71-75, 26-30 x RIB-135-144, 31-40 x RIB-20, 31-40 x 71-75, 31-40 x RIB-135-144, 31-40 x 101-105, 41-50 x RIB-20, RIB-20 x 71-75, RIB-20 x RIB-135-144, 61-70 x 71-75, 61-70 x 101-105, 71-75 x 51-60, 71-75 x 101-105 and RIB-135-144 x 101-105 exhibited the significant heterobeltiosis for grain yield and related traits across the environments.

Pawar et al. (2015) concluded that the cross combinations RHRBI 138 x S-12/30088 and S-12/30109 x S-12/30088 exhibited significant negative heterosis and heterobeltiosis in desirable direction for days to 50 % flowering and days to maturity in all environments and over pooled values. So these cross combinations could be further exploited for obtaining desirable transgressive segregants and to identify early and high yielding superior genotypes.

Patel et al. (2016) conducted that the experimental material was comprised six male sterile lines, 10 restorer pollinators and two standard check hybrids. These lines and testers were crossed in line × tester factorial mating system. Thus, 16 parents, 60 crosses, and two standard checks formed the experimental material for the present study. For grain yield highest significant positive heterobeltiosis and standard heterosis were observed in the hybrid ICMA 98444 × J 2526 and ICMA 96222 × AIB-2 respectively. The majority of yield and yield contributing characters had a more numbers of hybrids founds significant positive heterobeltiosis and standard heterosis under study. The hybrids GHB 558 and GHB 538 were used as standard hybrids. The hybrid ICMA 96222 × AIB-2 expressed high standard heterotic value for six traits of 14 traits studied including grain yield per plant.
Rafiq et al., (2016) observed that the heterosis for different traits was contributed by the diverse nature of the female parents belonging to different cytoplasmic sources *i.e.* A1, A4 and A5. The present study offers great scope for exploitation of the diverse cytoplasmic sources (A4 and A5) for development of high yielding superior performing hybrids of pearl millet on standard scale.

Bagra, et al. (2017b) conducted that the experimental material comprised of 8 parents and resultant 28 hybrids along with a standard check variety GHB 732. High heterosis was observed for plant height, number of effective tillers per plant, ear head length, fodder yield per plant, harvest index, whereas the magnitude of heterosis was moderate for days to 50 per cent flowering, days to maturity, blast score and low for downy mildew disease. The range of heterobeltiosis was from -31.43 to 140.75 per cent for grain yield per plant and the highest heterobeltiosis was registered by the cross ICMB1 94555 x ICMB4 05333 followed by ICMB4 10444 x ICMB4 05333 and ICMB1 94555 x ICMB4 10444, while the standard heterosis ranged from -50.90 to 51.24 % for grain yield per plant and the cross ICMB1 95444 x JMSB1 20102 showed the highest standard heterosis for this trait followed by ICMB1 95444 x ICMB4 05333, ICMB5 01777 x ICMB1 04999 and JMSB1 20102 x JMSB1 20064.

### 2.2 Combining Ability and Gene Action

Combining ability is referred as ability of a parent to transmit its performance to its offsprings. As the combining ability often depends upon complex interaction systems among genes, certain combinations nick well to produce superior offsprings, whereas other involving equally promising parents produced disappointing progeny.

The concept general and specific combining ability as measure of gene action through their investigation on corn was proposed by Sprague and Tatum (1942). They defined the term GCA as the average performance of a line in a set of hybrids which can be recognized as a measure of additive gene action including additive × additive interaction. The specific combining ability refers to those instances when certain cross combinations do relatively better or worse than would be expected on the basis of average performance of parental lines involved. This is controlled by non-additive genetic variance including dominance and epistatic interactions.

Hybrids among two unrelated inbreds were likely to exhibit more vigour than their parents. However, very few lines producing such hybrids were economically
valuable in breeding. Hence, line selection should be based on combining ability rather than their per se performance for producing superior hybrids.

Navale and Harinarayana (1992) assessed combining ability from 12 × 12 full diallel. The mean sum of squares due to GCA was significant for all the six traits. Significant reciprocal mean square for grain yield and ear length indicated role of cytoplasm in expression of both of these traits. The predominance of dominant components for grain yield and additive component for plant height, days to 50 per cent flowering and maturity was observed. It was also revealed that presence of at least one good general combiner is essential in producing high SCA effects for grains yield in pearl millet.

Aher and Ugale (1995) carried out a diallel analysis involving 8 parents in F₁ and F₂ generation for plant height, total number of tillers, productive tillers, ear head length and girth, grain weight and grain yield per plant. Variances for GCA and SCA were highly significant in both generations which indicated the role of additive as well as non-additive gene effects for expression of these traits. Non-additive gene effects, however, were predominant for plant height, total number of tillers, productive tillers, ear head length, grain weight and grain yield per plant except ear head girth which has additive type of gene action in F₁ generation.

Rudranaik et al. (1996) revealed that the female 81A was the best combiner for grain yield and several other yield components. Among males, genotype IP-12993 had highest gca effects for fodder and grain yield. It also had significant negative gca effect for days to 50 per cent flowering. The hybrid 842A × PMBDN-48 recorded the maximum heterosis for grain yield and fodder yield.

Azhaguvel and Jayaraman (1998) reported that, variances due to hybrids and line x tester interaction were significant for all characters such as number of productive tillers, panicle length, panicle girth, 1000 grain weight and grain yield per plant, whereas, variances due to lines and testers were significant for all above characters, except for grain yield per plant.

Combining ability estimates in pearl millet were obtained by Latha and Shanmugsundaram (1998) from line × tester analysis of crosses involving 10 male sterile lines and 6 restorers. They found predominant non-additive gene action for traits like plant height, number of productive tillers, ear thickness, 1000-grain weight
and grain yield per plant. For ear length, additive type of gene action was predominant.

The results of combining ability obtained by Mohan et al., (1999) from data on five yield related traits in the parents and 30 progeny of five lines and six testers of pearl millet crosses indicated the role of additive gene action for number of productive tillers per plant, ear head length, ear head girth and 1000-grain weight, whereas non-additive gene action for grain yield per plant was observed.

Joshi et al., (2000) assessed combining ability using line × tester mating design. The estimate of GCA and SCA variance revealed predominance of additive gene action for 50% flowering, days to maturity, plant height, effective tillers per plant, ear head length, 1000-grain weight and grain yield per net plot.

The combining ability for grain yield and its components traits was studied by Mohan et al., (2002) using line × tester mating design. The results indicated the importance of both additive and non-additive gene actions for all the characters with the predominance of former for days to first flowering, plant height and total number of tillers, while non-additive gene action was important for grain yield per plant and protein content. They also advocated for the selection of parents based on per se performance and combining ability to produce superior cross combinations.

Combining ability for grain yield and yield components were studied in 40 F₁ and their parents by Lakshmana et al., (2003). The estimates of GCA revealed significant variation among the parents for plant height, ear length, number of days to maturity and number of 50% flowering. The estimates of GCA and SCA variances suggested the predominance of non-additive gene effects for fodder and grain yield.

Ansodariya (2004) reported that both GCA and SCA variances were highly significant for the characters like days to flowering, day to maturity, effective tillers per plant, plant height, ear head length, ear head girth, ear head weight, 1000-grain weight, dry fodder and grain yield per plant. However, predictability ratio of GCA:SCA variances suggested pre dominance of additive gene action for plant height, ear head length, ear head girth and 1000-grain weight and non-additive gene actions for ear head weight, dry fodder and grain yield per plant. Both additive and non-additive gene actions were equally important for days to flowering, days to maturity and effective tillers per plant.
Sushir et al. (2005) reported the importance of both additive and non-additive gene effects for all the characters with the predominance of former for number of tillers per plant and ear head length, while non-additive gene action was important for days to 50% flowering, ear head girth and grain yield.

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

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

Chandrashekara et al. (2007) observed that the cytoplasmic effects on general combining ability (GCA) for various agronomic characters were largely non-significant. However, cytoplasmic effects on specific combining ability and heterosis were found to be modulated by cytoplasmic-nuclear interactions and influenced by the environmental conditions.

Meena Pareek et al. (2008) identified female parent Pb 317 A to be good general combiner for ear length as well as ear girth. Male parent PIB 136 showed high gca effects for reduced plant height as well as tillers per plant; PIB 289 for tillers per plant as well as ear girth; PIB 1234-8 for ear length, ear girth and dry fodder yield. Some crosses identified for high sca effects along with high gca of both the parents are Pb 317A x PIB 1234-8 and ICMA 97333 x PIB 686 for ear length as well as ear girth, ICMA 92333 x PIB 1234-8 for leaves per plant and ICMA 93333 x PIB 686 for dry fodder yield.

Vaghasiya et al. (2008) studied combining ability in a line × tester fashion using 12 newly developed B-lines as females and seven broad based restore lines as males for final selection of superior B-lines before embracing for their conversion into male sterile version ‘A’ lines in pearl millet. Both GCA and SCA variance were significant.
for all the characters. Female (B-lines) parents B12, B11, B10 and B8 and male parents R1 and R2 were identified as the best general combiners for grain yield and some important yield components.

Arulselvi et al. (2009) reported predominance of non-additive genetic variance for grain Fe and Zn. They found some degree of relationship between specific combining ability effects of crosses and general combining ability effects of their parents. Cross involving both parents having superior GCA or one parent having superior gca had large sca effects suggesting that both GCA and SCA were important for grain Fe and Zn in pearl millet.

Manga (2009) reported that ICMA 94555 possess good general combining ability for grain yield, while ICMA 94222 was best combiner for early flowering. ICMA 94555 x CZI 98/9, ICMA 97111 x CZI 1676-2 and ICMA 97111 x CZI 96/1604 were identified as potential hybrids.

Lakshmana et al. (2010) investigated the combining ability and quantified the magnitude of heterosis of alloplasmic isonuclear lines of pearl millet. The results revealed that the lines with A4 cytoplasm are significantly better general combiner for grain yield per ear head, ear weight, ear length and productive tillers per plant than the lines with A1 and A5 cytoplasm. Pollinators IP-1497, IP-973, IP-872 and IP-10085 proved their utility for breeding high yielding hybrids. None of the pollinators proved to be good combiners simultaneously for all the traits.

Vagadiya et al. (2010b) studied combining ability in a line × tester fashion for grain yield and 13 component trait 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, length of protogyny, 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. Male parents J-2290 and H77/833-2 were identified as the best general combiners for grain yield per plant along with days to 50 per cent flowering number of effective tillers per plant, ear head weight, ear head girth, days to maturity and dry fodder yield per plant.
Lakshmana et al. (2011) carried-out combining ability analysis in pearl millet and reported that majority of characters like, days to 50% flowering, days to maturity, 1000-grain weight, grain yield, dry fodder yield, harvest index and threshing index were under the control of non-additive gene action as SCA variance were greater than GCA variances. Among the testers, ICMA 94555 emerged as a best general combiner, which showed significant gca effect for majority of the characters. The female ICMA 94555 recorded maximum plus points by exhibiting significant positive gca effect for nine quantitative traits.

Chaudhary et al. (2012) identified female parent ICMA-841 and male parents J-2482 and J-2340 were the best general combiners for grain yield per plant along with one or more component traits. Among the 45 crosses, nine displayed significant and positive sca effects for grain yield.

Yadav et al. (2012) studied combining ability for maturity traits in pearl millet. Variance due to GCA and SCA were significant for panicle emergence, effective tillers, plant height, ear length, ear weight, dry fodder yield, grain yield per plant and total biological yield per plant in all the three environment (two stress and one normal) and on pooled basis indicating the importance of both additive and non-additive gene actions. Preponderance of non-additive gene was recorded for all the characters, which suggested the success of hybrid breeding by making use of the expected heterosis.

Parmar et al. (2013) performed line × tester analysis using 5 lines and 10 testers and reported that the estimated component of variance for SCA were larger in magnitude than the GCA for all the characters viz., grain yield, earliness, productive tillers per plant, ear length, ear weight, 1000-grain weight, threshing index and harvest index indicating the predominance of non-additive gene action for the genetic control of these characters. Among the parents, J-2473, J-2474, ICMA 91777, J-2452, J-2444 and J-2405 were found as good general combiners for grain yield and its components traits.

Bhuri Singh and Sharma. (2014) revealed the estimates of gca effects indicated that the parents 71-75 and 76-80 emerged as good general combiners for grain yield and its components in the entire environment. Out of 45 crosses combinations only seven combinations such as 26-30 x 71-75, 26-30 x RIB-135-144,
31-40 × 76-80, 31-40 × RIB-135-144, 31-40 × 101-105, 41-50 × RIB-20 and RIB-20 × 71-75 showed significant and positive $sca$ effects in all the three environment for grain yield and other yield attributing characters. These parents and crosses have immense potential for pearl millet improvement and may be utilized in multiple crossing programme.

Khandagale et al. (2014) observed 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 parents, PT 4801 was the best general combiner followed by PT 4108 and PT 4563 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. They produced significant and desirable $sca$ effects for most of the traits studied, indicating potential for exploiting hybrid vigour in breeding programme.

Jagendra Singh and Ravi Sharma (2014) revealed in general combining ability analysis GIB 144 found 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. 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.

Combining ability was studied in an 8 × 8 diallel set including reciprocals, for grain yield and its 11 component traits by Bhadalia et al. (2014) in pearl millet. They found that both GCA and SCA variances were highly significant for all the characters. The ratio of GCA and SCA variances revealed preponderance of non-additive gene action in expression of grain yield per plant, day to flowering, days to maturity, number of effective tillers per plant, ear head length, ear head girth, ear head weight, plant height, number grains per square cm, 1000-grain weight, dry fodder yield per plant and harvest index.

Patel et al. (2014) concluded that the hybrid AIB-9 x AIB-34 depicted the highest relative heterosis, heterobeltiosis, standard heterosis and $sca$ effect for grain
yield per plant, therefore, this cross may be further exploited to get desirable segregants for restorer lines.

An experiment was conducted by Singh and Sharma (2014) with four male sterile lines (female parents) and nine inbreds used as testers (male parents) of pearl millet in line × tester fashion. In general combining ability analysis GIB 144 found 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. 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.

A line × tester analysis using six line and eleven testers was carried out by Mungra et al. (2015) to study the combining ability and gene action for grain yield and 14 quantitative traits in pearl millet. The ratio of GCA variance and SCA variance indicated the predominance of non-additive gene action for the characters days to 50% flowering, length of protogyny, number of nodes per plant, plant height, number of productive tillers per plant, ear head weight per plant, days to maturity, 1000-grains weight, dry fodder yield per plant, grain yield per plant, harvest index and threshing index and additive gene action for ear head girth and ear head length. Significant and positive sca effect for grain yield per plant was displayed by the cross ICMA 05333 × J-2527 followed by ICMA 05333 × J-2340, JMSA 20064 × 283 SB 11 and ICMA 92777 × STPT 115.

Bhardwaj et al. (2015) concluded that 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 mid parent heterosis (MPH) and batter parent heterosis (BPH) was observed by the cross PB 543A x PIB 136.

Kanatti et al. (2016) development of inbred lines with high general combining ability (GCA) is an important aspect of hybrid breeding research were crossed with 14 diverse inbred lines in each of two experiments to produce 56 top cross hybrids, which were evaluated along with their parental lines for grain Fe and Zn densities. Results showed that there was highly significant and moderately high positive correlation between the top cross hybrid performance per se (a measure of GCA) produced with the two testers, both for Fe and Zn densities in both experiments. However, the correlation between performance per se of lines and their top cross hybrids averaged over both testers (giving more reliable estimates of GCA than individual testers) was even higher for both micronutrients and in both experiments. Thus, each tester was effective in identifying 30 to 35% of the top-ranking high general combiners.

Lubadde et al., (2016) reported that the study of the genetic effects for rust resistance and yield-related traits of improved pearl millet genotypes. A higher proportion of general combining ability (GCA) effect was observed for grain yield, days to 50% flowering, days to 50% anthesis, flower-anthesis interval, days to 50% physiological maturity, plant height, total tiller number, number of productive tillers, percentage of productive tillers, panicle area, leaf area, 1000-grain weight, biological yield and harvest index. Eleven hybrids performed better than the best male parent and five crosses performed better than the best female parent for grain yield while all the fifteen selected best crosses performed better than all parents for area under disease progress curve. The additive gene action was predominant for grain yield, rust severity at 50% physiological maturity, days to 50% flowering, days to 50% anthesis, total tiller number, percentage of productive tillers, panicle area, 1000-grain weight, biological yield, harvest index and leaf area. High better-parent heterosis was also observed for most traits including grain yield and rust resistance.

Jeeterwal et al. (2017) they taken ten inbred lines and their full diallel crosses were used to study the nature of gene action and heterosis for Fe and Zn (micronutrients). The general combining ability (GCA) effects of parents and specific combining ability (SCA) effects of hybrids showed significant differences for both of the micronutrients. However, the predictability ratio $(2\frac{\sigma^2_{gca}}{2\sigma^2_{gca} + \sigma^2_{sca}})$ was
around unity both for Fe and Zn densities, implying preponderance of additive gene action. Further, highly significant positive correlation between mid-parent values and hybrid performance, and no correlation between mid-parent values and mid-parent heterosis confirmed again the predominant role of additive gene action for these micronutrients. This showed that there would be little opportunity, if any, to exploit heterosis for these mineral micronutrients in pearl millet. In general, high Fe and Zn levels in both of the parental lines would be required to increase the probability of breeding high Fe and Zn hybrids.

Bagra, et al. (2017a) they studied the combining ability analysis of yield and yield contributing characters. The experimental material comprised of 8 parents and resultant 28 hybrids developed through half diallel mating. The analysis of variance for combining ability revealed significant mean sum of squares due to gca and sca for all the traits, except mean sum of square due to gca for days to 50 per cent flowering. These results suggested the existence of additive and non-additive gene actions for various traits in the materials under study. The mean sum of squares due to gca were higher than corresponding sca for most of the characters except days to 50 per cent flowering, fodder yield per plant, grain yield per plant, which suggested that in the expression of all these traits both additive and non-additive components of variation played an important role. The estimates of $\sigma^2$ SCA were greater than the corresponding $\sigma^2$ GCA for all the characters. The parental line ICMB1 95444 gave desirable gca effect simultaneously for grain yield per plant with other characters. The cross ICMB5 01777 x ICMB1 04999 and ICMB 95444 x JMSB1 20102 expressed significant sca effect for in desirable direction for grain yield per plant.