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Combining Ability Analysis for Grain Yield and Its Attributing Traits in Pearl Millet [*Pennisetum glaucum* (L.) R. Br.)] Under a Randomized Block Design

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The experimental material comprised of sixty three genotypes consisting of six CMS lines and eight restorers as tester lines crossed in line × tester mating design. The resultant forty eight hybrids along with their fourteen parents and standard check (GHB 1129) were evaluated in "randomized block design" at Ketanbhai Patel Farm Village Ishanpur Mota, Ta & Dist. Gandhinagar, Gujarat during, *summer* 2024. The analysis of variance for combining ability revealed that the mean square due to females (lines) and males (testers) was significant for all the characters under study. This indicated significant contribution of females and males towards general combining ability variance component for these traits. The line × tester interaction was significant for all the characters. This indicates significant contribution of hybrids for specific combining ability variance component. The variance component due to females was higher than that of males for days to 50% flowering, days

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to maturity, plant height, earhead length, test weight and grain yield per plant. The ratio of σ2gca / σ2sca below than unity for the all the traits which was suggested greater role of non-additive gene action in the inheritance of these traits. Among the parents, female 97111 A was good general combiner for grain yield per plant, number of effective tiller per plant, test weight and harvest index and another line ICMA 14222 was good general combiner for grain yield per plant, earhead girth, test weight and harvest index. Whereas tester ICMR 1203 was good general combiner for grain yield per plant, days to 50% flowering, days to maturity, plant height, test weight, seed setting and harvest index. Best three hybrids which possessed significant positive SCA effects for grain yield per plant and its attributing characters were 97111 A x ICMR 1907, ICMA 14222 x HTP-03/13 R and 94555 A x ICMR 18777. They have good genetic architecture on the basis of SCA effects and are important to use that in further breeding programme to enhance the CGMS effectivity.

Keywords: Pearl millet; LxT mating design; GCA; SCA.

1. INTRODUCTION

“Pearl millet [*Pennisetum glaucum* (L.) R. Br.] is believed to have been domesticated in Sub-Saharan Africa some 4000 to 5000 yr ago” (Munson, 1975). “Archaeological evidence suggests that pearl millet was first domesticated at the southern edge of the Sahara Desert in West Africa around 2500 BC” (Manning *et al*., 2011). “Pearl millet is a diploid (2n = 2x = 14), warm-season C4 annual cereal crop grown in West Africa and on the Indian subcontinent for food and forage. Pearl millet (*Pennisetum glaucum* (L.) R. Br.) is one of the most cultivated cereals ranking after rice, wheat, maize, barley and sorghum in terms of area planted to these crops in the world”. (Khairwal *et al*., 2007). “Pearl millet is a climate resilient crop and one of the most widely grown millets worldwide. Pearl millet (*Pennisetum glaucum* (L.) R. Br.) is cultivated in environments of low and erratic rainfall, high temperatures, and low soil fertility and is the main source of food and fodder for the farming communities in arid and semiarid tropics of sub-Saharan Africa and South Asia. Pearl millet [*Pennisetum glaucum* (L.) R. Br.] known by several names, such as bulrush millet, spiked millet, cattail millet, candle millet, bajra, is a climate resilient nutritious cereal” (Anuradha *et al*., 2017).

“Pearl millet is a highly cross-pollinated species, with outcrossing rates of more than 85%, because of its protogynous nature of flowering. Therefore, individual plants of natural populations mate randomly and are highly heterozygous and heterogeneous. Early breeding efforts in genetic improvement of pearl millet, which started as early as the 1930s, attempted to capitalize on such existing genetic variation within traditional landraces by subjecting them to simple mass selection” (Athwal, 1961). “The greater urgency for population improvement programs started with the acquisition of a diverse range of germplasm from across the world in the 1970s with the establishment of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)” (Gill, 1991; Witcombe, 1999). “Eventually, a large number of populations and trait-based composites of the broad genetic base were established, and a diverse range of elite breeding materials was developed” (Rai & Anand Kumar, 1994; Rai *et al*., 2006).

“The breeding methods of pearl millet are fundamentally those which are largely adapted for cross pollinated crops. Its genetic improvement has been carried out through conventional breeding procedures. For developing composites, synthetics and hybrids, methods of breeding like hybridization followed by selection is important. Use of cytoplasmic genetic male sterility and techniques of population improvement along with modern biotechnological techniques have provided a great scope for genetic up-gradation in this crop. Yield is one of the most important economic character and is the product of multiplicative interaction of contributing characters. Hence, the important objective in Pearl millet improvement is to develop varieties, which have high yield potential. The other objectives are oriented to develop new varieties with wider adaptability, earlier maturity, disease resistance and high oil content with high yield potential” (Rai & Anand Kumar, 1994).

“The combining ability studies provide useful information regarding the selection of suitable parents for effective hybridization programme and at the same time elucidates the nature and magnitude of gene action. Since, the nature of gene action varies with genetic architecture of population involved in hybridization, it is necessary to evaluate the parents for their combining ability. The line x tester mating design has been widely used in crop plant for testing the performance of genotypes in hybrid combinations and also for characterizing the magnitude and nature of gene action" (Kempthorne, 1957).

2. MATERIALS AND METHODS

The present investigation was carried out to derive information on magnitude of relative heterosis, heterobeltiosis, standard heterosis, general combining ability (GCA) of parental lines and specific combining ability (SCA) of hybrids in pearl millet [*Pennisetum glaucum* (L.) R.Br.)." The field experiment was conducted at Ketanbhai Patel Farm Village Ishanpur Mota, Ta & Dist. Gandhinagar, Gujarat. The experiments consist of six CMS lines and eight testers (restorer parent). These were obtained from the HAU, Hissar and ICRISAT, Hyderabad. Six CMS lines and eight male parents were used to produce 48 hybrids using line × tester mating design. The experiment was formed with 48 hybrids, 14 parents and one standard check (GHB 1129). The crosses were made at Ketanbhai Patel Farm Village Ishanpur Mota, Ta & Dist. Gandhinagar, Gujarat during *kharif,* 2023. At the same time CMS lines were maintained by cross with maintainer line and male parent were selfed to get sufficient seeds for conducting experiment. The seeds of all the crosses and their parental lines were harvested separately, cleaned and store properly in seed bag for sowing in next season.

A set of 63 genotypes comprising of 14 parents (6 female and 8 male parents) and their 48 F_1's with a standard check GHB 1129 were grown in randomized block design with two replications during summer 2024 and evaluated at Ketanbhai Patel Farm Village Ishanpur Mota, Ta & Dist. Gandhinagar, Gujarat. The experiment was sown on 10th March, 2024. Each hybrids and parents represented single row having 4 meter length spaced at 45 cm between rows and 15 cm apart from plant to plant within row.

Five plants were randomly selected and tagged from each net plot of parents and F1's in all the replications to record the periodical observations. Recording the various observations like, Days to 50 % flowering, Days to maturity, Plant height (cm), Number of effective tiller per plant, Earhead length (cm), Ear head girth (mm), Test weight (g), Grain yield per plant (g), Harvest Index (%) and Seed setting (%).Analysis of variance technique suggested by Snedecor and Cochran (1967) and reviewed by Panse and Sukhatme (1985) for Randomised Complete Block Design was followed to test the differences among the genotypes for the characters under study. The variation among the hybrids was partitioned further into sources attributable to general and specific combining ability components in accordance with the procedure suggested by Kempthorne (1957) and modified by Arunachalam (1974). The analysis of variances for the combining ability was based on the following statistical model.

3. RESULTS AND DISCUSSION

3.1 Combining Ability

"The analysis of variance for combining ability and estimation of variance components for various characters was carried out as per line × tester analysis following the procedure" suggested by Kempthorne (1957). "The salient features of the results obtained are presented below. In any breeding programme, the information about combining ability is of immense help to the plant breeders in the choice of elite parents for hybridization programme. Constant efforts are being made to improve quantitative and qualitative characters in pearl millet through hybridization. Proper selection of parents is very crucial in any planned hybridization programme. Certain parents nick well, whereas others which appears equally good but produce poor progenies in combinations. Eventually, the lines, which produce good progenies on crossing, are of immense value for the plant breeders. In a heterosis breeding programme, much of the success depends upon isolation of valuable gene combinations as determined in the form of lines with high combining ability. This analysis is a powerful tool to discriminate good as well as poor combiners and choose appropriate parental material in breeding programme. The concept of general and specific combining ability as a measure of gene action" was proposed by Sprague and Tatum (1942). The general combining ability is an average performance of a line in hybrid combinations and can be recognized as a measure of additive gene action and 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.

Table 1. Particulars of parents used

Sr. No.	Lines (Females)	Source	Sr. No.	Testers (Male)	Source
1	94555 A	H.A.U., Hissar	1	H 77/833-2-202R	H.A.U., Hissar
2	97111 A	H.A.U., Hissar	2	HTP – 03/13 R	H.A.U., Hissar
3	47 A	H.A.U., Hissar	3	ICMR 06222	ICRISAT, Hyderabad
4	ICMA 14222	ICRISAT, Hyderabad	4	ICMR 14222	ICRISAT, Hyderabad
5	ICMA 15666	ICRISAT, Hyderabad	5	ICMR 1203	ICRISAT, Hyderabad
6	ICMA 21999	ICRISAT, Hyderabad	6	ICMR 1907	ICRISAT, Hyderabad
			7	ICMR 19555	ICRISAT, Hyderabad
			8	ICMR 18777	ICRISAT, Hyderabad
[C]	**Standard check:**				
	1	GHB 1129			JAU, Junagadh

Table 2. Analysis of variance (Mean square) for combining ability, and estimates of components of variance for various characters in pearl millet

Source of variation	d.f.	Days to 50 % flowering	Days to maturity	Plant height (cm)	Number of effective tiller per plant	Earhead length (cm)	Earhead girth (mm)	Test weight (g)	Grain yield per plant (g)	Harvest index (%)	Seed setting (%)
Replication	2	0.25	0.24	178.00*	0.04	13.72*	1.43	1.15**	1.67	7.30	31.67**
Female	5	68.23**	68.23**	1104.46**	2.79**	41.52**	17.97**	16.80**	3733.96**	419.13**	17.93**
Male	7	4.08**	4.08**	180.44**	4.79**	29.19**	52.55**	10.91**	2525.49**	700.53**	27.37**
Female × males	35	7.18**	7.18**	597.26**	2.78**	17.53**	33.53**	7.99**	1214.79**	725.50**	37.95**
Error	94	1.29	1.29	37.52	0.02	3.22	0.73	0.06	0.60	9.85	5.21
σ^2 Females		2.54**	2.54**	21.13	0.00	1.00	-0.65	0.37	104.97*	-12.77	-0.83
σ^2 Males		-0.17	-0.17	-23.16	0.11	0.65	1.06	0.16	72.82	-1.39	-0.59
σ^2 gca		1.38*	1.38*	2.18	0.05	0.85	0.08	0.28	91.18	-7.89	-0.73
σ^2 sca		1.96**	1.96**	186.57**	0.92**	4.77**	10.93**	2.64**	404.73**	238.55**	10.91**
σ^2 gca/ σ^2 sca		0.70	0.70	0.01	0.05	0.18	0.007	0.11	0.23	-0.03	-0.07

** and** significant at P = 0.05 and P = 0.01 levels, respectively.*

Table 3. Estimation of general combining ability(GCA) effects of parents for various characters in pearl millet

Lines	Parents	Days to 50 % flowering	Days to maturity	Plant height (cm)	Number of effective tiller per plant	Earhead length (cm)	Earhead girth (mm)	Test weight (g)	Grain yield per plant (g)	Harvest index (%)	Seed setting (%)
	47 A	-1.53**	-1.53**	2.93*	-0.15**	0.17	0.17	-1.18**	-13.63**	-5.22**	-0.19
	94555 A	-2.11**	-2.11**	10.24**	-0.05	2.17**	-0.42*	-0.58**	-7.76**	-3.19**	0.81
	ICMA 14222	-0.32	-0.32	0.88	-0.24**	-0.10	1.57**	0.81**	12.41**	5.52**	0.26
	ICMA 15666	1.22**	1.22**	-1.17	0.45**	-1.33**	-0.87**	0.37**	9.61**	3.39**	0.89
	ICMA 21999	0.35	0.35	-10.42**	-0.39**	-1.38**	0.10	-0.34**	-12.25**	-2.23**	-1.44**
	97111 A	2.39**	2.39**	-2.46	0.38**	0.48	-0.55**	0.92**	11.63**	1.73**	-0.32
S.Em. ±		0.19	0.19	1.00	0.02	0.29	0.14	0.04	0.13	0.51	0.37
Testers	H 77/833-2-202R	-0.67*	-0.67*	0.07	0.51**	-2.76**	-2.46**	-0.36**	-1.63**	8.20**	1.46**
	HTP-03/13 R	0.00	0.00	3.02*	0.16**	-0.96*	1.76**	-0.94**	-13.83**	-5.54**	0.01
	ICMR 06222	0.39	0.39	3.10*	0.05	0.40	2.39**	-0.45**	-4.78**	-6.29**	-0.71
	ICMR 14222	0.33	0.33	-0.71	-0.77**	0.96*	1.29**	0.88**	1.01**	-2.87**	-0.76
	ICMR 1203	-0.61*	-0.61*	-6.92**	-0.82**	0.70	-1.75**	0.22**	22.00**	7.22**	2.24**
	ICMR 1907	-0.33	-0.33	0.71	0.20**	0.77	0.01	-0.29**	-11.77**	-5.35**	-1.21*
	ICMR 19555	0.44	0.44	1.46	0.18**	0.08	-0.82**	1.39**	11.63**	6.52**	-0.04
	ICMR 18777	0.44	0.44	-0.73	0.49**	0.81	-0.42*	-0.45**	-2.64**	-1.90*	-0.99
S.Em. ±		0.22	0.22	1.19	0.03	0.35	0.17	0.05	0.15	0.61	0.44

** and ** significant at P = 0.05 and P = 0.01 levels, respectively.*

3.2 Analysis of Variance for Combining Ability

The analysis of variance for combining ability by partitioning the total genetic variance into general combining ability representing additive genetic variance and specific combining ability as a measure of non-additive genetic variance were carried out for ten different characters and are presented in Table 1. The analysis of variance for combining ability revealed that the mean square due to females (lines) and males (testers) was significant for all the characters under study. The results are in close agreement of Pipariya *et al.* (2025). This indicated significant contribution of females and males towards general combining ability variance component for these traits. The line × tester interaction was significant for all the characters. This indicates significant contribution of hybrids for specific combining ability variance component. The variance component due to females was higher than that of males for days to 50% flowering, days to maturity, plant height, earhead length, test weight and grain yield per plant. The ratio of σ^2gca / σ^2sca below than unity for the all the traits which was suggested greater role of non-additive gene action in the inheritance of these traits. The similar results were also reported by Pipariya *et al.* (2025).

The presence of predominantly large amount of non-additive gene action it must be required to maintain heterozygosity in the population. Breeding methods such as biparental mating followed by reciprocal recurrent selection may increase the frequency of genetic recombinations and fasten the rate of genetic improvement.

3.3 Estimation of General Combining ability and Specific Combining Ability Effects

General combining ability effects of female (line) and males (tester) as well as specific combining ability effects of crosses for all the characters were also estimated. The character wise results are presented in table number 3 and 4.

General and specific combining ability effects were estimated for parents and crosses, respectively. Based on general combining ability effects, the parents were classified as good, average and poor combiners for different traits. The character wise distribution of parents is presented in table number 5. The estimates of general combining ability (GCA) effects of fourteen parents and estimates of specific combining ability effects of forty eight crosses for ten different characters elucidate in following paragraphs.

Early flowering is considered as desirable for this crop. Therefore, genotypes with negative gca and sca values are to be considered for this trait. The estimate of GCA effect revealed that out of fourteen parents, four parents 47 A (-1.53), 94555 A (-2.11), H 77/833-2-202R (-0.67) and ICMR 1203 (-0.61) were good general combiners which exhibited significant negative GCA effects. Among the forty eight crosses, ninteen crosses showing negative SCA effect were non significant for days to 50% flowering and days to maturity. Lower plant height is considered as desirable for this crop. Therefore, genotypes with negative gca and sca values are to be considered for this trait. The estimate of GCA effect revealed that, only two parents ICMA 21999 (-10.42) and ICMR 1203 (-6.92) expressed significant negative GCA effect indicating that it was good combiner for dwarfness. Out of forty eight hybrids, eight hybrids were exhibited significant negative SCA effects for plant height.

For number of effective tillers per plant, the lines ICMA 15666 (0.45) and 97111 A (0.38) were good general combining lines having significant positive value for GCA effect and the tester H 77/833-2-202R (0.51), HTP-03/13R (0.16), ICMR 1907 (0.20), ICMR 19555 (0.18) and ICMR 18777 (0.49) was good general combiner which showed significant positive value for GCA effect. The perusal of specific combining ability effect revealed that twenty one crosses recorded significant positive SCA effects. The lines 94555 A (2.17) and tester ICMR 14222 (0.96) showed significant positive value for GCA effects were good general combining parents for earhead length. The results of SCA effect revealed that nine hybrids recorded significant positive SCA effects for this trait. The lines ICMA 14222 (1.57) showed significant positive GCA effects and the testers HTP-03/13 R (1.76), ICMR 06222 (2.39) and ICMR 14222 (1.29) recorded significant positive value for GCA effects thus, they were found good combining parents for earhead girth. The results of SCA effect revealed that seventeen hybrids recorded significant positive SCA effects for this trait therefore, they were good hybrid combinations contributing towards more earhead girth.

Table 4. The estimates of specific combining ability (sca) for various characters in pearl millet

Crosses	Days to 50 % flowering	Days to maturity	Plant height (cm)	Number of effective tiller per plant	Earhead length (cm)	Earhead girth (mm)	Test weight (g)	Grain yield per plant (g)	Harvest index (%)	Seed setting (%)
47 A x H 77/833-2-202R	-0.42	-0.42	1.38	0.97**	0.81	-3.97**	0.32*	5.87**	8.72**	-3.08*
47 A x HTP-03/13 R	-0.08	-0.08	-0.31	0.29**	-0.42	-4.12**	-0.10	17.13**	23.08**	5.03**
47 A x ICMR 06222	-0.47	-0.47	12.94**	0.44**	-0.68	-2.48**	0.47**	-8.82**	-9.22**	-1.58
47 A x ICMR 14222	3.25**	3.25**	-3.05	1.32**	-1.71	0.98*	0.11	12.43**	-14.44**	-0.19
47 A x ICMR 1203	0.53	0.53	-7.87*	-0.77**	-0.38	1.76**	-0.20	-10.49**	-1.35	-1.53
47 A x ICMR 1907	-1.08	-1.08	-7.9*	-0.68**	-0.85	-0.57	0.28	3.37**	-7.66**	-3.08*
47 A x ICMR 19555	-0.86	-0.86	-2.28	-0.57**	3.11**	4.52**	-1.36**	2.75**	6.49**	4.08**
47 A x ICMR 18777	-0.86	-0.86	7.08*	-1.01**	0.11	3.86**	0.48**	-22.25**	-5.62**	0.36
94555 A x H 77/833-2-202R	0.83	0.83	-9.36**	0.84**	0.18	-3.18**	-2.21**	-12.64**	0.53	0.25
94555 A x HTP-03/13 R	-1.5*	-1.5*	-1.91	-0.87**	-3.12**	-2.73**	1.32**	2.56**	-9.16**	3.36*
94555 A x ICMR 06222	1.11	1.11	0.01	-1.6**	-1.87	4.74**	2.80**	19.11**	-4.01*	-4.25**
94555 A x ICMR 14222	-0.83	-0.83	4.52	0.19*	1.93	1.71**	-2.49**	-26.31**	-5.93**	5.14**
94555 A x ICMR 1203	0.11	0.11	-1.4	0.23**	-1.11	0.95	-1.87**	4.91**	5.08**	-1.53
94555 A x ICMR 1907	-0.17	-0.17	-2.03	1.25**	-1.01	0.18	1.64**	-17.66**	-0.96	-2.75*
94555 A x ICMR 19555	-0.28	-0.28	-2.62	1.13**	1.48	0.98	1.00**	9.24**	-8.60**	2.42
94555 A x ICMR 18777	0.72	0.72	12.81**	-1.17**	3.52**	-2.65**	-0.19	20.78**	23.05**	-2.64*
ICMA 14222 x H 77/833-2-202R	-0.96	-0.96	-4.94	-0.84**	0.88	-2.57**	1.36**	4.62**	-14.16**	-0.87
ICMA 14222 x HTP-03/13 R	0.38	0.38	4.18	-0.49**	3.05**	4.52**	0.97**	28.29**	5.59**	1.24
ICMA 14222 x ICMR 06222	-0.68	-0.68	-40.94**	-0.44**	3.02**	-0.12	1.48**	18.57**	16.51**	-0.71
ICMA 14222 x ICMR 14222	-1.62*	-1.62*	-0.26	-0.53**	3.16**	2.68**	1.08**	14.48**	12.77**	0.01
ICMA 14222 x ICMR 1203	0.32	0.32	10.85**	-0.68**	-0.08	3.73**	-2.23**	-6.50**	1.44	0.68
ICMA 14222 x ICMR 1907	0.04	0.04	16.43**	0.37**	-3.62**	0	0.32*	-22.71**	-13.54**	1.46
ICMA 14222 x ICMR 19555	3.26**	3.26**	11.14**	1.45**	-4.66**	-4.58**	-1.39**	-20.83**	3.44	-0.71
ICMA 14222 x ICMR 18777	-0.74	-0.74	3.53	1.15**	-1.75	-3.67**	-1.58**	-15.93**	-12.05**	-1.10
ICMA 15666 x H 77/833-2-202R	-0.5	-0.5	21.19**	-0.72**	-2.88**	5.21**	-0.23	-17.08**	2.07	2.50
ICMA 15666 x HTP-03/13 R	1.17	1.17	-5.6	0.73**	2.85**	0.36	0.91**	-16.84**	7.46**	-6.72**
ICMA 15666 x ICMR 06222	-0.22	-0.22	0.79	-0.16	0.06	-6.54**	-0.61**	20.67**	17.82**	4.00**
ICMA 15666 x ICMR 14222	-1.17	-1.17	19.93**	-0.24**	-1.64	0.43	2.03**	16.75**	13.12**	-3.28*
ICMA 15666 x ICMR 1203	0.78	0.78	6.87	1.67**	-0.64	-2.29**	1.75**	-4.00**	-22.73**	-1.28
ICMA 15666 x ICMR 1907	-0.5	-0.5	-4.59	-0.31**	3.22**	2.87**	-1.80**	-10.31**	-13.93**	5.17**

Crosses	Days to 50 % flowering	Days to maturity	Plant height (cm)	Number of effective tiller per plant	Earhead length (cm)	Earhead girth (mm)	Test weight (g)	Grain yield per plant (g)	Harvest index (%)	Seed setting (%)
ICMA 15666 x ICMR 19555	0.72	0.72	-4.41	-1.26**	1.88	-1.33**	0.56**	3.27**	-13.73**	-5.33**
ICMA 15666 x ICMR 18777	-0.28	-0.28	-34.18**	0.3**	-2.85**	1.27*	-2.60**	7.54**	9.93**	4.94**
ICMA 21999 x H 77/833-2-202R	0.38	0.38	-4.8	-0.82**	1.73	-1.02*	0.98**	7.35**	-2.65	0.83
ICMA 21999 x HTP-03/13 R	-0.96	-0.96	-5.72	-0.36**	-2.3*	0.36	-1.42**	4.82**	0.42	2.94*
ICMA 21999 x ICMR 06222	-1.35*	-1.35*	-1.87	0.72**	2.74**	2.63**	-1.94**	-2.33**	5.83**	-1.00
ICMA 21999 x ICMR 14222	-2.29**	-2.29**	-9.02*	-0.47**	-1.99	-2.77**	-0.27	-29.79**	-23.82**	-2.28
ICMA 21999 x ICMR 1203	-0.35	-0.35	7.35*	-0.32**	0.24	-1.43**	1.42**	15.70**	12.61**	2.72*
ICMA 21999 x ICMR 1907	1.38*	1.38*	-5.44	0.57**	-0.73	-1.1*	-1.10**	18.06**	22.89**	-2.83*
ICMA 21999 x ICMR 19555	0.6	0.6	2.1	-0.59**	-0.87	3.07**	0.23	-3.67**	9.11**	-3.33*
ICMA 21999 x ICMR 18777	2.6**	2.6**	17.4**	1.27**	1.17	0.27	2.10**	-10.13**	-24.40**	2.94*
97111 A x H 77/833-2-202R	0.67	0.67	-3.46	0.57**	-0.73	5.52**	-0.22	11.87**	5.49**	0.38
97111 A x HTP-03/13 R	1	1	9.35**	0.7**	-0.06	1.6**	-1.68**	-35.96**	-27.39**	-5.85**
97111 A x ICMR 06222	1.61*	1.61*	29.07**	1.04**	-3.28**	1.77**	-2.20**	-47.21**	-26.93**	3.54**
97111 A x ICMR 14222	2.67**	2.67**	-12.12**	-0.28**	0.25	-3.03**	-0.46**	12.43**	18.31**	0.60
97111 A x ICMR 1203	-1.39*	-1.39*	-15.81**	-0.13	1.95	-2.72**	1.13**	0.38	4.95**	0.93
97111 A x ICMR 1907	0.33	0.33	3.53	-1.21**	2.98**	-1.39**	0.67**	29.24**	13.19**	2.04
97111 A x ICMR 19555	-3.44**	-3.44**	-3.93	-0.16	-0.93	-2.66**	0.96**	9.25**	3.28	2.88*
97111 A x ICMR 18777	-1.44*	-1.44*	-6.63	-0.54**	-0.19	0.91	1.80**	19.99**	9.10**	-4.51**
S.Em. ±	0.49	0.49	2.66	0.06	0.78	0.37	0.11	0.34	1.36	0.99
Range	-3.44 to 3.26	-3.44 to 3.26	-40.94 to 29.07	-1.60 to 1.67	-4.66 to 3.52	-6.54 to 5.52	-2.60 to 2.80	-47.21 to 29.24	-27.39 to 23.08	-6.72 to 5.17
No. of +^{ve} significant	6	6	12	21	9	17	23	27	21	12
No. of -^{ve} significant	7	7	8	24	7	20	16	20	18	12

** and ** significant at P = 0.05 and P = 0.01 levels, respectively.*

Table 5. Summary table showing general combining ability effects of parents for various characters in Pearl millet

Sr. No.	Parents	Days to 50 % flowering	Days to maturity	Plant height	Number of effective tiller per plant	Earhead length	Earhead girth	Test weight	Grain yield per plant	Harvest index	Seed setting
FEMALE PARENTS (Lines)											
1	47 A	G	G	P	P	A	A	P	P	P	P
2	94555 A	G	G	P	P	G	P	P	P	P	A
3	ICMA 14222	A	A	P	P	P	G	G	G	G	A
4	ICMA 15666	P	P	A	G	P	P	G	G	G	A
5	ICMA 21999	P	P	G	P	P	A	P	P	P	P
6	97111 A	P	P	A	G	A	P	G	G	G	A
MALE PARENTS(Testers)											
1	H 77/833-2-202R	G	G	P	G	P	A	P	P	G	G
2	HTP-03/13 R	P	P	P	G	P	G	P	P	P	A
3	ICMR 06222	P	P	P	A	A	G	P	P	P	P
4	ICMR 14222	P	P	A	P	G	G	G	G	P	P
5	ICMR 1203	G	G	G	P	A	P	G	G	G	G
6	ICMR 1907	A	A	P	G	A	A	P	P	P	P
7	ICMR 19555	P	P	P	G	A	P	G	G	G	P
8	ICMR 18777	P	P	A	A	A	P	P	P	P	P

G = Good general combiner
A = Average general combiner
P = Poor general combiner

The line 97111 A (0.92), ICMA 14222 (0.81) and ICMA 15666 (0.37) was good general combiner which showed significant positive value of GCA effect for test weight. However, testers ICMR 19555 (1.39), ICMR 14222 (0.88) and ICMR 1203 (0.22) were found to have significant positive GCA effects with respect to test weight. The analysis of specific combining ability (SCA) effects revealed that out of forty-eight hybrids, twenty-three exhibited significant positive SCA effects for this trait, which is in agreement with the findings of Rasitha *et al*. (2023). Thus, these twenty three hybrids were considered as good specific combiners for contributing towards more test weight. The lines ICMA 14222 (12.41), ICMA 15666 (9.61), and 97111 A (11.63) were identified as good combiners, exhibiting significant positive GCA effects, while the testers ICMR 1203 (22.00), ICMR 19555 (11.63), and ICMR 14222 (1.01) also showed significant positive GCA effects for grain yield per plant. Similar results were reported by Surendhar et al. (2023).Among the forty eight hybrids, twenty seven hybrids expressed positive and significant SCA effects and thus, they were good hybrid combinations, contributing towards higher grain yield. The lines ICMA 14222 (5.52), ICMA 15666 (3.39) and 97111 A (1.73) and testers H-77/833-2-202 R (8.20), ICMR 1203 (7.22) and ICMR 19555 (6.52) showed significant positive value for GCA effects for harvest index which indicate that they were good general combiners for this trait. The perusal of SCA effect revealed that among them forty eight crosses twenty one crosses recorded significant and positive SCA effects for this trait. These hybrids were considered for better harvest index. Among the fourteen parental lines, two parents H 77/833-2-202 R (1.46) and ICMR 1203 (2.24) had significant and positive GCA effects, hence, these parents were proved to be good general combiners for seed setting. Out of forty eight crosses, twelve crosses were exhibited significant positive SCA effects for this trait.

4. SUMMARY AND CONCLUSION

The analysis of variance for parents, hybrids and parents vs. hybrids revealed that mean sum of squares of parents were highly significant for all of the characters. Whereas, hybrids also differed highly significant for all the characters. Comparison of mean squares due to parents vs. hybrids was found significant for almost all the characters except seed setting. This indicate that considerable amount of genetic variability present among the parents and hybrids for all the characters studied.

The summary of general combining ability effect of the parents revealed that, line 97111 A was good general combiner for grain yield per plant, number of effective tiller per plant, test weight and harvest index and another line ICMA 14222 was good general combiner for grain yield per plant, earhead girth, test weight and harvest index. Whereas tester ICMR 1203 was good general combiner for grain yield per plant, days to 50% flowering, days to maturity, plant height, test weight, seed setting and harvest index. It suggested that these parents might be presumed to be relatively greater number of favourable alleles for developing superior hybrids in pearl millet.

Based on high SCA effect hybrids, The top hybrid having high sca effect for yield 97111 A x ICMR 1907 exhibited significant sca effects in desired direction for grain yield per plant, earhead length, test weight and harvest index. This hybrid also recorded significant heterosis (in desired direction) over standard check for earhead length, earhead girth, test weight, harvest index, seed setting and grain yield per plant.

The second ICMA 14222 x HTP-03/13 R has significant sca effects in desired direction for grain yield per plant, earhead length, earhead girth, test weight and harvest index. This hybrid also recorded significant heterosis (in desired direction) over standard check for earhead length, earhead girth, test weight, harvest index, seed setting and grain yield per plant.

The third hybrid having high sca effect for yield 94555 A x ICMR 18777 registered significant sca effects in desired direction for grain yield per plant, earhead length and harvest index. It is also recorded significant standard heterosis for earhead length, earhead girth, test weight, harvest index and grain yield per plant.

The last hybrid having high sca effect for yield 97111 A x ICMR 18777 registered significant sca effects in desired direction for days to 50% flowering, days to maturity, grain yield per plant, test weight and harvest index. It is also recorded significant standard heterosis for earhead length, earhead girth, test weight, harvest index and grain yield per plant.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that they have no known competing financial interests or non-financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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