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EXPLORING COMBINING ABILITY AND GENE ACTION FOR SEED YIELD AND ITS COMPONENT TRAITS IN PEARL MILLET (*PENNISETUM GLAUCUM* (L.) R. BR.)

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ABSTRACT

Millets, the earliest cultivated food crops, are crucial for nutrition and food security. Among millets, pearl millet [*Pennisetum glaucum* (L.) R. Br.], a staple in arid regions, is valued for its resilience and nutritional content, including high protein and carbohydrates. A field study was conducted in *kharif* 2023 at RRS, AAU, Anand, and evaluated 16 parental lines (Seven lines and nine testers) and their 63 hybrids using a randomized complete block design. Statistical analysis revealed significant variance in combining ability for traits like days to flowering, plant height and grain yield per plant, highlighting both additive and non-additive genetic variances. Among the hybrids, 33 showed significant specific combining ability (SCA) for grain yield per plant, with ICMA 05444 × ICMR 17276 exhibiting the highest SCA effect. The study identified key parents with strong general combining abilities (GCA) for various traits, suggesting their potential to breed high-yielding and robust cultivars. The results underscore the importance of both GCA and SCA in selecting parents and hybrids for breeding programmes to improve pearl millet yield and quality
***Keywords*: Pearl millet, Combining ability, GCA, SCA**

Introduction

Millets, hailed as the earliest cultivated food crops, have been integral to human diets for millennia, offering a rich source of nutrition and sustenance. Recognizing their potential, the Government of (GoI) declared 2018 as the "National Year of Millets". It rebranded them as "Nutri-Cereals" in April 2018 to promote their production and consumption for economic and nutritional benefits. This initiative aligns with the global recognition of millets, as evidenced by the United Nations designating 2023 as the "International Year of Millets" (Anonymous, 2023). This international acknowledgment underscores the crucial role of millets in sustainable food systems and highlights their importance in addressing global food security and nutrition challenges.

Among the various types of millets, Pearl millet [*Pennisetum glaucum* (L.) R. Br.], also known as *Bajra*, Cattail millet, or Bulrush millet, stands out as a staple food for millions, particularly in the world's poorest farming communities. This diploid crop, with a chromosome number of 2n=2x=14 and a substantial genome size of 1.76 Gb (Varshney *et al.*, 2017), is often referred to as the "Poor man's crop" due to its resilience and nutritional value. Originating from Africa, specifically from *Pennisetum glaucum* subsp. *Monodii* Maire, pearl millet has adapted to thrive in arid and semi-arid regions.

Pearl millet grains are nutritionally rich, containing higher levels of protein (14%), carbohydrates (70%), fat (5.7%), fiber (2.0%) and ash (2.1%) compared to many other cereals (Sade, 2009). It also offers a good balance of amino acids, making it an essential food source for those in nutrient-deficient regions. The promotion of pearl millet and other millets is crucial not only for enhancing food security and nutrition but also for supporting sustainable agricultural practices and economic stability in vulnerable communities.

In Asia, pearl millet stands as a pivotal cereal crop, extensively cultivated across the arid and semi-arid regions of India, Pakistan, Syria, Myanmar and Saudi Arabia (Yadav *et al.*, 2022). India, in particular, boasts a significant production scale, with a national average productivity of 1,510 kg/ha from an area of 7.57 million hectares, resulting in a total output of 11.43 million tonnes during 2023-24 (Anonymous, 2024). This resilient crop thrives in harsh environments with minimal rainfall (300-500 mm/year) and high daytime temperatures exceeding 30°C. As an allogamous species, pearl millet is highly heterozygous and heterogeneous, displaying considerable inbreeding depression balanced by its genetic load. Its protogynous flowering and wind-borne pollination mechanisms facilitate its cross-pollination, making it ideal for hybrid development.

The genetic improvement of pearl millet has historically relied on traditional breeding methods suited to cross-pollinated crops. Significant advancements have been achieved through the use of Cytoplasmic Genetic Male Sterility (CGMS) and population improvement techniques, complemented by modern biotechnological approaches (Bidinger *et al.*, 2007). Enhancing grain yield potential in pearl millet varieties or hybrids necessitates selecting parents with strong general combining abilities (GCA), a concept elucidated by Sprague and Tatum (1942). GCA and specific combining ability (SCA) are critical in understanding a biotype's ability to transmit desirable traits to its progeny.

Combining ability analysis provides valuable insights for selecting appropriate parents for hybridization, highlighting the gene actions influencing desirable traits. Understanding the genetic composition and evaluating available genotypes for combining ability is crucial before parent selection. GCA, associated with additive gene action and fixable gene effects, contrasts with SCA, which involves non-additive gene action and non-fixable effects (Birchler *et al.*, 2001). This distinction underscores the importance of strategic parent selection in breeding programs aimed at improving pearl millet yields and quality.

Materials and Methods

Experimental materials

The plant material comprised seven lines and nine restorer parents (testers). The lines were crossed in line × tester mating design procedure as proposed by Kempthorne (1957). Hybrids were produced in summer 2023. Thus, 16 parents and their 63 crosses formed the experimental material for the current study. A list of parents (Seven lines and nine testers) used in the crossing programme is given in Table 1.

Field trial

A field trial was conducted during *kharif* 2023 at the Regional Research Station (RRS), AAU, Anand. The study evaluated 63 hybrids, 16 parent lines and one check hybrid using a randomized complete block design (RCBD) with three replications. Each entry was sown in a single row of 4 meters in length, with inter-row and intra-row spacings of 60 cm and 10 cm, respectively. Standard agronomic practices were adhered to throughout the experiment. At the time of hybridization, to prevent cross-pollination from foreign pollen, panicles were covered with glassine paper bags at the panicle emergence stage, ensuring the collection of selfed seeds.

Statistical analysis was used to obtain estimates of general and specific combining ability variances and effects. The variance components of general combining ability (GCA) (σ^2_{gca}) and specific combining ability (SCA) (σ^2_{sca}) were calculated and used for the estimation of $\sigma^2_{sca}/\sigma^2_{gca}$ ratio and the predictability ratio $2\sigma^2_{gca}/(\sigma^2_{gca} + \sigma^2_{sca})$ (Baker, 1978).

Table 1 : The inbred lines used in line × tester trial of pearl millet.

Sr. no.	Lines	Sr. no.	Testers
1.	ICMA 04999	1.	ICMR 17193
2.	ICMA 98444	2.	ICMR 17264
3.	ICMA 704	3.	ICMR 17276
4.	ICMA 02444	4.	ICMR 17305
5.	ICMA 785	5.	ICMR 17327
6.	ICMA 05444	6.	ICMR 17560
7.	ICMA 95333	7.	ICMR 17336
		8.	ICMR 17441
		9.	ICMR 17444

Results and Discussion

Genetic variability and genetic variance

The analysis of variance (ANOVA) for combining ability revealed that mean square values due to lines were significant for all the characters showing the ultimate variation among lines for the studied character. Whereas, variance due to testers was significant for the characters, except productive tillers per plant. The variance due to hybrids was significant for all the characters except productive tillers per plant and earhead length. Kumawat *et al.* (2019) also found similar results for mean square values of lines, testers and hybrids.

The genetic parameters for combining ability revealed the importance of both additive and non-additive components of genetic variance for days to 50% flowering, plant height, earhead girth and test weight. The preponderance of non-additive genetic variance for days to physiological maturity, dry earhead weight per plant, stover yield per plant, panicle harvest index, grain yield per plant and protein content was seen as only σ^2_{sca} was found significant. The value more than one-half (0.5) of the predictability ratio for days to 50% flowering (Gavali *et al.*, 2024), plant height (Gavali *et al.*, 2024), productive tillers per plant (Lubadde *et al.*, 2016), earhead length (Maheswari *et al.*, 2023) and earhead girth (Maheswari *et al.*, 2023) suggested a preponderance of additive genetic variance. Whereas, less than one-half (0.5) value of predictability ratio for days to physiological maturity (Maheswari *et al.*, 2023), dry earhead weight per plant (Nandaniya *et al.*, 2016), stover yield per plant (Kumawat *et al.*, 2019), test weight (Maheswari *et al.*, 2023; Gavali *et al.*, 2024), panicle harvest index (Nandaniya *et al.*, 2016), grain yield per plant (Kumawat *et al.*, 2019; Chaudhry *et al.*, 2022) and protein content (Barathi and Reddy, 2022) suggested prime role of non-additive genetic variance for inheritance of these characters. The average degree of dominance more than one for days to physiological maturity, dry earhead weight per plant, stover yield per plant, test weight, panicle harvest index, grain yield per plant and protein content indicated the presence of over-dominance among the interacting alleles. The remaining characters days to 50% flowering, plant height, productive tillers per plant, earhead length and earhead girth less than one value for degree of dominance revealed the presence of partial dominance for the inheritance of these characters (Table 2).

Table 2 : Analysis of variance for combining ability for studied traits of pearl millet.

Sources of variation	**df**	**DFF**	**DPM**	**PH**	**PTP**	**EL**	**EG**	**DEWP**	**SYP**	**TW**	**PHI**	**GYP**	**PC**
Replications	2	6.40	3.68	17.83	3.49**	3.22	0.25	13.00	209.18	0.008	145.37	51.28	0.12
Lines	6	178.83**	16.37**	2974.61**	1.07**	95.08**	17.51**	981.05**	6586.08**	7.26**	287.38**	213.74**	40.62**
Testers	8	71.54**	17.76**	838.32**	0.38	15.04**	3.74**	1286.91**	12173.68**	10.07**	102.55*	582.15**	28.23**
Lines × testers	48	15.88**	10.31**	189.54**	0.35	3.57	0.64**	1047.50**	4329.88**	2.23**	177.29**	267.86**	20.23**
Error	124	3.85	1.57	41.60	0.31	2.69	0.11	14.01	185.18	0.04	49.3353	17.98	0.09
Genetic parameters													
σ^2_{gca} (lines)		6.03**	0.22	103.15**	0.03*	3.39**	0.62**	-2.46	83.56	0.19**	4.08	-2.00	0.76
σ^2_{gca} (testers)		2.65**	0.35	30.89**	0.002	0.55**	0.15**	11.40	373.51*	0.37**	-3.56	14.97*	0.38
σ^2_{gca} (Average)		4.55**	0.28	71.54**	0.02	2.15**	0.42**	3.60	210.42	0.27**	0.74	5.42	0.59
σ^2_{sca}		4.01**	2.91**	49.31**	0.01	0.29	0.18**	344.50**	1381.57**	0.73**	42.65**	83.29**	6.71**
$\sigma^2_{gca}/\sigma^2_{sca}$		1.14	0.10	1.45	1.50	7.36	2.37	0.01	0.15	0.37	0.02	0.07	0.09
Predictability ratio		0.69	0.16	0.74	0.75	0.94	0.83	0.02	0.23	0.42	0.03	0.12	0.15
Dominance variance (σ^2_D)		16.04	11.66	197.24	0.04	1.17	0.70	1377.99	5526.27	2.93	170.61	333.18	26.85
Additive variance (σ^2_A)		18.22	1.13	286.15	0.06	8.58	1.66	14.41	814.67	1.07	2.94	21.68	2.37
Degree of dominance		0.94	3.22	0.83	0.82	0.37	0.65	9.78	2.56	1.65	7.61	3.92	3.37

*, **, Significant at 0.05 and 0.01 levels of probability, respectively;
df: Degree of freedom, DFF: Days to 50% flowering, DPM: Days to physiological maturity, PH: Plant height, PTP: Productive tillers per plant, EL: Earhead length, EG: Earhead girth, DEWP: Dry earhead weight per plant, SYP: Stover yield per plant, TW: Test weight, PHI: Panicle harvest index, GYP: Grain yield per plant and PC: Protein content

Combining ability

Parents with a significant GCA effect in the desired direction were categorized as good, those with a non-significant GCA effect as average and those with a significant GCA effect in the undesired direction as poor general combiners. Similarly, the crosses were classified as good, average or poor specific combiners based on their performance.

General combining ability (GCA) effects of parents

The variation in the estimates of GCA effects for parents in the present investigation ranged in both directions for all the investigated traits. Kumawat *et al.* (2019), Chaudhry *et al.* (2022) and Maheswari *et al.* (2023) also found a similar variation in the GCA estimates in both directions.

Among the lines, ICMA 05444 and ICMA 04999 for days to 50% flowering, ICMA 704, ICMA 04999 and ICMA 05444 for days to physiological maturity, ICMA 04999, ICMA 05444 and ICMA 704 for plant height, ICMA 04999 for productive tillers per plant, ICMA 02444 for earhead length, ICMA 98444, ICMA 95333 and ICMA 704 for earhead girth, ICMA 95333, ICMA 785, ICMA 704 and ICMA 02444 for dry earhead weight per plant, ICMA 02444 and ICMA 785 for stover yield per plant, ICMA 785, ICMA 704 and ICMA 05444 for test weight, ICMA 04999 for panicle harvest index, ICMA 785 for grain yield per plant and ICMA 02444, ICMA 95333, ICMA 05444 and ICMA 98444 for protein content recorded significant values in the desired direction for the GCA effect, hence they were considered as good general combiners for respected characters.

Table 3 : GCA effects of parents for grain yield and its component characters in pearl millet.

Parents	DFF	DPM	PH	PTP	EL	EG	DEWP	SYP	TW	PHI	GYP	PC
Lines												
ICMA 04999	-1.57**	-0.57*	-18.83**	0.38**	-0.42	-0.74**	-3.09**	-5.03	-0.67**	4.56**	0.88	-0.84**
ICMA 98444	-0.46	0.39	5.05**	0.06	-1.57**	0.92**	-2.89**	-4.44	0.02	-2.55	-2.58**	0.12*
ICMA 704	2.10**	-0.96**	-2.84*	-0.06	0.23	0.70**	2.58**	-6.21*	0.38**	-1.31	1.36	-0.17**
ICMA 02444	1.87**	1.24**	14.91**	0.03	3.84**	-0.31**	1.50*	24.98**	0.00	-2.42	1.35	2.06**
ICMA 785	1.17**	0.61*	0.87	-0.22*	-0.37	-0.10	5.13**	14.38**	0.80**	2.59	2.95**	-1.92**
ICMA 05444	-4.94**	-0.54*	-4.56**	-0.01	-1.87**	-1.18**	-10.55**	-23.44**	0.09*	2.88*	-5.13**	0.19**
ICMA 95333	1.84**	-0.17	5.41**	-0.19	0.17	0.71**	7.32**	-0.24	-0.61**	-3.74**	1.17	0.55**
S. E. (g_i) ±	0.38	0.24	1.24	0.11	0.32	0.06	0.72	2.62	0.04	1.35	0.82	0.06
Testers												
ICMR 17193	1.81**	1.60**	6.12**	0.02	1.60**	0.66**	12.75**	34.55**	1.55**	0.99	9.08**	-0.37**
ICMR 17264	-4.24**	-0.93**	-0.43	0.13	0.56	-0.74**	-3.63**	-30.38**	0.16**	3.44*	-0.75	-1.75**
ICMR 17276	1.10*	-0.43	-7.28**	-0.13	-0.03	0.07	3.28**	-19.00**	0.08	2.77	2.22*	-0.56**
ICMR 17305	-0.19	0.55*	0.21	0.13	-0.89*	-0.38**	1.38	16.51**	-0.51**	0.51	-0.44	-0.18**
ICMR 17327	0.05	-0.64*	-5.52**	-0.11	-1.34**	0.42**	7.06**	7.24*	-0.34**	-2.58	1.47	1.35**
ICMR 17560	-0.19	-0.93**	-4.28**	-0.09	-0.07	-0.07	0.54	-17.33**	-0.96**	0.33	4.33**	-0.69**
ICMR 17336	0.52	0.31	12.96**	0.21	-0.02	-0.23**	-5.36**	27.52**	0.20**	-2.04	-4.63**	1.57**
ICMR 17441	-0.81	1.07**	1.37	0.01	0.45	0.06	-1.11	7.68*	0.06	-2.59	-1.92*	-0.75**
ICMR 17444	1.95**	-0.60*	-3.16*	-0.18	-0.26	0.20**	-14.90**	-26.79**	-0.24**	-0.83	-9.36**	1.37**
S. E. (g_j) ±	0.43	0.27	1.41	0.12	0.36	0.07	0.82	2.97	0.04	1.53	0.93	0.06
Range of GCA values for parents	-4.24 to 2.10	-0.96 to 1.60	-18.83 to 14.91	-0.22 to 0.38	-1.87 to 3.84	-1.18 to 0.92	-14.90 to 12.75	-30.38 to 34.55	-0.96 to 1.55	-3.74 to 4.56	-9.36 to 9.08	-1.92 to 2.06

*, **, Significant at 0.05 and 0.01 levels of probability, respectively;
df: Degree of freedom, DFF: Days to 50% flowering, DPM: Days to physiological maturity, PH: Plant height, PTP: Productive tillers per plant, EL: Earhead length, EG: Earhead girth, DEWP: Dry earhead weight per plant, SYP: Stover yield per plant, TW: Test weight, PHI: Panicle harvest index, GYP: Grain yield per plant and PC: Protein content

Among the testers, ICMR 17264 for days to 50% flowering, ICMR 17264, ICMR 17560, ICMR 17327 and ICMR 17444 for days to physiological maturity, ICMR 17336 and ICMR 17193 for plant height, ICMR 17193 for earhead length, ICMR 17193, ICMR 17327 and ICMR 17444 for earhead girth, ICMR 17193, ICMR 17327 and ICMR 17276 for dry earhead weight per plant, ICMR 17193, ICMR 17336, ICMR 17305, ICMR 17441 and ICMR 17327 for stover yield per plant, ICMR 17193, ICMR 17336 and ICMR 17264 for test weight, ICMR 17264 for panicle harvest index, ICMR 17193, ICMR 17560 and ICMR 17276 for grain yield per plant and ICMR 17336, ICMR 17444 and ICMR 17327 for protein content recorded significant values in the desired direction for the GCA effect, hence they were considered as good general combiners for respected characters.

Specific combining ability (SCA) effects of hybrids

The variation in the estimates of SCA effects for the hybrids in the present investigation varied in both directions for all the studied characters. Kumawat *et al.* (2019), Chaudhry *et al.* (2022) and Maheswari *et al.* (2023) also found a similar variation in the SCA estimates in both directions. The total number of hybrids with significant estimates of SCA effects in both directions with top-ranking three crosses for different studied traits is mentioned in Table 4.

For grain yield per plant, a total of 33 hybrids were recorded with significant SCA estimates among them 16 hybrids had positive and 17 hybrids had negative SCA values. The cross combination ICMA 05444 × ICMR 17276 (20.71) followed by ICMA 02444 × ICMR 17560 (16.79) and ICMA 95333 × ICMR 17193 (16.76) had substantial GCA effect estimates.

For days to 50% flowering, nine hybrids had negative significant SCA estimates among them the cross ICMA 02444 × ICMR 17264 (-4.21) had the highest negative significant SCA estimate. The cross combination ICMA 704 × ICMR 17193 had a substantial negative significant SCA estimate for days to physiological maturity (-2.47) and plant height (-14.54). For plant height, the cross ICMA 95333 × ICMR 17305 (17.72) had the maximum positive significant SCA effect.

The cross combination ICMA 05444 × ICMR 17444 had the highest significant SCA estimate in the desired direction for productive tillers per plant (0.72) and earhead girth (1.08) among three and 22 hybrids with positive significant estimates. For earhead length, only one cross ICMA 04999 × ICMR 17276 (3.06) had a positive significant estimate and one cross ICMA 02444 × ICMR 17327 (-2.37) recorded a negative significant SCA effect.

For dry earhead weight per plant, out of 63 hybrids evaluated, 47 depicted significant estimates, among them 23 crosses had positive SCA effects, of which the cross ICMA 95333 × ICMR 17327 (40.72) had a substantial estimate. The crosses, ICMA 02444 × ICMR 17305 (92.26), ICMA 98444 × ICMR 17327 (1.94), ICMA 05444 × ICMR 17305 (18.07) and ICMA 05444 × ICMR 17264 (5.92) recorded maximum SCA estimates for stover yield per plant, test weight, panicle harvest index and protein content among 14, 22, seven and 29 crosses with significant and positive SCA effects, respectively. The hybrids that were recorded with significant values in the desired direction for the SCA effect, hence they were considered as good specific combiners for respected characters.

The SCA effect values largely inform the role of intra- and inter-allelic interactions in heterosis expression. The crosses with high SCA effects do not necessarily yield higher mean values or heterotic effects and *vice versa.* Therefore, plant breeders must consider all these aspects independently when selecting crosses to exploit heterotic effects or develop parental lines. Based on the data on combing ability, parents such as ICMA 04999, ICMA 02444, ICMA 785, ICMR 17193, ICMR 17276 and ICMR 17560 exhibit notable performance across multiple traits, making them prime candidates for future breeding programmes. Their superiour combining ability in key areas such as plant height, yield and maturity traits suggests their potential to develop high-yielding hybrids. Plant breeders can use these parents to exploit their genetic potential, ensuring the development of robust, high-performing cultivars that meet the economic goals.

The cross ICMA 05444 × ICMR 17276 (P × G) showed the highest SCA effect value for grain yield per plant, with a poor general combiner as a female parent and a good general combiner as a male parent. The selected hybrids based on their SCA effect were categorized into six groups of general combiner parents: G × G, G × A, G × P, A × A, A × P and P × P. These groups revealed that a hybrid with high SCA effect doesn't always involve parents with high GCA effects, highlighting the importance of both intra- and inter-allelic interactions. Therefore, GCA effect information should be considered alongside *per se* performance to predict a cross's performance.

Table 4 : Specific combining ability (SCA) effects of top-ranking three hybrids for different studied traits.

Traits	**Hybrid (Line × Tester)**	**GCA estimates of parents**				**SCA**	**Range of SCA**	**No. of hybrids with significant SCA estimates**		
		Line		**Tester**				**Total**	**Positive**	**Negative**
DFF	ICMA 02444 × ICMR 17264	1.87**	P	-4.24**	G	-4.21**	-4.21 to 4.46	**18**	**9**	**9**
	ICMA 05444 × ICMR 17444	-4.94**	G	1.95**	P	-3.92**				
	ICMA 785 × ICMR 17441	1.17**	P	-0.81	A	-3.84**				
DPM	ICMA 704 × ICMR 17193	-0.96**	G	1.60**	P	-2.47**	-2.47 to 5.66	**24**	**12**	**12**
	ICMA 02444 × ICMR 17276	1.24**	P	-0.43	A	-2.31**				
	ICMA 02444 × ICMR 17305	1.24**	P	0.55*	P	-2.29**				
PH	ICMA 704 × ICMR 17193	-0.06	A	6.12**	G	-14.54**	-14.54 to 17.72	**21**	**10**	**11**
	ICMA 02444 × ICMR 17276	14.91**	P	-7.28**	P	-13.89**				
	ICMA 95333 × ICMR 17444	5.41**	P	-3.16**	P	-12.84**				
PTP	ICMA 05444 × ICMR 17444	-0.01	A	-0.18	A	0.72*	-0.56 to 0.72	**3**	**3**	**0**
	ICMA 785 × ICMR 17327	-0.22*	P	-0.11	A	0.66*				
	ICMA 02444 × ICMR 17560	0.03	A	-0.09	A	0.65*				

	ICMA 04999 × ICMR 17276	-0.42	A	-0.03	A	3.06*				
EL	--	--	--	--	--	--	-2.37 to 3.06	**2**	**1**	**1**
	--	--	--	--	--	--				
	ICMA 05444 × ICMR 17444	-1.18**	P	0.20 **	G	1.08**				
EG	ICMA 05444 × ICMR 17264	-1.18**	P	-0.74**	P	0.68**	-1.05 to 1.08	**22**	**12**	**10**
	ICMA 02444 × ICMR 17444	-0.31**	P	0.20**	G	0.64**				
	ICMA 95333 × ICMR 17327	7.32**	G	7.06**	G	40.72**				
DEWP	ICMA 05444 × ICMR 17276	-10.55**	P	3.28**	G	34.97**	-36.71 to 40.72	**47**	**23**	**24**
	ICMA 02444 × ICMR 17305	1.50*	G	1.38	A	32.68**				
	ICMA 02444 × ICMR 17305	24.98**	G	16.51**	G	92.26**				
SYP	ICMA 05444 × ICMR 17560	-23.44**	P	-17.33**	P	74.11**	-65.05 to 92.26	**32**	**14**	**18**
	ICMA 95333 × ICMR 17305	-0.24	A	16.51**	G	60.15**				
	ICMA 98444 × ICMR 17327	0.02	A	-0.34**	P	1.94**				
TW	ICMA 02444 × ICMR 17444	0.003	A	-0.24**	P	1.49**	-1.75 to 1.94	**42**	**22**	**20**
	ICMA 05444 × ICMR 17444	0.09*	G	-0.24**	P	1.43**				
	ICMA 05444 × ICMR 17305	2.88*	G	0.51	A	18.07**				
PHI	ICMA 785 × ICMR 17276	2.59	A	2.77	A	12.79**	-17.55 to 18.07	**14**	**7**	**7**
	ICMA 02444 × ICMR 17264	-2.42	A	3.44*	G	11.87**				
	ICMA 05444 × ICMR 17276	-5.13**	P	2.22*	G	20.71**				
GYP	ICMA 02444 × ICMR 17560	1.35	A	4.33**	G	16.79**	-21.36 to 20.71	**33**	**16**	**17**
	ICMA 95333 × ICMR 17193	1.17	A	9.08**	G	16.76**				
	ICMA 05444 × ICMR 17264	0.19**	G	-1.75**	P	5.92**				
PC	ICMA 04999 × ICMR 17560	-0.84**	P	-0.69**	P	4.94**	-6.96 to 5.92	**54**	**29**	**25**
	ICMA 05444 × ICMR 17305	0.19**	G	-0.18**	P	4.17**				

*, **, Significant at 0.05 and 0.01 levels of probability, respectively; General combing ability of parents: G = Good, A = Average, P = Poor
DFF: Days to 50% flowering, DPM: Days to physiological maturity, PH: Plant height, PTP: Productive tillers per plant, EL: Earhead length, EG: Earhead girth, DEWP: Dry earhead weight per plant, SYP: Stover yield per plant, TW: Test weight, PHI: Panicle harvest index, GYP: Grain yield per plant and PC: Protein content

Conclusion

The analysis of variance for combining ability demonstrated the significance of both additive and non-additive genetic variance across multiple traits in pearl millet. Notably, additive variance predominated in traits such as days to 50% flowering, plant height, and earhead girth, while non-additive variance was crucial for traits including days to physiological maturity, stover yield, and grain yield per plant. Superior general combiners among lines and testers were identified for their respective traits, highlighting their breeding potential. Specific combining ability (SCA) effects varied, with notable crosses such as ICMA 05444 × ICMR 17276 exhibiting high SCA for grain yield. The study underscores the importance of evaluating both GCA and SCA effects, as hybrids with high SCA do not always involve parents with high GCA. This comprehensive analysis provides valuable insights for breeding programs aiming to develop high-yielding and robust pearl millet cultivars.

Future Scope

Future research should focus on leveraging the observed gene actions in pearl millet breeding. Given the predominant role of non-additive gene action in most traits, heterosis breeding presents a promising approach for enhancement. To fully exploit both additive and non-additive gene actions, recurrent selection through intermating among desirable segregants followed by rigorous selection can be employed. This strategy may offer a robust alternative for comprehensive trait improvement. Further studies should explore optimizing these breeding techniques to maximize genetic gains and improve pearl millet's agronomic performance.

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