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Combining ability analysis for yield and yield attributing traits in pearl millet (*Pennisetum glaucum* (L.) R. Br.)

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Abstract
The present study was conducted to evaluate combining ability in pearl millet (*Pennisetum glaucum* (L.) R. Br.) for yield and related traits using a line × tester mating design. Five CMS lines and six restorers were crossed to produce 30 hybrids, which were evaluated along with parents and checks in an RBD during *Rabi* 2024-2025. Analysis of variance revealed significant variability among genotypes for most traits. General combining ability (GCA) effects indicated that lines 246A and 267A, and testers 1121R and 1071R, were superior combiners for yield and its components. Specific combining ability (SCA) effects identified promising hybrids such as 264A × 1071R and 246A × 1121R for key agronomic traits. The predominance of additive gene action for most characters suggests the effectiveness of simple selection and recombination breeding. Overall, the study identified promising parents and hybrids for enhancing pearl millet productivity.

Keywords: Pearl millet, combining ability, line × tester, additive gene action, hybrids

Introduction
Pearl millet (*Pennisetum glaucum* (L.) R. Br.) belongs to family Poaceae and genus Pennisetum. It is fourth important cereal food crop after rice, wheat and maize in India. It is a highly cross-pollinated, which exhibits a tremendous amount of diversity at both phenotypic and genotypic levels and it has protogyny and anemophily mechanisms, which meet the biological criteria for hybridization. It is widespread across Africa and India's arid and semi-arid areas, where it was traditionally cultivated.

Pearl millet is a short day C4 type warm weather crop and it can adapt well to drought and adverse agro ecological conditions, capable of rapid and vigorous growth, hence it is grown under marginal lands of low and erratic rainfall with high temperature and low soil fertility than any other cereals and also it rightly termed as poorman's food and nutri-cereal as it is a good source of carbohydrates, proteins, fat and minerals. Protein content of pearl millet is higher than barley, maize, sorghum and rice. It is having a low glycemic index, rich source of vitamins (thiamine, riboflavin and niacin) and minerals (P, K, Mg, Fe, Zn, Cu and Mn). To bring millets into the mainstream for exploiting the nutritional rich properties and promoting their cultivation, Govt. of India has declared Year 2023 as the "International Year of Millets" by FAO Committee on Agriculture (COAG) forum.

According to the concept of combining ability, the general combining ability is the average performance of a strain in a series of cross combinations, estimated from the performance of F_1 from the crosses, whereas specific combining ability is used to designate those cases in which certain combinations do relatively better or worse than would be expected on the basis of average performance of lines involved. General combining ability and specific combining ability reveals additive and non-additive gene actions, respectively. This helps the breeders to assess the parents for adoption in heterosis breeding programme. Therefore, it is essential to study combining ability to select superior combination of parents and to attain maximum success in the breeding programme.

The choice of the parents is governed by *per se* performance of the parents and behaviour of the parents in respective hybrid combinations. The mode of gene action depends upon the genetic structure and extent of divergence between the parents involved. Therefore, it is necessary to estimate the genetic potentialities of parents in hybrid combinations through systematic studies with regard to general combining ability and specific combining ability. A wide range of variability and cytoplasmic male sterility sources are available in pearl millet.

Keeping the above fact in mind, the present investigation was conducted to assess the combining ability for yield and yield attributing traits. To determine the nature and magnitude of gene action, line × tester mating design was utilized with a view to identify good combiners including CMS lines and restorers.

Materials and Methods

Five inbred lines *viz*., 267A, 211A, 246A, 264A and 287A were crossed with six inbred testers *viz*., 1138R, 1142R, 1233R, 1071R, 1095R and 1121R in a line x tester mating design in *Kharif*, 2023-2024 to generate 30 crosses. In total 44 genotypes, thirty F1s along with their parents (5 lines and 6 testers) and three checks (ABV 04, Pratap and Kaveri super boss) were evaluated in randomized block design with three replication at Agricultural Research Station, Ananthapuramu during *Rabi*, 2024-2025. Each entry was sown in two rows of 4m length with a spacing of 45 cm between the rows and 15 cm between the plants in a row. Intercultural operations and irrigation schedule were followed when necessary. Need based plant protection measures were adopted to raise a healthy crop.

Data were recorded on five randomly selected plants of each genotype in each replication for seven characters *viz*., plant height, number of productive tillers plant-1, flag leaf length, flag leaf width, panicle length, panicle grith, 1000 grain weight and on plot basis for 50 percent flowering and days to maturity, grain yield plot-1, fodder yield plot-1 and harvest index. The Analysis of Variance (ANOVA) for line × tester was done as per Kempthorne (1957) [7]. The gene action controlling the traits were identified through analysing the variances of general combining ability (GCA) and specific combining ability (SCA). The effects of general combining ability (gca) and specific combining ability (sca) were calculated and their significance were tested. The standard heterosis of the hybrids over the commercial hybrid were calculated for all the traits (Meredith and Bridge, 1972) [6]. All the analysis was carried out using the INDOSTAT statistical software.

Results and Discussion

Analysis of variance for combining ability in a line × tester mating design for yield and yield attributing traits revealed that studied genotypes recorded high significant differences for all the characters (Table 1). This indicated the presence of phenotypic variability in the material selected for the present investigation for yield and yield attributing traits.

The parents differed significantly for all the characters except days to 50% flowering and number of productive tillers plant-1 indicating the existence of sufficient variability in the studied genotypes. Mean sum of squares due to parents vs crosses were significantly different for all the characters except flag leaf length and flag leaf width. The crosses effects were partitioned into lines, testers and line × tester effect. Lines effect exhibited significant for all the characters except number of productive tillers plant-1, grain yield plot-1, fodder yield plot-1 and harvest index indicating the presence of variability for most of the traits except for these four traits. Tester effect exhibited non-significant difference for all the traits except for plant height, flag leaf length, flag leaf width and panicle length representing the presence of variability for these four traits among the testers. Line × tester effect recorded significant difference for all the traits except for flag leaf length, flag leaf width and thousand grain weight, that which represents the presence of variability for these traits among the crosses in the present study.

Estimates of general combining ability effects

In the present investigation among the 11 parents (five lines and six testers) evaluated for combining ability pertaining to different yield and its atttributing traits. The estimates of general combining ability effects of parents for all the characters have been given in Table 2. General combining ability effects suggested that the line 246A and 267A were found to be the best general combiners for yield and some of its attributes. Line 246A exhibited significant gca effect in desirable direction for days to 50% flowering, days to maturity, number of productive tillers plant-1, panicle girth, 1000 grain weight, grain yield plot-1 and fodder yield plot-1. Therefore, 246A proved to be good general combiner for above all the traits; 267A for plant height, flag leaf length, flag leaf width, panicle length.

Among the testers 1121R for grain yield plot-1 and number of productive tillers plant-1; 1071R recorded significant gca effect in desirable direction for traits like plant height, flag leaf length, flag leaf width, panicle length, panicle girth, and fodder yield plot-1; From the studies on general combining ability effects it is apparent that the inclusion of 246A and 267A as female parent and 1121R and 1071R as male parents in crossing programme would provide greater opportunity to generate more number of desirable transgressed segregants for grain yield and yield attributing traits, as these parents possessed high gca effects in desirable direction. Combining ability analysis revealed that GCA was highly significant for all the studied characters indicated that additive variance is predominant for these characters. These results were in conformity with Bhasker *et al.* (2017), Gavali *et al.* (2018), Badurkar *et al.* (2018) Kanfany *et al.* (2018) and Patel *et al.* (2018) [1, 8, 9].

Estimates of specific combining ability effects

The SCA effects (table 3.) showed that four hybrids recorded higher sca effects for yield and yield attributing traits. Significantly high sca effects in desirable direction was recorded by the cross 264A × 1071R for plant height, number of productive tillers plant-1, panicle length, panicle girth, grain yield plot-1 and fodder yield plot-1; 246A × 1121R for plant height, number of productive tillers plant-1, panicle length, panicle girth and harvest index; 267A × 1095R for number of productive tillers plant-1, grain yield plot-1 and fodder yield plot-1; 267A × 1138R for number of productive tillers plant-1, grain yield plot-1.

The estimates of gca variance (σ^2 GCA) were greater than the sca variance (σ^2 SCA) and the ratio of gca variance to sca variance σ^2 GCA/σ^2 SCA was greater than unity indicating the preponderance of additive gene action in the inheritance of all the expect number of productive tillers plant-1. Hence, simple selection techniques and recombination breeding with pedigree selection would be effective for improvement of the character. The similar results were reported by Surendhar *et al.* (2023) for grain yield per plant; Davda and Dangariya (2018) for days to 50% flowering, plant height and panicle length; Saini *et al.* (2018) [2, 4] earhead girth.

Table 1: Analysis of Variance for combining ability in a Line × Tester design with respect to yield and yield attributing traits in pearl millet

Source of variation	df	Mean Sum Of Squares											
		Days to 50% flowering	Days to maturity	Plant height (cm)	Number of productive tillers plant^{-1}	Flag leaf length (cm)	Flag leaf width (cm)	Panicle length (cm)	Panicle girth (cm)	1000 grain weight (g)	Grain yield plot-1 (kg)	Fodder yield plot^{-1} (kg)	Harvest index (%)
Replicates	2	1.927	1.927	30.077 *	0.184	18.015	0.444 **	5.328	0.004	1.38	0.013	0.127	18.789
Treatments	40	50.353 ***	49.874 ***	1259.319 ***	0.833 ***	18.986 ***	0.216 ***	21.571 ***	0.138 ***	5.235 ***	1.091 ***	1.076 ***	117.650 ***
Parents	10	7.291	17.218 ***	1161.528 ***	0.105	14.034 *	0.239 **	20.364 ***	0.140 ***	6.298 ***	0.138 **	0.325 **	191.660 ***
Parents (Line)	4	3.333	3.233	509.347 ***	0.171	20.161 *	0.554 ***	16.000 ***	0.160 ***	7.407 ***	0.258 ***	0.064	183.308 ***
Parents (Testers)	5	10.456	29.789 ***	403.981 ***	0.072	6.389	0.013	15.528 ***	0.137 ***	3.825 *	0.069	0.551 ***	226.529 ***
Parents (L vs T)	1	7.298	10.304	7557.992 ***	0.007	27.754	0.117	62.005 ***	0.078	14.230 **	0.001	0.241	50.729
Parents vs Crosses	1	1376.954 ***	1176.011 ***	31149.210 ***	13.215 ***	6.796	0.005	399.672 ***	0.673 ***	37.890 ***	27.952 ***	20.978 ***	344.225 ***
Crosses	29	19.457 ***	22.302 ***	262.353 ***	0.656 ***	21.114 ***	0.215 ***	8.949 ***	0.119 ***	3.742 ***	0.494 ***	0.649 ***	84.316 ***
Line Effect	4	78.289 ***	69.372 **	984.120 ***	0.867	59.465 **	0.482 **	20.557 *	0.312 **	17.774 ***	1.086	0.54	143.346
Tester Effect	5	16.453	27.273	327.471 *	0.489	33.319 *	0.542 ***	14.885 *	0.173	2.214	0.185	1.003	113.647
Line * Tester Eff.	20	8.442 *	11.646 **	101.721 ***	0.656 ***	10.393	0.081	5.143 **	0.067 ***	1.318	0.452 ***	0.582 ***	65.177 ***
Error	80	4.543	4.543	9.195	0.098	7.03	0.084	2.037	0.021	1.341	0.05	0.099	23.016
□² GCA		46.46	47.06	644.78	0.61	45.27	0.50	17.16	0.24	9.85	0.59	0.71	121.44
□² SCA		6.17	9.37	97.12	0.61	6.88	0.04	4.12	0.06	0.65	0.43	0.53	53.67
□² GCA/□² SCA		7.53	5.02	6.64	1.00	6.58	12.90	4.16	4.16	15.21	1.37	1.33	2.26

Table 2: Estimates of gca effect of lines and testers for yield attributing traits in pearl millet

Sl. No	Source	Days to 50% flowering	Days to maturity	Plant height (cm)	Number of productive tiller plant^{-1}	Flag leaf length (cm)	Flag leaf width (cm)	Panicle length (cm)	Panicle girth (cm)	1000 grain weight (g)	Grain yield per plot (kg)	Fodder yield per plot (kg)	Harvest index (%)
	LINES												
1	267A	1.567 **	1.600 **	9.364 ***	-0.127	2.629 ***	0.231 **	1.536 ***	0.097 **	-0.502	-0.055	-0.065	0.08
2	211A	-1.656 **	-1.289 *	-11.292 ***	0.107	-1.880 **	-0.147 *	-1.163 **	-0.154 ***	0.148	0.089	-0.173 *	4.005 ***
3	246A	-2.211 ***	-2.511 ***	1.684 *	0.262 ***	1.027	0.047	0.044	0.121 ***	0.914 **	0.315 ***	0.264 ***	0.39
4	264A	2.678 ***	2.211 ***	-0.445	0.062	-1.151	0.038	-0.828 *	0.066	0.878 **	0.013	0.075	-0.558
5	287A	-0.378	-0.011	0.688	-0.304 ***	-0.624	-0.169 *	0.411	-0.131 ***	-1.439 ***	-0.362 ***	-0.101	-3.917 **
	SE (g_i) Lines	0.502	0.502	0.715	0.074	0.625	0.068	0.336	0.034	0.273	0.053	0.074	1.131
	CD @ 5%	1.006	1.006	1.431	0.148	1.251	0.137	0.673	0.068	0.546	0.106	0.148	2.264
	CD @ 1%	1.338	1.338	1.904	0.197	1.665	0.182	0.896	0.090	0.727	0.141	0.197	3.012
	TESTERS												
1	1138R	-0.133	0.167	-3.915 ***	-0.156	0.986	0.046	0.153	0.07	0.437	-0.130 *	-0.273 **	2.299
2	1142R	-0.467	-0.567	1.485	-0.009	-0.436	0.042	0.326	-0.058	-0.308	-0.027	-0.346 ***	3.615 **
3	1233R	-1.600 **	-1.900 **	-5.407 ***	-0.076	0.192	-0.114	-0.35	-0.094 *	0.195	-0.104	0.038	-2.089
4	1071R	0	-0.7	7.848 ***	0.138	2.164 **	0.337 ***	1.719 ***	0.162 ***	-0.187	0.07	0.234 **	-2.444
5	1095R	0.733	1.233 *	-0.639	-0.182 *	-0.743	-0.122	-0.773 *	-0.114 **	-0.499	0.024	0.280 **	-2.720 *
6	1121R	1.467 **	1.767 **	0.628	0.284 ***	-2.162 **	-0.189 *	-1.075 **	0.034	0.361	0.167 **	0.067	1.339
	SE (g_j) tester	0.550	0.550	0.783	0.081	0.685	0.075	0.369	0.037	0.299	0.058	0.081	1.239
	CD @ 5%	1.102	1.102	1.567	0.162	1.370	0.150	0.738	0.074	0.598	0.116	0.163	2.480
	CD @ 1%	1.466	1.466	2.085	0.215	1.823	0.200	0.981	0.099	0.796	0.154	0.216	3.299

*:Significant at 5% level; ** : Significant at 1% level

Table 3: Estimates of SCA for yield and yield attributing traits in 30 crosses of pearl millet (*Pennisetum glaucum* L.)

Sl. No.	Cross Combination	Days to 50% flowering	Days to maturity	Plant height (cm)	Number of productive tiller plant^{-1}	Flag leaf length (cm)	Flag leaf width (cm)	Panicle length (cm)	Panicle girth (cm)	1000 grain weight (g)	Grain yield plot^{-1} (kg)	Fodder yield plot^{-1} (kg)	Harvest index (%)
1	267A × 1138R	1.967	2.333	3.356	0.433 *	-1.686	-0.154	0.285	0.158	0.328	0.537 ***	0.179	3.244
2	267A × 1142R	-0.7	-0.933	-4.177 *	-0.247	-1.397	-0.05	0.632	-0.044	-0.313	-0.492 ***	-0.278	-2.458
3	267A × 1233R	3.100 *	3.067 *	-7.985 ***	0.22	4.275 **	0.333	1.008	0.143	0.701	0.321 *	-0.062	4.866
4	267A × 1071R	-1.167	-2.800 *	7.260 ***	-0.460 *	1.783	-0.038	-0.222	-0.096	-0.348	-0.439 **	0.088	-6.434 *
5	267A × 1095R	-1.233	-0.067	3.147	0.460 *	-1.544	-0.119	-0.503	-0.11	-0.122	0.323 *	0.366 *	0.281
6	267A × 1121R	-1.967	-1.6	-1.601	-0.407 *	-1.432	0.028	-1.2	-0.052	-0.246	-0.25	-0.294	0.5
7	211A × 1138R	-1.144	-1.111	-2.122	-0.667 ***	0.536	0.051	-0.096	-0.068	-0.062	-0.393 **	-0.722 ***	7.130 *
8	211A × 1142R	-0.144	0.289	2.945	0.187	1.045	0.155	1.011	0.017	-0.356	0.115	-0.075	2.619
9	211A × 1233R	-2.011	-0.378	2.277	0.453 *	-2.029	-0.143	-0.793	-0.11	0.528	0.448 **	0.31	0.8
10	211A × 1071R	0.056	-0.911	-4.438 *	0.173	-0.875	-0.127	-0.309	0.031	0.216	0.144	0.017	0.818
11	211A × 1095R	0.989	0.822	2.536	0.293	1.205	0.172	0.056	0.067	-0.036	-0.004	0.381 *	-5.362
12	211A × 1121R	2.256	1.289	-1.198	-0.440 *	0.117	-0.108	0.132	0.062	-0.289	-0.310 *	0.088	-6.005 *
13	246A × 1138R	-0.589	-2.889 *	-6.331 ***	0.178	-2.571	-0.229	-1.103	-0.159	-0.264	-0.116	-0.213	0.706
14	246A × 1142R	-0.589	-0.489	3.969 *	0.364 *	0.585	0.048	-0.009	0.145	-0.429	0.342 *	0.22	0.804
15	246A × 1233R	0.878	-0.822	-1.739	-0.436 *	-0.123	0.111	-0.667	-0.128	0.152	-0.382 **	-0.081	-2.883
16	246A × 1071R	1.278	1.978	-3.727 *	-0.049	-0.255	0.033	-1.249	-0.121	-0.637	0.331 *	-0.097	5.207
17	246A × 1095R	0.544	2.044	-4.994 **	-0.796 ***	0.679	-0.048	0.296	0.002	0.195	-0.381 **	-0.13	-2.657
18	246A × 1121R	-1.522	0.178	12.822 ***	0.738 ***	1.684	0.085	2.732 **	0.261 **	0.982	0.207	0.3	-1.178
19	264A × 1138R	0.189	1.056	2.232	-0.022	1.207	0.32	0.116	0.112	-0.791	-0.113	0.301	-6.240 *
20	264A × 1142R	1.522	-0.211	-3.268	-0.036	0.296	-0.11	-1.517	-0.153	1.341 *	0.024	-0.01	0.27
21	264A × 1233R	-0.678	-0.211	-1.776	-0.236	-1.665	-0.227	-0.568	-0.04	-0.462	-0.2	0.182	-4.405
22	264A × 1071R	1.389	3.256 *	4.802 **	0.684 ***	-1.69	-0.024	3.216 ***	0.291 ***	0.266	0.526 ***	0.718 ***	-0.377
23	264A × 1095R	-1.344	-2.678 *	1.256	-0.262	0.583	0.001	0.008	-0.026	-0.592	-0.248	-0.540 **	2.805
24	264A × 1121R	-1.078	-1.211	-3.245	-0.129	1.268	0.041	-1.256	-0.184 *	0.238	0.012	-0.651 ***	7.946 **
25	287A × 1138R	-0.422	0.611	2.865	0.078	2.514	0.013	0.797	-0.044	0.789	0.085	0.453 *	-4.841
26	287A × 1142R	-0.089	1.344	0.532	-0.269	-0.53	-0.043	-0.116	0.034	-0.243	0.012	0.142	-1.235
27	287A × 1233R	-1.289	-1.656	9.224 ***	-0.002	-0.458	-0.074	1.02	0.134	-0.919	-0.187	-0.35	1.621
28	287A × 1071R	-1.556	-1.522	-3.898 *	-0.349	1.036	0.156	-1.436	-0.105	0.503	-0.561 ***	-0.726 ***	0.785
29	287A × 1095R	1.044	-0.122	-1.944	0.304	-0.924	-0.006	0.143	0.068	0.555	0.310 *	-0.076	4.933
30	287A × 1121R	2.311	1.344	-6.778 ***	0.238	-1.638	-0.046	-0.408	-0.087	-0.685	0.341 *	0.557 **	-1.264
	SE(s_{ij})	1.231	1.231	1.751	0.181	1.531	0.168	0.824	0.083	0.669	0.130	0.182	2.770
	CD @ 5%	2.463	2.463	3.505	0.362	3.064	0.335	1.649	0.166	1.338	0.259	0.363	5.544
	CD @ 1%	3.278	3.278	4.663	0.482	4.077	0.446	2.195	0.221	1.780	0.345	0.484	7.377

*:Significant at 5% level; ** : Significant at 1% level

Conclusion

Line 246A and testers 1121R & 1071R were good general combiners for yield and most of the yield traits, indicating it's potential as a parents for developing high yielding pearl millet hybrid. Therefore, it offered the best possibilities for cross 264A × 1071R and 267A × 1095R showing high sca effects for yield and yield attributing traits can be further tested in multi-locations to assess its stability and adaptability.

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