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Heterosis and combining ability studies of newly developed restorers in the pearl millet [*Pennisetum glaucum* (L.) R. Br.]

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Abstract
The maximum amount of positive heterosis for the traits per plant grains yield and per plant fodder yield over the better parent was found in the hybrid DHLB- 16A × S-21/14 (123.88% and 18.48%), followed by DHLB-23A × S-21/09 (116.69% and 4.17%) and DHLB-23A x S-21/18 (113.78%). These hybrids were evaluated using a 3 × 8 line x tester crossing design. In case of grain yield, the range of heterosis, over better parent found to be -46.51% (DHLB-16A x S-21/15) to 123.88 percent (DHLB-16A x S-21/14). Fodder yield, the range of heterosis over better parent was -44.68 percent (DHLB-16A x S-21/09) to 18.48 percent (DHLB-16A x S-21/14). The good × average combiner had higher frequency among hybrids with favorable and significant SCA impacts for grain yield. Among hybrids *viz*., DHLB -16A x S-21/14, DHLB -23A x S-21/15, DHLB-14A x S-21/13, DHLB -23A x S-21/18 and DHLB -16A x DHLBI -967 found to be good Specific combiners. Between three females, two lines *viz*., DHLB -16 A, DHLB -23A and among males *viz*., S-21/09, S-21/13 and S-21/14 were best general combiners and gave top yielding hybrid combinations.

Keywords: Heterosis, combining ability *viz*., GCA i.e. General Combining Ability effects, and SCA i.e. Specific Combining Ability effects

Introduction
The protogynous flowering pattern and anemophilous pollination mechanism, make the Pearl millet (*Pennisetum glaucum* (L.)R.Br.) a heavily cross-pollinated crop which satisfies one of the crucial biological prerequisites for hybrid production. With an average productivity of 1132 kg/ha, India is the world's largest producer of pearl millet in terms of both area (7.48 million hectare) and production (9.41 million ton). The only way to achieve the quantum leap in pearl millet's productivity from 303 kg/ha to 1250 kg/ha can be through the creation of hybrids using the cytoplasmic genetic male sterility (CGMS) technique. The cytoplasmic male sterility line of pearl millet Tift 23A grown in Tifton, Georgia, USA, was initially developed by Burton (1958) [1]. The improvement of pearl millet's traits, such as early flowering, the per plant productivity of tillers, per-plant grain and fodder yields, ear-head size and girth, iron and zinc content in the grains, etc. In order to calculate the heterosis for yield and morpho-nutritional characteristics as well as the general combining ability (GCA) effects, and specific combining ability (SCA) effects, the current study was done with keeping these aims in mind.

Materials and Methods
At the Bajra Research Scheme farm, of College of Agriculture, Dhule, during summer 2022, twenty-four crosses was made by line × tester mating design using three CMS (Cytoplasmic Male Steriles) line and eight male lines. At the Dhule location, during the Kharif of 2022, parents and twenty-four F1 hybrids were such planted in a plot having two rows of three metres each, spaced 50 cm apart from one another and 15 cm apart from the plants, in a Randomized Block Design (RBD) with two replications. As per the recommendations, All agronomic guidelines as per recommendation and plant protection precautions were followed. Twenty-four hybrids were used, with five competitive plants selected at random for taking observations from each replication for grains yield and fodder's yield character.

Result and Discussion

The hybrids DHLB- 16A x S-21/14 (123.88% for grain yield and 18.48 % for fodder yield) and DHLB- 23A x S-21/09 (116.69% for grain yield and 4.17% for fodder yield) both showed significant heterobeltiosis for grain yield per plant character as well as heterosis for fodder yield character. The range of heterosis over better parent was -46.51 percent (DHLB- 16 A x S-21/15) to 123.88 percent (DHLB-16A x S-21/14). Around eighteen of the twenty-four hybrids showed desired significant amount of heterosis over the superior parent. These findings were consistent with research by Patil (1994) [7], Vaghashiya (2009) [13], Vagadiya *et al.* (2010) [12], and Thakare *et al.* (2014) [10].

For the per plant fodder yield (g) character, heterobeltiosis ranged from -44.68 (DHLB- 16A x S-21/09) to +21.718. (DHLB- 16A x S-21/14) above the best parent. DHLB- 16A x S-21/14 above the better parent recorded the highest positive standard heterosis for per plant fodder yield (g) character (18.48%).

Almost all parental combinations (good x good character, good x average character, good x poor character, average x good character, average x average character, and poor x poor character) produced hybrids with positive and significant SCA impacts for the grain yield character (as shown in table 5). The crosses with high SCA effects had good x good, good x bad, good x average, or average x poor GCA effects for the parents were in general combinations. This was demonstrated in the top five hybrids for per plant grain yield, which were DHLB- 16A x S-21/14 (average x avarage), DHLB- 23A x S-21/15 (good x poor), DHLB- 14A x S-21/13 (poor x good), DHLB- 23A x S-21/18 (good x good), and DHLB- 16A x DHLBI- 967 (average x good). One of the parents of the top five hybrids, DHLB- 16A x S-21/14, DHLB- 23A x S-21/15, DHLB- 14A x S-21/13, DHLB- 23A x S-21/18, and DHLB- 16A x DHLBI- 967, was determined to be a good general (GCA) combiner (Table 4). As per the research conducted by Ingale *et al.*(1999) [4], Hapse (1989) [3], Rasal (1992) [8], and Thakare *et al.* (2014) [10], most traits have at least one or more average general combiners for high SCA effects.

A good combiner may be responsible for the high yielding potential of cross combinations (high X low character) or (low X high character), but heterosis in (high x high combiners) interacts favourably with itself. Different hybrids displayed both positive and negative heterosis for diverse traits. Additionally, the level of heterosis that hybrids expressed differed between cros5ses. The performance of the hybrids DHLB- 16A x S-21/14 (123.88%), DHLB- 23A x S-21/09 (116.69%), and DHLB-23A x S-21/18 (113.78%) over the better parent in the current experiment demonstrated favourable and highly significant SCA(Specific C.A.) effects on grain yield per hectare. Due of their economic viability, these combinations can be used commercially. Sashi *et al.* (2001) [14], Unnikrishnan *et al.* (2004) [11], and Sushir (2005) [9] and Thakare *et al.* (2014) [10] obtained comparable results.

The highest yielding hybrid combinations came from thei deal female parents DHLB-16A and DHLB-23A, and the male parents S-21/09, S-21/18, S-21/13, and DHLBI-967. In the present study, amongst top five hybrid combinations *viz.*, DHLB-16A x S-21/14, DHLB- 23A x S-21/09, DHLB-14A x S-21/13, DHLB- 23A x S-21/18 and DHLB-16A x DHLBI-967 were exhibited significant and favourable heterobeltiosis, General Combining Ability effects (GCA) and Specific Combining Ability (SCA) effects for per plant grain yield and fodder yield after comprehensive testing can be used for commercial growing. in the state and federal (National) trials.

Table 1: Partitioning of the variance for different morpho-nutritional traits in L x T mating design in pearl millet.

Source of Variations	DF	Grain Yield/plot	Fodder Yield/plot
Replicates	2	0.01777	0.06981
Treatments	34	0.17023**	0.86976**
Parents (Line)	2	0.01947	0.28
Parents (Testers)	7	0.02194*	0.1547
Parents (L vs T)	1	0.03459	0.0092
Parents vs Crosses	1	1.66962**	5.89969**
Crosses	23	0.16918**	0.95739**
Error	68	0.00939	0.16216

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

Table 2: Heterosis for Grain yield and fodder yield in pearl millet.

Sr. No	Crosses	Grain Yield/plot		Fodder Yield/plot	
		MP (%)	BP (%)	MP (%)	BP (%)
1	DHLB 14 A x S-21/09	85.24**	59.68**	-35.87**	-37.23**
2	DHLB 14 A x S-21/10	83.56**	64.05**	-13.97	-14.44
3	DHLB 14 A x S-21/13	136.3**	95.87**	-41.3**	-42.55**
4	DHLB 14 A x S-21/14	-0.66	-16.25	-12.09	-13.04
5	DHLB 14 A x S-21/15	22.39	-5.26	-21.14*	-23.33*
6	DHLB 14 A x S-21/18	4.79	-3.61	-17.24	-20
7	DHLB 14 A x S-21/19	97.39**	91.48**	-0.6	-7.78
8	DHLB 14 A x DHLBI 967	0.79	-13.35	-36.17**	-38.78**
9	DHLB 16 A x S-21/09	76.94**	74.1**	-39.53**	-44.68**
10	DHLB 16 A x S-21/10	71.6**	62.16**	-16.17	-21.35
11	DHLB 16 A x S-21/13	42.18**	37.82**	-32.56**	-38.3**
12	DHLB 16 A x S-21/14	126.24**	123.88**	28.24**	18.48
13	DHLB 16 A x S-21/15	-39.97**	-46.51**	-32.52**	-35.29**
14	DHLB 16 A x S-21/18	36.9*	25.58	-17.28	-20.24
15	DHLB 16 A x S-21/19	86.75**	62.98**	-38.06**	-38.46**
16	DHLB 16 A x DHLBI 967	41.23**	39.41*	-27.27**	-34.69**

17	DHLB 23 A x S-21/09	136.67**	116.69**	5.26	4.17
18	DHLB 23 A x S-21/10	34.72*	28.25	-30.81**	-33.33**
19	DHLB 23 A x S-21/13	87.5**	64.54**	-4.21	-5.21
20	DHLB 23 A x S-21/14	33.29*	19.14	-12.77	-14.58
21	DHLB 23 A x S-21/15	107.91**	69.37**	10.5	4.17
22	DHLB 23 A x S-21/18	117.71**	113.78**	-24.44*	-29.17**
23	DHLB 23 A x S-21/19	62.37**	56.41**	10.98	0
24	DHLB 23 A x DHLBI 967	11.87	2.13	-11.34	-12.24
	CD at 5 %	0.138	0.1593	0.5732	0.6618
	CD at 1 %	0.1842	0.2126	0.7651	0.8835

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

Table 3: Analysis of variance for combining ability.

Source	DF	Grain Yield/plot	Fodder Yield/plot
Replication	2	0.01209	0.02625
Females	2	0.1451	3.16292
Males	7	0.14425	0.53714
Female x Males	14	0.18508**	0.85244**
Error	46	0.01287	0.19147

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

Table 4: The Estimates of General Combining ability effect for Grain yield and fodder yield in pearl millet.

Sr. No.	Parent	Grain Yield/plot	Fodder Yield/plot
A) Female			
1	DHLB 14 B	-0.089**	-0.142
2	DHLB 16 B	0.033	-0.271**
3	DHLB 23 B	0.055**	0.413**
	SE	0.0198	0.0822
	CD at 5%	0.0398	0.1655
	CD at 1%	0.0532	0.2209
B) Male			
1	S-21/09	0.184**	-0.106
2	S-21/10	-0.021	-0.106
3	S-21/13	0.171**	-0.194
4	S-21/14	0.003	0.561**
5	S-21/15	-0.05	0.039
6	S-21/18	-0.088**	-0.15
7	S-21/19	-0.005	0.072
8	DHLBI 967	-0.196**	-0.117
	SE	0.0323	0.1342
	CD at 5%	0.065	0.2702
	CD at 1%	0.0868	0.3607

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

Table 5: The Estimates of Specific Combining ability effect for Grain yield and fodder yield in pearl millet.

Sr. No.	Crosses	Grain Yield/plot	Fodder Yield/plot
1	DHLB 14 A x S-21/09	-0.043	-0.236
2	DHLB 14 A x S-21/10	0.117*	0.364
3	DHLB 14 A x S-21/13	0.257**	-0.314
4	DHLB 14 A x S-21/14	-0.228**	-0.203
5	DHLB 14 A x S-21/15	0.013	-0.047
6	DHLB 14 A x S-21/18	-0.164**	0.242
7	DHLB 14 A x S-21/19	0.083	0.386
8	DHLB 14 A x DHLBI 967	-0.035	-0.192
9	DHLB 16 A x S-21/09	-0.062	-0.34
10	DHLB 16 A x S-21/10	0.08	0.26
11	DHLB 16 A x S-21/13	-0.193**	-0.051
12	DHLB 16 A x S-21/14	0.409**	0.893**
13	DHLB 16 A x S-21/15	-0.389**	-0.385
14	DHLB 16 A x S-21/18	-0.047	0.204
15	DHLB 16 A x S-21/19	0.068	-0.651**
16	DHLB 16 A x DHLBI 967	0.134*	0.071
17	DHLB 23 A x S-21/09	0.105	0.576*
18	DHLB 23 A x S-21/10	-0.197**	-0.624*
19	DHLB 23 A x S-21/13	-0.064	0.365
20	DHLB 23 A x S-21/14	-0.181**	-0.69**
21	DHLB 23 A x S-21/15	0.375**	0.432
22	DHLB 23 A x S-21/18	0.211**	-0.446

23	DHLB 23 A x S-21/19	-0.151**	0.265
24	DHLB 23 A x DHLBI 967	-0.099	0.121
	SE	0.056	0.2325
	CD at 5%	0.1126	0.468
	CD at 1%	0.1504	0.6247

*, ** denotes level of significance at 5% and 1 %, respectively

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