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Combining ability and gene action studies for grain yield and component traits in pearl millet (*Pennisetum glaucum* (L.) R. Br.)

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Abstract
An experiment was conducted with 46 treatments consisting of 36 hybrids which were developed through 9 x 9 diallel mating design along with nine inbreds and one standard check, *viz.*, Phule Aadishakti. The hybrids, parents and standard check were evaluated during *Kharif*- 2019 for ten characters. Analysis of variance for combining ability revealed that the mean sum of squares due to GCA and SCA were highly significant for all the characters. However, σ2gca/ σ2sca ratio was less than unity for all the characters except for grain Fe and Zn content, suggesting predominance of non-additive gene effects. Among all nine inbreds, DHLBI- 181138 was good general combiner for grain yield and had significant GCA effects for seven other characters. The inbreds, DHLBI-1708 and DHLBI-181181 were also found good general combiners along with high *per se* performance for most of the characters which should be further utilized in breeding programme for developing high yielding and early maturing varieties. The hybrid DHLBI-1708 x DHLBI-18963 evinced highly significant SCA effects for grain yield per plant followed by DHLBI-1708 x DHLBI-181138 and DHLBI-181181 x DHLBI-181138. They produced desirably significant SCA effect for most of the traits studied, indicating potential for exploiting hybrid vigour in breeding programme.

Keywords: Pearl millet, GCA, SCA, gene action, grain yield, diallel analysis

Introduction
Pearl millet [*Pennisetum glaucum* (L.) R. Br.] is highly cross-pollinated crop because of protogynous flowering condition and wind borne pollination mechanism, which satisfy one of the essential biological demand for hybrid development. India is a major producer of pearl millet both in terms of area (7.54-million ha) and production (10.36 million ton) with national average productivity of 1374 kg/ha. (Anonymous, 2021) [1]. Combining ability provides 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 varies with genetic architecture of population involve in hybridization therefore, it is necessary to evaluate the parents for their combining ability. This information enables the breeder to their utility in development of high yielding hybrids in pearl millet, whereas hybrids are being cultivated on commercial scale. Keeping the above fact in mind, the present investigation was conducted to assess the combining ability for yield and its contributing traits. To determine the nature and magnitude of gene action, half diallel mating design was utilized with a view to identify good combiners.

Materials and Methods
The present investigation was carried at Post Graduate Farm, Mahatma Phule Krishi Vidyapeeth, Rahuri, during *Kharif*- 2019. The experimental material consisting of nine inbred lines *viz.*, DHLBI-1103, DHLBI-967, DHLBI-1013, DHLBI-1708, DHLBI-18963, DHLBI-181181, DHLBI-181138, DHLBI-1035 and DHLBI-1603 which were obtained from Bajra Research Scheme, College of Agriculture, Dhule. Thirty six hybrids were produced through 9 x 9 half daillel mating design. A total of 46 treatments, including 36 F1s, nine inbred lines, and Phule Aadishakti as a standard check, were grown in a randomised block design with three replications. One row of each entry was planted in each replication, with a three metre row length and a 50 x 15 cm spacing between each entry.

Five competitive plants from each replication were randomly selected to record the observations on ten characters *viz.*, days to 50% flowering, days to maturity, plant height (cm), number of effective tillers/plant, earhead length (cm), earhead girth (cm), 1000-gain weight (g), grain yield/plant (g), grain iron (mg/kg) and grain zinc (mg/kg) content. Statistical analysis was done. Data was subjected to analysis of variance to find significant differences among genotypes for the recorded data. After obtaining, the significance, data recorded on parents and their F1s were subjected to combining ability analysis and the testing of significance of different genotypes was based on procedure given by Griffing (1956) [3] Model I (fixed effect model), Method II (parents and F1s excluding reciprocals).

Result and Discussion

Analysis of variance for combining ability was done for ten characters and presented in table 1. The mean sum of square due to treatments, inbreds and hybrids were highly significant for the all the characters studied in the present investigation. It indicates that presence of sustainable genetic variability among treatments with regards to characters under investigation. The mean sum of square due to inbred *v/s* hybrid were found to be significant for all characters except days to 50 percent flowering and days to maturity.

The analysis of variance for combining ability (general and specific combining ability) divulged that the variance due to parents i.e. general combining ability (GCA) effects and specific combining ability (SCA) effects were highly significant for all the characters (Table 2). This suggested that both the additive and non- additive gene effects were important in the inheritance of all the ten characters. However, σ2gca/ σ2sca ratio was less than one for all the characters except grain Fe and Zn, suggesting predominance of non-additive gene effects in control of the studied characters. The similar results were earlier reported by Joshi *et al.*, (2001) [4], Rathore *et al.*, (2004) [9], Shanmuganathan *et al.*, (2005) [10], Govindaraj *et al.* (2013) [2], Patel *et al.*, (2014) [7] and Kumawat *et al.*, (2019) [8]. Estimates of GCA and SCA effects for ten characters are presented in table 3 and table 4, respectively. In the present investigation the parent, DHLBI-181138 showed positively significant GCA effect for plant height, number of effective tillers per plant, earhead length, earhead girth, 1000-grain weight, grain yield per plant, grain Fe and grain Zn and also had high *per se* performance. Therefore, DHLBI-181138 proved to be good general combiner for above mentioned traits. The parent DHLBI-181181 recorded desirably significant GCA effect for days to 50% flowering, days to maturity, number of effective tillers per plant, earhead length and grain Zn content. While, DHLBI-1708 exhibits significant GCA effect in desirable direction for days to 50% flowering, days to maturity, number of effective tillers per plant and grain yield per plant and prove to be good inbred for developing early maturing hybrids. The parent DHLBI-967 was good general combiner for days to 50% flowering, days to maturity, plant height and earhead girth. DHLBI-1013 was identified as a good general combiner for plant height, grain Fe and grain Zn content. Parent DHLBI-18963 was showed significant positive GCA effects for earhead length and grain yield per plant. Parent DHLBI- 1035 was good general combiner for earhead length and 1000-grain weight, parent DHLBI- 1603 was also good general combiner for grain Fe and grain Zn content and the parent

DHLBI-1103 proved to be a good general combiner for days to maturity and number of tillers per plant.

The data on GCA effects revealed that the effects varied significantly for different characters and in different parents. The good general combiners had fixable component of variance like additive variance and additive x additive epistatic component; therefore, parents *viz.*, DHLBI- 181138, DHLBI-1708 and DHLBI-18963 offered the best possibilities of exploitation for development of improved high yielding lines in pearl millet.

Sprague and Tatum (1942) [10] reported that the SCA effect is due to non-additive genetic proportion. It is an important parameter for judging and selecting superior cross combinations, which might be exploited through heterosis breeding programme. The cross DHLBI-1708 x DHLBI-18963 evinced high significant SCA effects for grain yield as well as desirably significant SCA effect for plant height, number of effective tillers per plant, 1000-grain weight and grain Fe content. The cross DHLBI-1708 x DHLBI-181138 exhibited significant SCA effect in desirable direction for days to 50 percent flowering, plant height, number of effective tillers per plant, earhead girth, 1000-grain weight, grain yield per plant, grain Fe and grain Zn content. The cross combination, DHLBI-181181 x DHLBI-181138 displayed significant SCA effect in desirable direction for number of effective tillers per plant and grain yield per plant. Similar results were also reported by Govindaraj *et al.*, (2013) [2], Kanatti *et al.*, (2014) [5] and Khandagale *et al.*, (2014) [6].

Table 1: Analysis of variance for ten characters in 9 x 9 half diallel crosses in pearl millet.

Sources of variation	d.f.	Mean sum of squares									
		Days to 50% flowering	Days to maturity	Plant height (cm)	No. of effective tillers/plant	Earhead length (cm)	Earhead girth (cm)	1000-grain weight (g)	Grain yield per plant (g)	Grain Fe (mg/kg)	Grain Zn (mg/kg)
Replication	2	0.47	0.46	24.58	0.0073	0.024	0.14	0.20	4.46	4.42	0.67
Treatment	44	40.28**	39.73**	719.08**	0.42**	29.73**	2.73**	4.70**	263.81**	380.12**	198.85**
Parents	8	64.14**	70.98**	372.81**	0.34**	33.13**	1.12**	2.21**	57.62**	330.44**	223.02**
Hybrids	35	35.92**	33.72**	605.14**	0.44**	26.17**	2.92**	4.50**	230.55**	401.15**	195.44**
Parents *Vs.* Hybrid	1	1.66	0.90	7475.41**	0.30**	127.21**	9.00**	31.41**	3077.22**	41.40**	124.66**
Error	88	4.26	3.86	35.24	0.014	1.62	0.19	0.34	13.81	1.80	2.35
Total	134	16.03	15.58	259.61	0.14	10.83	1.02	1.77	95.76	126.06	66.84

*, ** Significant at 5 and 1 percent level, respectively

Table 2: Analysis of variance for combining ability of ten characters in pearl millet

Sources of variation	d.f.	Mean sum of squares									
		Days to 50% flowering	Days to maturity	Plant height (cm)	No. of effective tillers/plant	Earhead length (cm)	Earhead girth (cm)	1000-grain weight (g)	Grain yield per plant (g)	Grain Fe (mg/kg)	Grain Zn (mg/kg)
GCA	8	38.74**	36.47**	654.00**	0.35**	32.88**	2.02**	2.13**	123.47**	535.83**	277.17**
SCA	36	7.80**	8.08**	147.61**	0.092**	4.80**	0.66**	1.44**	80.04**	35.79**	19.42**
Error	88	1.42	1.28	11.74	0.38	0.54	0.06	0.11	4.60	0.60	0.78
σ2gca		3.39	3.19	58.38	0.032	2.94	0.17	0.18	10.81	48.65	25.12
σ2sca		6.37	6.79	135.86	0.088	4.26	0.60	1.32	75.43	35.18	18.63
σ2gca/ σ2sca		0.53	0.47	0.42	0.36	0.68	0.29	0.14	0.14	1.38	1.34

*, ** Significant at 5 and 1 percent level, respectively

Table 3: Estimates of general combining ability effects of in breds for ten characters in pearl millet

Sr. No	In breds	Days to 50% flowering	Days to maturity	Plant height (cm)	No. of effective tillers/plant	Earhead length (cm)	Earhead girth (cm)	1000-grain weight (g)	Grain yield per plant (g)	Grain Fe (mg/kg)	Grain Zn (mg/kg)
1.	DHLBI-1103	-0.32	-1.22**	-7.19**	0.07**	-3.33**	-0.69**	0.05	0.98	-2.94**	-2.60**
2.	DHLBI-967	-1.47**	-1.07**	2.59**	-0.03*	-0.97**	0.59**	-0.39**	-1.54*	-10.28**	-4.26**
3.	DHLBI-1013	0.41	0.81*	3.38**	-0.02	0.35	-0.05	0.08	-0.56	4.89**	4.28**
4.	DHLBI-1708	-2.89**	-2.71**	1.59	0.25**	-0.86**	-0.17*	-0.49**	3.01**	-5.52**	-8.42**
5.	DHLBI-18963	0.35	0.14	1.84	0.004	1.14**	-0.21**	-0.16	1.33*	-2.20**	-0.72**
6.	DHLBI-181181	-1.96**	-1.74**	-3.47**	0.10**	2.56**	0.08	-0.27**	-1.53*	0.15	0.86**
7.	DHLBI-181138	2.38**	2.11**	14.77**	0.22**	1.39**	0.70**	0.95**	6.20**	13.88**	8.09**
8.	DHLBI-1035	0.86*	0.93**	-0.52	-0.09**	0.62**	-0.03	0.38**	-2.67**	-2.23**	-1.49**
9.	DHLBI-1603	2.65**	2.75**	-13.01**	-0.35**	-0.92**	-0.21**	-0.17**	-5.23**	4.25**	4.26**
	SE(gi)	0.33	0.32	0.97	0.018	0.20	0.07	0.10	0.61	0.22	0.25
	CD at 5%	0.67	0.64	1.93	0.037	0.41	0.14	0.20	1.21	0.43	0.50
	CD at 1%	0.88	0.86	2.58	0.049	0.55	0.19	0.27	1.63	0.58	0.66

*, ** Significant at 5 and 1 percent level, respectively

Table 4: Estimates of specific combining ability effects of crosses for ten characters in pearl millet.

Sr. no.	Crosses	Days to 50% flowering	Days to maturity	Plant height (cm)	No. effective tillers/plant	Earhead length (cm)
1.	DHLBI-1103 x DHLBI-967	-2.06	-2.35*	3.17	0.12*	0.97
2.	DHLBI-1103 x DHLBI-1013	0.061	1.10	5.28	0.18**	-1.78**
3.	DHLBI-1103 x DHLBI-1708	0.69	2.28*	1.06	-0.29**	1.31
4.	DHLBI-1103 x DHLBI-18963	0.78	1.10	9.92**	-0.05	0.31
5.	DHLBI-1103 x DHLBI-181181	3.75**	4.64**	2.01	0.15*	1.34*
6.	DHLBI-1103 x DHLBI-181138	-0.24	-0.20	8.32*	0.03	1.94**
7.	DHLBI-1103 x DHLBI-1035	0.72	-1.64	14.96**	0.37**	3.72**
8.	DHLBI-1103 x DHLBI-1603	5.15**	1.49	-21.32**	-0.12*	-5.62**
9.	DHLBI-967 x DHLBI-1013	-0.12	-0.04	7.42*	0.39**	0.18
10.	DHLBI-967 x DHLBI-1708	3.18**	4.13**	1.39	-0.60**	0.17
11.	DHLBI-967 x DHLBI-18963	-3.27**	3.61**	2.25	0.02	1.50*
12.	DHLBI-967 x DHLBI-181181	-3.75**	-4.83**	14.46**	-0.23**	1.97**
13.	DHLBI-967 x DHLBI-181138	2.24*	2.64*	5.55	-0.25**	3.14**
14.	DHLBI-967 x DHLBI-1035	0.75	1.16	6.03	-0.17**	-3.41**
15.	DHLBI-967 x DHLBI-1603	-1.03	0.01	14.89**	0.15*	1.12
16.	DHLBI-1013 x DHLBI-1708	-4.03**	-4.41**	2.60	-0.06	0.84
17.	DHLBI-1013 x DHLBI-18963	-2.27*	-1.26	1.46	-0.32**	1.62*
18.	DHLBI-1013 x DHLBI-181181	4.69**	4.28**	15.78**	-0.01	0.43
19.	DHLBI-1013 x DHLBI-181138	-0.30	-0.56	7.62*	0.03	-0.51
20.	DHLBI-1013 x DHLBI-1035	-3.12**	-2.04	-12.83**	-0.24**	-0.95
21.	DHLBI-1013 x DHLBI-1603	1.75	0.80	8.54**	0.08	2.68**
22.	DHLBI-1708 x DHLBI-18963	-0.30	-0.74	10.69**	0.60**	-2.83**
23.	DHLBI-1708 x DHLBI-181181	-2.00	-1.86	4.12	0.40**	1.31
24.	DHLBI-1708 x DHLBI-181138	-2.33*	-0.04	7.92*	0.42**	1.14
25.	DHLBI-1708 x DHLBI-1035	3.51**	0.80	6.40*	0.45**	1.58*
26.	DHLBI-1708 x DHLBI-1603	0.72	1.64	1.66	0.29**	1.67*
27.	DHLBI-18963 x DHLBI-181181	-6.24**	-8.38**	-8.79**	-0.31**	0.64
28.	DHLBI-18963 x DHLBI-181138	-0.24	0.77	0.29	-0.06	1.63*
29.	DHLBI-18963 x DHLBI-1035	0.93	0.61	7.93*	-0.36**	-0.08
30.	DHLBI-18963 x DHLBI-1603	-0.84	-0.53	-8.91**	0.21**	3.23**
31.	DHLBI-181181 x DHLBI-181138	2.72*	0.64	-3.27	0.31**	-0.38

32.	DHLBI-181181 x DHLBI-1035	-1.09	0.49	-6.42*	-0.01	0.83
33.	DHLBI-181181 x DHLBI-1603	0.45	0.67	-0.93	-0.18**	-1.85**
34.	DHLBI-181138 x DHLBI-1035	-2.42*	-3.01**	6.66*	0.07	1.33*
35.	DHLBI-181138 x DHLBI-1603	-0.87	-0.50	16.82**	-0.34**	0.75
36.	DHLBI-1035 x DHLBI-1603	-4.36**	-3.32**	1.11	0.21**	0.75
	SE ±	1.09	1.03	3.13	0.06	0.67
	CD at 5%	2.16	2.06	6.22	0.11	1.33
	CD at 1%	2.91	2.75	8.35	0.16	1.78

Table 4: Contd…

Sr. no.	Crosses	Earhead girth (cm)	1000-grain weight (g)	Grain yield/plant (g)	Grain Fe (mg/kg)	Grain Zn (mg/kg)
1.	DHLBI-1103 x DHLBI-967	0.29	-0.12	6.27**	1.94**	-2.12*
2.	DHLBI-1103 x DHLBI-1013	-0.61**	-1.86**	5.19*	1.25	2.27**
3.	DHLBI-1103 x DHLBI-1708	0.17	0.19	-0.24	-4.82**	-7.51**
4.	DHLBI-1103 x DHLBI-18963	1.10**	1.12**	3.97*	2.82**	3.33**
5.	DHLBI-1103 x DHLBI-181181	0.46*	0.75*	3.76	7.37**	4.88**
6.	DHLBI-1103 x DHLBI-181138	0.84**	0.31	2.56	-0.65	4.12**
7.	DHLBI-1103 x DHLBI-1035	0.25	1.08**	9.18**	4.29**	6.51**
8.	DHLBI-1103 x DHLBI-1603	-2.34**	1.00**	-9.49**	-4.87**	2.01*
9.	DHLBI-967 x DHLBI-1013	0.19	1.46**	8.20**	6.84**	6.11**
10.	DHLBI-967 x DHLBI-1708	-0.01	-1.10**	-12.29**	-8.27**	3.83**
11.	DHLBI-967 x DHLBI-18963	-0.08	1.08**	3.31	-1.26	5.99**
12.	DHLBI-967 x DHLBI-181181	0.28	1.70**	3.17	0.63	-3.92**
13.	DHLBI-967 x DHLBI-181138	0.88**	-1.01**	0.66	-7.90**	-2.28**
14.	DHLBI-967 x DHLBI-1035	0.62**	0.55	-11.17**	-2.18**	-8.14**
15.	DHLBI-967 x DHLBI-1603	0.35	0.94**	7.04**	-2.26**	-1.48
16.	DHLBI-1013 x DHLBI-1708	-0.03	-0.48	-4.46*	-6.08**	1.35
17.	DHLBI-1013 x DHLBI-18963	-0.32	0.90**	3.93*	-2.02**	-1.12
18.	DHLBI-1013 x DHLBI-181181	-0.06	0.11	3.45	2.22**	-1.08
19.	DHLBI-1013 x DHLBI-181138	0.09	0.86**	3.58	5.61**	4.08**
20.	DHLBI-1013 x DHLBI-1035	0.38	-0.60	0.78	-4.73**	-2.98**
21.	DHLBI-1013 x DHLBI-1603	0.89**	0.95**	0.89	-2.87**	-5.32**
22.	DHLBI-1708 x DHLBI-18963	0.24	1.15**	13.29**	6.53**	-1.61*
23.	DHLBI-1708 x DHLBI-181181	-0.38	0.13	9.10**	5.73**	0.65
24.	DHLBI-1708 x DHLBI-181138	0.64**	1.15**	11.53**	13.34**	6.54**
25.	DHLBI-1708 x DHLBI-1035	0.06	1.16**	7.96**	-0.92	-3.11**
26.	DHLBI-1708 x DHLBI-1603	0.68**	-1.45**	6.80**	-0.21	-5.62**
27.	DHLBI-18963 x DHLBI-181181	-0.12	-3.21**	-11.71**	-0.54	-0.72
28.	DHLBI-18963 x DHLBI-181138	0.85**	0.60	4.58*	-4.16**	-5.38**
29.	DHLBI-18963 x DHLBI-1035	-1.12**	-1.45**	-9.42**	-5.98**	-1.20
30.	DHLBI-18963 x DHLBI-1603	0.72**	0.75*	6.52**	1.14	1.77*
31.	DHLBI-181181 x DHLBI-181138	-0.04	0.46	9.66**	1.30	-0.65
32.	DHLBI-181181 x DHLBI-1035	0.80**	0.47	4.50*	-10.34**	0.28
33.	DHLBI-181181 x DHLBI-1603	-0.30	0.31	-6.99**	-4.77**	1.66*
34.	DHLBI-181138 x DHLBI-1035	-0.93**	0.43	4.06*	8.80**	3.70**
35.	DHLBI-181138 x DHLBI-1603	1.80**	0.12	-4.97*	8.05**	2.90**
36.	DHLBI-1035 x DHLBI-1603	0.09	-0.21	8.02**	7.32**	4.43**
	SE ±	0.23	0.31	1.96	0.70	0.80
	CD at 5%	0.46	0.61	3.90	1.41	1.60
	CD at 1%	0.61	0.83	5.23	1.86	2.13

*, ** Significant at 5 and 1 percent level, respectively

Conclusion

In the present investigation, DHLBI-181138, DHLBI-1708 and DHLBI-18963 were potential parents having good general combining ability for grain yield per plant and also had good *per se* performance for most of the characters indicating great potential and should be included in further breeding programme for pearl millet improvement. The cross DHLBI-1708 x DHLBI- 18963, DHLBI-1708 x DHLBI-181138 and DHLBI-181181 x DHLBI-181138 were good specific combiner for grain yield per plant. They produced desirably significant SCA effects and high *per se* performance for most of the traits, indicating potential for obtaining desirable transgressive segregants.

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