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Combining ability and gene action studies for nutritional traits in pearl millet [*Pennisetum glaucum* (L.) R Br.]

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Abstract
The forty hybrids used in the experiment were produced by a line x tester mating design with four male sterile lines and ten restores serving as parental material. Two hybrids, Aadishakti and Pratap, were used as standard checks. "During the Kharif 2018 season, the parents, hybrids, and two standard checks were evaluated for a total of 12 traits". Notable variations were noted for each of the twelve characters under investigation. The greatest general combiner for grain yield among the females was determined to be DHLB-787A, which also had noteworthy GCA impacts for eight additional traits. Due to their strong GCA effects, DHLB-754A and DHLB-769A were excellent general combiners for earliness. For grain iron and zinc concentration (ppm), DHLB-754-A and DHLB-787A were good general combiners. For the majority of the characters under examination, it was discovered that S-18/05, S-18/08, S-18/06, S-18/07, S-18/03, and S-18/04 were good general combiners among the male parents. "The cross DHLB-760 x S-18/05 is the best specific combiner for grain yield per plant; DHLB-760 x S-18/09 and DHLB-769A x S-18/09 are the next best combinations". The best specific combiner for iron content (ppm) was the cross combination DHLB-760 x S-18/01. For the majority of the variables under investigation, they generated noteworthy and advantageous SCA effects, with the possibility of utilizing hybrid vigor in breeding programs.

Keywords: GCA, gene action, grain yield, SCA, iron content, and zinc content, pearl millet

Introduction

"Pearl millet (*Pennisetum glaucum* (L.) R. Br.) is a highly cross-pollinated crop that meets one of the essential biological requirements for hybrid generation with its protogynous flowering and wind-borne pollination mechanism". India is a major producer of pearl millet, with an average productivity of 1243 kg/ha, and an area of 6.3 million ha and 8.61 million tons, respectively (Anonymous, 2020) [2].

It is vital to assess the parents' combining ability because it offers valuable insight into the selection of appropriate parents for a successful hybridization program and clarifies how the genetic architecture of the population involved in hybridization affects the type and amount of gene action. With the use of this knowledge, breeders can generate high-yielding F1 hybrids for pearl millet, a crop where hybrids are grown commercially.

With the aforementioned point in mind, the current study was conducted to assess the combining capacity for yield and its contributing attributes. "The type and degree of gene action was evaluated using line x tester mating design in order to identify suitable combiners, such as CMS lines and restorers".

Materials and Methods

The current study was conducted in Kharif of 2018 at the Bajra Research Scheme, College of Agriculture Dhule. The ten testers (S-18/01, S-18/02, S-18/03, S-18/04, S-18/05, S-18/06, S-18/07, S-18/08, S-18/09, and S-18/10) and the four male sterile lines (DHLB-754A, DHLB-760A, DHLB-769A, and DHLB-787A) used in the experiment. The forty F1 hybrids were created by crossing all fourteen parents in accordance with Kempthorne's 1957 [10] Line x Tester mating plan. 56 treatments in all, including 40 F1s, 10 restorers (Male parents), 4 male sterile lines (Female parents), and 2 check hybrids, Pratap and Aadishakti, were cultivated in a randomized block design with three replications. Every entry was planted in two rows of 4.5 meters each, spaced 50 by 15 cm apart, for each replication. “Ten competitive plants were randomly selected in order to record the observations on 12 characters: days to 50% flowering, days to maturity, plant height (cm), number of effective tillers/plant, earhead length (cm), earhead girth (cm), grain yield/plant (g), fodder yield/plant (g), 1000 - grain weight (g), grains/cm2, grain iron content (ppm), and zinc content (ppm)”. And the statistical analysis was finished. To identify significant differences among genotypes for the recorded data, analysis of variance was applied to the data. Following the acquisition of significance, combining ability analysis was applied to the data on parents and their F1 offspring, and Kempthorne's (1957) [10] method was used to examine the significance of various genotypes.

Results and discussion

Variance analysis for the ability to combine

Twelve characters underwent analysis of variance for combining ability, which is displayed in Table 1. With the exception of days to maturity, the number of effective tillers per plant, earhead girth per plant, grain yield per plot, and zinc content, all traits had mean owing to lines that were significant. With the exception of days to maturity, no effective tillers/plant, 1000-grain weight (g), and the studied iron and zinc content (ppm), tester-related variations were significant for all the characteristics. All characters showed significant mean squares owing to the line x tester, with the exception of zinc content (ppm). There were notable variations observed in each of the parents' attributes, suggesting that the materials chosen were varied and contributed significantly to the genetic variety of the crosses.

Combing ability study (Table 2) indicated that GCA was very significant for every character that was studied, with the exception of zinc concentration. These findings were consistent with those of Patil *et al*. (2005) [24], Lakshmana *et al*. (2003) [13], and Badurkar *et al*. (2018) [4]. The significantly significant SCA variations for every feature show that epistatic gene activity is predominant. The analysis also showed that the days to 50% flowering, earhead girth, grain yield/plot, fodder yield/plot, 1000 grain weight, iron content, and zinc content had larger mean sum of squares for SCA, which suggested a preponderance of non-additive gene action to influence these features. Therefore, heterosis breeding will be fruitful (Dhuppe *et al*., 2006; Karvar *et al*., 2017; Shruti R. *et al*., 2020; Gaoh *et al*., 2023 and so on) [6, 9, 25, 7].

General and specific combining ability

Tables 3 and 4 provide estimates of the GCA and SCA effects for twelve characters, respectively. The parent, DHLB-787A, demonstrated a strong positive GCA effect in the current study for the following parameters: plant height, days to 50% blooming, days to maturity, number of effective tillers per plant, grain yield per plant, 1000 grain weight, and iron and zinc content (ppm). In light of the grain production per plant, days to 50% blooming, days to maturity, number of effective tillers per plant, and iron and zinc content (ppm), DHLB-787A turned out to be a good general combiner. “On the other hand, DHLB-754A showed a desirable positive significant general combining ability effect for earhead length, fodder yield, 1000-grain weight, grains/cm2, iron, and zinc content, and a desirable negative significant general combining ability effect for days to 50% flowering and days to maturity”. This made it an excellent parent for creating early maturing varieties. Positive GCA effects for grain iron content were demonstrated by the parents DHLB-754A and DHLB-787A, indicating their potential as good parents for grain zinc and iron content.

Parents S-18/05 showed significant +ve GCA effects for grain yield, effective tillers/plant, earhead girth, fodder yield, 1000-grain weight, and iron content; parents S-18/08 showed significant +ve GCA effects for earhead length, earhead girth, fodder yield, 1000-grain weight, grains/cm2, and zinc content. The tester, S-18/07, recorded significant GCA effects for zinc content, earhead length, earhead girth, grains/cm2, and plant height, “while the parent, S-18/06, recorded significant GCA effects for the number of effective tillers, earhead length, fodder yield, and grain/cm2”. S-18/04 showed a positive significant effect for iron content, while the parent S-18/03 was an excellent general combiner for 1000-grain weight, iron and zinc content, and desirable and negative GCA effect for days to 50% flowering and days to maturity.

The GCA effect data showed that the effects differed considerably between characteristics and between parents. Because the good general combiners had fixable components of variance such as additive variance and additive x additive epistatic component, the parents DHLB-787A, DHLB-754A, S-18/03, S-18/04, S-18/05, S-18/06, S-18/07, and S-18/08 offered the best opportunities of exploitation for development of improved high yielding and grain iron and zinc content lines in pearl millet.

According to Sprague and Tatum (1942) [20], non-additive genetic proportion is the cause of the SCA effect. It is a crucial factor in determining and choosing the best cross combinations, which may be used in a program of heterosis breeding. “In the cross DHLB-760 x S-18/09, a positive significant SCA effect was noted for grain yield per plant, 1000-grain weight, and a significant SCA effect in the negative direction for days to maturity. In the cross DHLB-760A x S-18/01, on the other hand, a positive significant SCA effect was noted for grain yield per plant, number of effective tillers per plant, earhead length, fodder yield per plant, iron, and zinc content (ppm)”. Similar results were also reported by Suryawanshi *et al*. (2021) [21], Rathore *et al*. (2004) [18], Bhandari *et al*. (2007) [5], and Gavali *et al*. (2018) [15]. For grain yield per plot, 1000-grain weight, and days to 50% flowering, the cross combination DHLB-769 A x S-18/09 demonstrated a positive significant SCA effect and a negative significant SCA effect.

Table 1: Analysis of variance for different characters in L x T mating in pearl millet.

Sources	D.F.	Days to 50% flowering	Days to maturity	Plant height (cm)	No. of effective tillers /plant	Ear head length (cm)	Ear head girth (cm)	Grain yield /Plot (kg)	Fodder yield /plot (kg)	1000 grain weight (g)	Grains /cm^2	Iron content (ppm)	Zinc content (ppm)
		1	2	3	4	5	6	7	8	9	10	11	12
Replications	2	4.37	1.608	197.08	0.003	3.75	0.92	0.184	0.126	0.126	3.72	4.43	1.40
Females	3	89.21**	43.355	2095.8**	0.265	17.6**	0.635	0.126	1.654**	45.2**	18.82**	329.5*	51.85
Males	9	68.81**	41.959	957.87**	0.267	15.7**	2.58**	0.543**	1.440**	7.234	16.99**	149.5	87.48
Female X Males	27	12.00**	22.13**	259.81**	0.22**	2.70**	0.73**	0.15**	0.347**	9.15**	2.851**	108.8**	77.06
Error	78	2.315	1.112	64.799	0.008	1.24	0.307	0.062	0.044	0.042	1.261	1.31	0.69

*, ** denote significant at 5% and 1% levels, respectively.

Table 2: Estimate of GCA, SCA, additive and dominance variances, gene action and heritability for different characters in pearl millet

Variances	Days to 50% flowering	Days to maturity	Plant height (cm)	No. of effective tillers/plant	Ear head length (cm)	Ear head girth (cm)	Grain yield/Plot (kg)	Fodder yield /plot (kg)	1000 grain weight (g)	No. of grain /cm^2	Fe Content (ppm)	Zn Content (ppm)
GCA	3.65**	1.96**	69.5**	0.012*	0.73**	0.06**	0.013**	0.071**	1.248**	0.79**	11.35**	3.28
SCA	3.21**	6.90**	64.41**	0.07**	0.49**	0.15**	0.030**	0.098**	3.040**	0.53**	35.8**	25.48**
σ^2A	14.64	7.85	278.15	0.048	2.94	0.25	0.052	0.284	4.995	3.174	45.40	13.15
σ^2D	12.86	27.63	257.67	0.282	1.97	0.62	0.12	0.392	12.160	2.144	143.52	101.95
σ^2A: σ^2D	1.13	0.28	1.079	0.173	1.49	0.41	0.426	0.724	0.410	1.480	0.31	0.12
h^2 (n.s.) %	64.58	34.73	61.62	24.88	62.02	34.43	34.08	55.129	45.00	62.54	38.49	20.38

*, ** denote significant at 5% and 1% levels, respectively

Table 3: Estimates of General Combining ability effects for different characters in pearl millet

Sr. No.	Parents	Days to 50% flowering	Days to maturity	Plant height (cm)	No. of effective tillers/plant	Ear head length (cm)	Ear head girth (cm)	Grain yield/Plot (kg)	Fodder yield/plot (kg)	1000 grain weight (g)	Grains/ cm^2	Iron Content (ppm)	Zinc Content (ppm)
(A) Females													
1.	DHLB-754A	-1.08**	-0.53*	3.89*	0.02	0.97**	-0.17	-0.03	0.24**	0.85**	0.96**	3.66**	0.91**
2.	DHLB-760A	0.28	0.63**	-8.52**	-0.13**	-0.88**	0.17	0.03	0.04	1.11**	-0.96**	-3.83**	-0.60**
3.	DHLB-769A	2.32**	1.30**	-5.14**	0.05**	0.06	-0.01	0.07	0.03	-0.42**	0.10	-1.40**	-1.55**
4.	DHLB-787A	-1.52**	-1.40**	9.76**	0.06**	-0.14	0.01	0.08*	-0.32**	-1.54**	-0.09	1.63**	1.25**
	SE+	0.28	0.22	1.48	0.01	0.20	0.09	0.04	0.04	0.03	0.20	0.19	0.14
(B) Males													
1	S-18/01	1.41**	2.26**	-5.45*	-0.02	0.21	0.21	0.02	-0.10	-0.27**	0.34	4.90**	-0.53*
2	S-18/02	-1.08*	-2.98**	1.53	0.10**	-0.70*	-0.64**	-0.08	0.005	0.01	-0.71*	-0.41	-1.60**
3	S-18/03	-3.75**	-0.98**	-0.28	-0.10**	-1.07**	-0.46**	-0.19**	-0.25**	0.82**	-1.09**	-1.00**	1.80**
4	S-18/04	0.16	-0.23	-6.07*	0.02	-0.83*	-0.60**	-0.09	-0.31**	1.32**	-1.01**	2.41**	2.30**
5	S-18/05	1.91**	1.93**	16.60**	0.25**	0.05	0.73**	0.57**	-0.69**	0.52**	0.04	4.91**	-0.80**
6	S-18/06	2.91**	0.85*	-9.48**	0.08**	1.57**	0.27	0.023	0.31**	-0.65**	1.56**	-5.00**	-6.50**
7	S-18/07	1.58**	1.6**	-11.6**	-0.08**	0.76*	0.36*	-0.14*	-0.51**	-0.93**	0.75*	0.08	1.96**
8	S-18/08	1.25**	0.68*	1.20	0.014	1.50**	0.35*	-0.027	0.21**	0.48**	1.66**	-2.80**	1.96**
9	S-18/09	-4.25**	-2.98**	11.8**	0.04	-1.97**	-0.047	0.04	-0.11	-0.32**	-1.98**	2.66**	-0.20
10	S-18/10	-0.16	-0.15	1.67	-0.31**	0.44	-0.18	-0.076	0.06	-0.99**	0.43	-4.90**	1.63**
	SE+	0.443	0.342	2.35	0.028	0.319	0.148	0.070	0.066	0.055	0.321	0.31	0.22

*, ** denote significant at 5% and 1% levels, respectively

Table 4: Estimates of Specific Combining ability effects for different characters in pearl millet

Sr. No	Parents	Days to 50% flowering	Days to maturity	Plant height (cm)	No. of effective tillers /plant	Ear head length (cm)	Ear head girth (cm)	Grain yield /Plot (kg)	Fodder yield /plot (kg)	1000 grain weight (g)	Grains/ cm²	Iron Content (ppm)	Zinc Content (ppm)
1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	DHLB-754A x S-18/01	-0.75	1.20	-2.43	0.21**	0.42	0.64*	0.03	-0.36**	-1.51**	0.29	-0.08	1.33**
2	x S-18/02	-2.91**	1.12	2.00	0.22**	1.47*	0.13	0.02	0.22	-1.51**	1.48*	1.75**	8.41**
3	x S-18/03	-0.92	-2.50**	3.72	0.03	-0.51	0.17	-0.01	-0.17	-1.06**	-0.50	2.33**	6.25**
4	x S-18/04	1.17	-0.97	8.86	0.21**	-0.80	0.12	0.00	0.07	1.24**	-0.61	0.25	-2.50**
5	x S-18/05	4.08**	-1.46*	6.14	-0.07	-1.51*	-0.03	-0.21	0.08	0.31**	-1.50*	-1.91**	0.33**
6	x S-18/06	-0.25	-0.05	6.17	-0.34**	1.87*	-0.80**	0.18	-0.30*	-1.98**	1.88**	6.33**	-6.00**
7	x S-18/07	-1.58	1.53*	-3.89	-0.17**	-0.75	-0.47	0.05	0.51**	0.61**	-0.73	-2.41**	-1.16**
8	x S-18/08	0.75	-2.50**	2.93	0.04	-0.15	0.25	0.02	-0.01	2.28**	-0.30	-6.16**	-12.20**
9	x S-18/09	-0.42	-0.22	-19.40**	-0.39**	-0.28	-0.16	-0.23	0.004	0.53**	-0.26	3.00**	2.66**
10	x S-18/10	0.83	3.90**	-4.04	0.25**	0.25	0.10	0.14	0.02	1.08**	0.27	-3.08**	2.83**
11	DHLB-760A x S-18/01	3.55**	0.70	11.70*	-0.06	1.40*	-0.44	-0.08	-0.13	1.69**	1.34*	11.40**	-1.13*
12	x S-18/02	0.38	-2.70**	-3.34	-0.30**	-0.73	-0.31	-0.15	-0.06	0.02	-0.65	-5.41**	-1.05*
13	x S-18/03	-0.62	2.60**	-7.89	-0.28**	0.01	-0.08	-0.05	0.11	-1.29**	0.09	-6.16**	-1.21**
14	x S-18/04	-1.87*	-0.13	4.26	-0.07	-0.11	0.26	0.04	-0.13	-2.38**	-0.53	2.08**	1.03*
15	x S-18/05	-0.62	4.30**	-0.75	0.33**	-0.12	-0.34	0.49**	0.46**	-1.97**	-0.04	1.91**	4.53**
16	x S-18/06	0.38	0.12	1.92	0.16**	-0.06	1.09**	-0.36*	-0.49**	0.34**	0.01	2.83**	0.86
17	x S-18/07	0.05	-1.90**	8.35	-0.2**	0.47	0.75*	-0.01	-0.03	-0.04	0.56	6.41**	-2.30**
18	x S-18/08	-1.62	1.28	-9.43*	0.48**	-0.44	-0.71*	-0.08	0.27*	1.17**	-0.52	-5.00**	0.70
19	x S-18/09	-0.12	-2.70**	4.27	0.03	0.03	-0.09	0.34*	0.10	2.67**	0.11	-6.16**	-2.13**
20	x S-18/10	0.47	-1.55*	-9.08	-0.07	-0.45	-0.13	-0.11	-0.07	-0.23*	-0.37	-1.91**	0.70
21	DHLB-769A x S-18/01	-2.48**	-2.60**	-0.32	0.13*	-0.14	-0.22	-0.10	0.34*	0.97**	0.24	-6.61**	-1.20**
22	x S-18/02	-0.32	-0.72	-3.72	-0.11*	-1.20	0.21	-0.15	-0.60**	1.14**	-1.24	6.88**	-2.78**
23	x S-18/03	0.68	0.62	-1.84	0.14*	-0.20	-0.31	0.17	0.25	2.63**	-0.24	-4.53**	-4.95**
24	x S-18/04	-0.57	-2.80**	-5.68	0.09	0.03	0.16	0.02	0.08	0.73**	0.15	-6.95**	1.30**
25	x S-18/05	-2.65**	-3.60**	1.38	-0.16*	1.59*	-0.35	0.28*	-0.32*	-0.46**	1.54*	1.21	6.13**
26	x S-18/06	0.35	1.45*	-5.72	0.32**	-1.16	0.38	0.19	0.66**	2.02**	-1.20	0.13	0.13
27	x S-18/07	2.35**	3.30**	-6.27	0.19**	0.26	-0.45	-0.21	-0.50**	-0.64**	0.22	1.38*	-0.36
28	x S-18/08	3.68**	4.20**	18.40**	-0.52**	0.19	0.20	-0.03	-0.03	-2.49**	-0.01	7.63**	6.63**
29	x S-18/09	0.52	2.20**	6.90	0.09	0.76	0.42	-0.08	0.22	-1.53**	0.71	3.13**	-1.53**
30	x S-18/10	-1.57	-2.20**	-3.12	-0.17**	-0.12	-0.04	-0.07	-0.10	-2.39**	-0.16	-2.28**	-3.36**
31	DHLB-787A x S-18/01	-0.32	0.73	-8.94	-0.28**	-1.68*	0.01	0.15	0.16	-1.15**	-1.88**	-4.71**	1.00*
32	x S-18/02	2.85**	2.30**	5.07	0.19**	0.45	-0.03	0.31*	0.45**	0.34**	0.40	-3.21**	-4.58**
33	x S-18/03	0.85	-0.68	6.01	0.11	0.70	0.21	-0.10	-0.19	-0.27**	0.65	8.36**	-0.08
34	x S-18/04	1.27	3.90**	-7.44	-0.22**	0.88	-0.54	-0.07	0.04	0.39**	0.99	4.61**	0.16
35	x S-18/05	-0.82	0.73	-6.77	-0.09	0.05	0.70*	-0.52**	-0.21	2.11**	0.00	-1.21	-11.00**
36	x S-18/06	-0.48	-1.51*	-2.36	-0.15**	-0.63	-0.67*	-0.04	0.13	-0.39**	-0.69	-9.30**	5.00**
37	x S-18/07	-0.82	-2.90**	1.81	0.20**	0.09	0.17	0. 17	0.01	0.06	-0.04	-5.38**	3.83**
38	x S-18/08	-2.81**	-3.00**	-11.90*	-0.02	0.40	0.24	0.06	-0.22	-0.96**	0.85	3.53**	4.83**
39	x S-18/09	0.02	0.65	8.29	0.26**	-0.51	-0.16	-0.09	-0.33*	-1.68**	-0.56	0.03	1.00*
40	x S-18/10	0.27	-0.18	16.20**	-0.01	0.32	0.06	0.04	0.15	1.53**	0.27	7.28**	-0.16
	SE+	0.89	0.69	4.71	0.06	0.63	0.29	0.14	0.13	0.11	0.64	0.62	0.44

*, ** denote significant at 5% and 1% levels, respective

Conclusion

In the current study, DHLB-760A and S-18/05 were viable parents for grain yield/plant, iron, and zinc content; however, S-18/01 and DHLB-760A performed better in terms of iron content. As a result, it provided the best opportunities for the cross DHLB-760A x S-18/05, and the best particular combiner for grain yield, grain iron, and zinc content was DHLB-760 x S-18/01. "They produced significant and desired SCA effects and heterosis for most of the parameters evaluated, indicating that hybrid" vigor may be used in breeding operations.

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