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Research Article

Combining ability analysis for grain yield and quality traits in pearl millet [*Pennisetum glaucum* (L.) R. Br.]

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Abstract
Combining ability analysis performed using 15 parental lines and their 54 hybrids in pearl millet in L x T mating design. The magnitude of SCA variances was higher than the GCA variances for all the characters, which indicated predominance of non-additive gene action in the inheritance of these traits and it was further supported by less magnitude of $\sigma^2_{gca} / \sigma^2_{sca}$ ratios. Based on general combining ability (gca) effects, none of the parent was good general combiners for all the characters. Among females, JMSA-9904 was good general combiner for grain yield per plant and protein content. Whereas, male parent J-2507 was good general combiner for grain yield per plant, Fe content and Zn content. The heterotic hybrid ICMA-96333 x J-2512 had recorded high sca effects for grain yield per plant and exhibited positive significant sca for Zn content. The hybrid ICMA-96333 x J-2510 was recorded high and favourable sca effect for Fe content (50.12) and Zn content (44.07). In case of protein content, hybrid JMSA-9904 x J-2538 was exhibited high positive sca effect, this cross also recorded positive sca effect for Fe content, Zn content and grain yield.

Key Word: Pear millet, combining ability, GCA, SCA, Fe and Zn content

Introduction

Pearl millet (family: *Poaceae*, subfamily: *Panicoideae*) is a multi- purpose cereal crop which provides food, fodder and fuel on more than 26 million ha in semi-arid environments of Asia and Africa. Pearl millet is a cereal crop that thrives in the arid and semi-arid tropical regions of Asia and Africa. Micronutrient malnutrition resulting from dietary deficiency of one or more micronutrients has been recognized as a serious human health problem worldwide. The most striking of these are iron (Fe) and zinc (Zn) deficiencies that rank 9th and 11th, respectively, among the top 20 risk factors contributing to global burden of disease (WHO,2002). A part from yield, quality traits have also an important role for increasing value addition because, pearl millet grain is richer source of, minerals, and antioxidants (Ragaee *et al*., 2006). Lack of iron impairs mental development and learning capacity in adults, it reduces the ability for physical labour. A recent study conducted under Consultative crop on International Agriculture Research (CGIAR) has shown that pearl millet accounts for a major share of Fe and Zn intake in some of the region of pearl millet growing areas in India and it is the cheapest source of Fe and Zn as compared to other cereals. An understanding of the nature of gene action and heterosis would be a significant input into designing effective breeding strategies for the development of open-pollination varieties (OPVS) and hybrids. There is lack of information available on the nature of gene action and heterosis for grain Fe and Zn densities in pearl millet. Thus, improvement in nutrient quality of pearl millet grains along with the increased yield may be helpful to alleviate malnutrition. Hence, to rectify relation of these quality traits with yield and appropriate selection of parent for hybridization, it is need to study gene action heterosis for yield and level of grain Fe and Zn densities.

Materials and methods

The experimental material consisted of six female lines (A lines) (ICMA-842, ICMA-08111, ICMA-96333, JMSA-9904, JMSA-20042 and JMSA 72) and nine restorer lines used as testers (J-2372, J-2454, J-2479, J-2496, J-2507, J-2510, J-2512, J-2538 and J-2556), crossed in a Line x Tester mating design. The resultant 54 hybrids along with their 15 parents addition of one check GHB-558 were evaluated in Randomized Block Design with three replications at Centre for Crop Improvement, S. D. Agricultural University, Sardarkrushinagar (Gujarat) during *kharif* 2014. Five representative plants taken from each plot and record data for grain yield per plant and its components traits viz., plant height (cm), no. of effective tillers per plant, ear head length (cm), ear head girth (mm), teat weight, harvest index, protein content, etc. Grain Fe and Zn densities analyzed at the central instrument laborator S.D.A.U., Sardarkrushinagar, following the method described by Johnson and Ulrich, 1959. The ground sample (1grm) was digested in closed tubes; and Fe and Zn in the digests were analyzed using an Atomic absorption spectrophotometer Model Elico SL-194. Protein content (%) was estimated based on Nitrogen content of each genotype by Micro-Kjeldahl's method. The crude protein was calculated by multiplying nitrogen content with 6.25 to obtain protein content in per cent. The data analysed as per the procedure suggested by Sukhatme and Amble (1989). The combining ability analysis performed for a Line x Tester matting design as per the method suggested by Kempthorne (1957).

Results and discussion

The analysis of variance for combining ability and estimation of variance components for grain yield and quality traits are presented in table 1. It revealed that mean squares due to females and male were highly significant for grain yield per plant. This indicated the importance of female and males for their contribution towards variance components of general combining ability. The ratio of σ^2_{gca} / σ^2_{sca} was less than unity for all the characters (Table 1), which suggested greater role of non-additive genetic variance in the inheritance of these characters. The results and important outcome from combining ability for yield and quality traits are mentioned below.

Four males *viz*., J-2538 (4.37), J-2556 (3.00), J-2454 (1.82) and J-2507 (1.16), where as females JMSA-20042 (3.60), JMSA-20072 (2.53) and J-9904 (2.42) showed significant positive *gca* effects for grain yield per plant. It showed that these parental lines having good combining ability toward increasing grain yield. (Table 2). The specific combining ability values of the hybrids ranged from -9.35 (ICMA-08111 x J-2454) to 11.89 (ICMA-96333 x J-2512) for this trait. Out of 54 hybrids, 17 hybrids *viz*., ICMA-96333 x J-2512 (11.89), JMSA-20042 x J-2496 (8.03), ICMA-08111 x J-2538 (8.00), JMSA-20042 x J-2510 (7.36), JMSA-9904 x J-2538 (6.42), JMSA-9904 x J2556 (5.12), ICMA-96333 x J-2454 (4.86), JMSA-20072 x J-2479 (4.75), ICMA-842 x J-2507 (4.37), JMSA-9904 x J-2479 (4.32), JMSA-20072 x J-2496 (3.66), ICMA-842 x J-2372(3.52), ICMA-08111 x J-2510 (3.25), JMSA-20072 x J-2507 (2.98), JMSA-20072 x J-2454 (2.61), ICMA-08111 x J-2512 (2.52) and ICMA-08111 x J-2372 (2.22) exhibited significant positive specific combining ability effects for grain yield per plant (Table 3). Earlier *gca* and *sca* effects of grain yield in pearl millet were also reported by Rasal and Patil (2003) and Laxmana *et al.* (2003).

Three males *viz.*, J-2496 (0.78), J-2479 (0.27) and J-2512 (0.25), three females *viz.*, JMSA-20072 (0.43), ICMA-96333 (0.30) and JMSA-9904 (0.25) exhibited significant positive general combining ability effects for protein content (Table 2), indicated they are good combiner for increasing protein content in pearl millet. With respect to specific combining ability effects of crosses, 15 hybrids found significant positive *sca* effects. Among these hybrid, the hybrid JMSA-9904 x J-2538 (2.26) followed by ICMA-08111 x J-2510 (1.91) and ICMA-842 x J-2454 (1.58) were top ranked for this component. The range of specific combining ability effects was observed from -2.01 (ICMA-842 x J-2556) to 2.26 (JMSA-9904 x J-2538) (Table 3).The results also accord with the finding of Suthamathi *et al.* (2007) and Dangaria *et al.* (2009).

Four males *viz.*, J-2479 (20.75), J-2510 (10.14), J-2496 (6.25) and J-2507 (2.69), and two females *viz.*, ICMA-96333 (17.88) and ICMA-842 (7.51) were exhibited significant positive general combining ability effects, indicated that these parental lines having favourable gene for high Fe densities (Table 2). In case of specific combining ability effects of 54 crosses, 25 exhibited significant positive specific combining ability effects for Fe content. The hybrid ICMA-96333 x J-2510 (50.12) followed by ICMA-842 x J-2479(41.88) and ICMA-96333 x J-2496 (31.01) exhibited significant positive specific combining ability effects for this component. The range of specific combining ability effects was observed from -38.01 (ICMA-842 x J-2512) to 50.12 (ICMA-96333 x J-2510) (Table 3).

Three males *viz.*, J-2510 (5.89), J-2507 (4.84) and J-2479 (3.34), and two females ICMA-842 (9.75) and ICMA-96333 (5.04) possessed highly significant positive general combining ability effects therefore these parents were good combiner for Zn content (Table 2). Perusal of the data for specific combining ability effects was ranged from -22.97 (ICMA-842 x J-2512) to 44.07 (ICMA-96333 x J-2510). Twenty four hybrids exhibited significant positive specific combining ability effects for this component. The cross ICMA-96333 x J-2510 (44.07) ranked first followed by ICMA-842 x J-2507 (30.42) and ICMA-08111 x J-2538 (26.05) for Zn content (Table 3).

Combining ability of grain iron and zinc densities in pearl millet and its association with grain yield and grain size was studied in Line x Tester design by Kanatti *et al*. (2014). Gene effects and heterosis for grain iron and zinc density in pearl millet also reported by Velu *et al*., (2011). The significant variability on grain Zn and Fe densities in pearl millet materials reported by Govindaraj *et al*., (2013).

Comparative study of parents and hybrids mean values for different characters revealed that among the males, J-2479 was promising for grain yield per plant, while, female ICMA-8111 were promising for grain yield per plant, protein content and Zn content. The female ICMA-6333 was found to be promising for Fe content and Zn content. JMSA-20042 was promising for grain yield per plant,' Fe' content and 'Zn' content. Out of 54 hybrids, the hybrids JMSA-20072 x J-2512, ICMA-96333 x J-2454 and JMSA-20072 x J-2510 were identified for high per *se* performance for grain yield per plant while, hybrid ICMA-842 x J-2556 was identified for high *per se* performance for Fe content and Zn content. The heterotic hybrid ICMA-9633 xJ-2512 had recorded high *sca* effects for grain yield per plant and exhibited positive significant *sca* for Zn content. The hybrid, ICMA-96333 x J-2510 was recorded high and favourable *sca* effect for Fe content (50.12) and Zn content (44.07). In case of protein content, hybrid JMSA-9904 x J-2538 exhibited high positive *sca* effect, this cross also recorded positive *sca* effect for Fe content, Zn content and grain yield (Table 4).

The crosses exhibiting high *sca* effects involved one parents possessing high *gca* effects, thereby suggesting that intra allelic interactions were important. High *per se* performance of hybrids did not ensure higher estimates of *sca* effects. The high *sca* effect no doubt revealed high heterotic response, but these might also be accompanied by poor *gca* effect for parents. The crosses that exhibited high *sca* effect for grain yield per plant also exhibited high, average, or poor *sca* effect for yield contributing characters. Breeding hybrids with high level of Fe and Zn densities will require incorporating them in both parental line, and application of genomics tools may significantly accelerate this process.

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Table 1. Analysis of variance for combining ability, estimates of components of variance and their ratio for yield and quality traits in pearlmillet.

Source of variation	d f	Mean square			
		Fe (mg/kg)	**Zn (mg/kg)**	**Protein (%)**	**GY (g)**
Replication	2	3.43	0.77	0.16	24.31
Crosses	53	1684.94**	660.60**	3.82**	107.51**
Females	5	3033.15	1075.96	4.05	270.68**
Males	8	2114.52	284.02	3.21	169.33*
F x M	40	1430.50**	683.99**	3.91**	74.75**
Error	106	2.38	1.04	0.25	3.81
Component of variance:					
σ^2gca		114.30**	30.18	0.15	9.62**
σ^2sca		476.11**	227.65**	1.23**	23.72**
σ^2gca / σ^2sca		0.24	0.13	0.12	0.41

*** and** indicates significant at P = 0.05 and P = 0.01 levels, respectively.**

Table 2. Per se performance of parental lines and their general combining ability (gca) effects of yield and quality traits in pearlmillet.

Genotype		**Performance *per se***				**GCA effects**			
		Fe (mg/kg)	**Zn (mg/kg)**	**Protein (%)**	**GY (g)**	**Fe (mg/kg)**	**Zn (mg/kg)**	**Protein (%)**	**GY (g)**
Female parents									
1.	ICMA-842	36.70	14.70	9.10	19.20	7.51**	9.75**	-0.18	-2.71**
2.	ICMA-08111	50.00	52.30	9.50	25.60	-8.97**	-6.77**	-0.57**	-2.42**
3.	ICMA-96333	117.70	51.00	9.00	21.60	17.88**	5.04**	0.30**	-3.41**
4.	JMSA-9904	34.30	20.70	9.00	20.50	-7.35**	-5.40**	0.25**	2.42**
5.	JMSA-20042	86.30	67.00	7.20	27.20	-6.79**	-1.73**	-0.26**	3.60**
6.	JMSA-20072	96.00	44.70	9.70	19.20	-2.27**	-0.88**	0.43**	2.53**
Male parents									
7.	J-2372	9.30	5.00	9.20	17.90	-12.25**	-5.55**	-0.36**	-6.01**
8.	J-2454	25.00	9.70	7.30	19.20	-5.14**	-0.55*	-0.50**	1.82**
9.	J-2479	40.00	20.70	5.90	24.50	20.75**	3.34**	0.27*	-1.26**
10.	J-2496	36.00	9.30	6.40	18.10	6.25**	-0.94**	0.78**	-0.14
11.	J-2507	33.70	5.70	7.00	14.40	2.69**	4.84**	-0.20	1.16*
12.	J-2510	29.70	11.30	8.20	17.70	10.14**	5.89**	0.14	-1.91**
13.	J-2512	52.30	21.00	8.90	20.10	-7.70**	-3.77**	0.25*	-1.02*
14.	J-2538	43.30	12.70	9.40	24.00	-4.53**	-3.27**	0.11	4.37**
15.	J-2556	19.30	11.70	10.10	23.30	-10.20**	0.01	-0.48**	3.00**

*** and** indicates significant at P = 0.05 and P = 0.01 levels, respectively.**

Table 3. Per *se* performance of hybrids and their Specific combining ability (sca) effects of yield and quality traits in pearlmillet.

Hybrid		per se performance				sca effects			
		Fe (mg/kg)	Zn (mg/kg)	Protein (%)	GY (g)	Fe (mg/kg)	Zn (mg/kg)	Protein (%)	GY (g)
1.	ICMA-842 x J-2372	36.30	10.30	7.20	23.40	-6.12**	-11.52**	1.00**	3.52**
2.	ICMA-842 x J-2454	56.30	38.00	7.30	34.30	0.10	21.14**	1.58**	2.10
3.	ICMA-842 x J-2479	40.00	17.00	7.70	22.10	41.88**	15.92**	0.33	1.21
4.	ICMA-842 x J-2496	32.30	9.00	9.70	16.20	-26.95**	-10.14**	-0.24	-1.00
5.	ICMA-842 x J-2507	50.30	19.00	8.20	27.60	28.60**	30.42**	-1.07**	4.37**
6.	ICMA-842 x J-2510	95.00	18.00	10.30	15.50	30.83**	7.03**	1.11**	-0.49
7.	ICMA-842 x J-2512	102.70	20.70	7.90	13.20	-38.01**	-22.97**	0.47	-2.72*
8.	ICMA-842 x J-2538	60.30	14.00	9.10	17.30	-25.51**	-18.80**	-1.19**	-6.86**
9.	ICMA-842 x J-2556	125.70	77.00	8.40	18.80	-4.84**	-11.08**	-2.01**	-0.14
10.	ICMA-08111 x J-2372	52.00	31.30	9.30	31.80	9.70**	-0.34	-1.23**	2.22*
11.	ICMA-08111 x J-2454	39.30	11.30	8.50	25.00	0.25	-9.01**	-0.52	-9.35**
12.	ICMA-08111 x J-2479	31.00	43.00	8.70	22.90	-29.64**	-7.23**	-0.07	-2.97**
13.	ICMA-08111 x J-2496	31.30	12.30	7.10	15.30	7.53**	6.72**	0.12	-1.70
14.	ICMA-08111 xJ-2507	26.00	5.70	6.70	29.00	2.08*	-7.39**	1.55**	0.86
15.	ICMA-08111 x J-2510	41.00	22.30	9.40	29.80	-29.36**	-9.45**	1.91**	3.25**
16.	ICMA-08111 x J-2512	46.00	28.00	10.40	25.30	5.47**	-1.12	-1.04**	2.52*
17.	ICMA-08111 x J-2538	31.00	16.30	7.50	24.70	22.31**	26.05**	-0.86**	8.00**
18.	ICMA-08111 x J2556	56.70	5.00	8.40	20.20	11.64**	1.77**	0.15	-2.83*
19.	ICMA-96333 x J-2372	50.30	23.70	9.40	24.20	-20.8**	-12.49**	1.14**	1.30
20.	ICMA-96333 x J-2454	50.00	17.00	11.20	37.60	-9.93**	-7.49**	-0.21	4.85**
21.	ICMA-96333 x J-2479	29.30	19.00	9.40	34.90	8.85**	-12.38**	1.18**	-4.16**
22.	ICMA-96333 x J-2496	45.30	19.70	8.60	20.50	31.01**	-5.43**	-1.75**	-7.63**
23.	ICMA-96333 x J-2507	40.30	31.70	7.80	29.10	-7.76**	-17.88**	0.41	-4.75**
24.	ICMA-96333 x J-2510	50.00	22.30	8.40	23.50	50.12**	44.07**	-0.63*	-0.21
25.	ICMA-96333 x J-2512	49.70	23.00	9.30	35.80	-5.71**	8.07**	0.13	11.89**

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26.	ICMA-96333 x J-2538	39.00	16.00	9.50	28.90	-21.54**	-12.43**	-0.52	-0.27
27.	ICMA-96333 x J2556	19.00	19.30	7.00	33.40	-24.21**	15.96**	0.25	-1.01
28.	JMSA-9904 x J-2372	44.00	25.00	8.50	21.30	3.40**	1.29*	-1.37**	-5.47**
29.	JMSA-9904 x J-2454	52.30	16.00	8.50	28.00	-9.043**	-10.38**	-1.67**	0.43
30.	JMSA-9904 x J-2479	27.00	9.30	7.50	31.00	-19.93**	2.40**	0.25	4.32**
31.	JMSA-9904 x J-2496	30.00	33.70	8.50	20.70	-0.43	12.35**	0.79**	-1.36
32.	JMSA-9904 x J-2507	54.00	14.30	9.40	31.30	-11.88**	-5.10**	-1.14**	-3.23**
33.	JMSA-9904 x J-2510	76.30	27.00	7.80	30.40	6.35**	-17.49**	-0.54*	-4.71**
34.	JMSA-9904 x J-2512	37.70	13.00	10.70	30.40	17.85**	10.85**	0.344	-1.53
35.	JMSA-9904 x J-2538	41.30	35.00	7.70	31.0	14.35**	3.68**	2.26**	6.42**
36.	JMSA-9904 x J2556	29.30	9.70	8.70	19.80	-0.65	2.40**	1.07**	5.12**
37.	JMSA-20042 x J-2372	47.00	14.00	9.50	21.30	16.85**	4.96**	0.59*	-1.42
38.	JMSA-20042 x J-2454	35.00	20.30	9.40	28.30	4.73**	11.96**	-0.03	-0.64
39.	JMSA-20042 x J-2479	56.70	23.00	9.50	28.70	-11.49**	-1.26*	-0.21	-3.16**
40.	JMSA-20042 x J-2496	61.30	9.70	7.00	30.50	2.68**	3.68**	0.19	8.03**
41.	JMSA-20042 x J-2507	72.70	24.70	7.80	15.40	-4.43**	-9.10**	1.37**	-0.23
42.	JMSA-20042 x J-2510	57.30	24.70	9.50	22.90	-31.88**	-6.82**	-1.43**	7.36**
43.	JMSA-20042 x J-2512	52.30	25.70	6.70	21.30	10.96**	8.51**	-0.13	-5.60**
44.	JMSA-20042 x J-2538	50.30	9.70	9.60	31.00	16.12**	-0.99	0.05	-4.36**
45.	JMSA-20042 x J-2556	57.30	13.70	7.70	37.00	-3.54**	-10.93**	-0.38	0.02
46.	JMSA-20072 x J-2372	56.70	11.30	9.90	25.20	-3.01**	18.10**	-0.13	-0.15
47.	JMSA-20072 x J-2454	49.30	18.30	10.60	25.40	13.88**	-6.23**	0.84**	2.61*
48.	JMSA-20072 x J-2479	65.00	9.30	9.20	24.20	10.33**	2.55**	-1.49**	4.75**
49.	JMSA-20072 x J-2496	54.30	17.30	9.10	34.90	-13.84**	-7.17**	0.89**	3.66**
50.	JMSA-20072 x J-2507	66.30	16.70	9.40	30.40	-6.68**	9.05**	-1.12**	2.98**
51.	JMSA-20072 x J-2510	51.30	19.00	9.70	37.30	-26.06**	-17.34**	-0.42	-5.20**
52.	JMSA-20072 x J-2512	68.30	35.00	8.50	40.40	9.44**	-3.34**	0.23	-4.56**
53.	JMSA-20072 x J-2538	56.00	37.30	9.50	31.70	-5.73**	2.49**	0.27	-2.93**
54.	JMSA-20072 x J-2556	61.30	26.00	9.30	33.10	21.60**	1.88**	0.92**	-1.15
			Number of $^{+ve}$ significant			25	24	15	17

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Number of $^{-ve}$ significant	24	26	13	17

*** and** indicates significant at P = 0.05 and P = 0.01 levels, respectively.**

Table 4. *Per se* performance of top five ranking hybrids with its parental line and general combining ability (gca) effects of parents

Fe (mg/kg)					
Hybrids	***Per se* performance**			**gca**	
P_1 x P_2	**F_1**	**P_1**	**P_2**	**P_1**	**P_2**
ICMA-842 x J-2556	125.7	36.7	19.3	7.51**	-10.20**
ICMA-842 x J-2512	102.7	36.7	52.3	7.51**	-7.70**
JMSA-9904 x J-2510	76.3	34.3	29.7	-7.35**	10.14**
JMSA-20042 x J-2507	72.7	86.3	33.7	-6.79**	2.69**
JMSA-20072 x J- 2512	68.3	96.0	52.3	-2.27**	-7.70**

Zn (mg/kg)					
Hybrids	***Per se* performance**			**gca**	
P_1 x P_2	**F_1**	**P_1**	**P_2**	**P_1**	**P_2**
ICMA-842 x J-2556	77.0	14.7	11.7	9.75**	0.01
ICMA-08111 x J-2479	43.0	52.3	20.7	-6.77**	3.34**
ICMA-842 x J-2454	38.0	14.7	9.7	9.75**	-0.55*
JMSA-20072 x J-2538	37.3	44.7	12.7	-0.88**	-3.27**
JMSA-9904 x J-2538	35.0	20.7	12.7	-5.40**	-3.27**
JMSA-20072 x J-2512	35.0	44.7	21.0	-0.88**	-3.27**

*and** indicates significan**t at P = 0.05 and P = 0.01 levels, respectively.**