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Combining ability studies in CGMS based hybrids of pearl millet [*Pennisetum glaucum* (L.) R. Br.]

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Abstract

The experimental material comprised of nine female lines, five male lines of pearl millet, their 45 hybrids developed by line $\times$ tester design and one standard check hybrid (GHB 1129). They were evaluated in randomized block design with three replications at Main Pearl Millet Research Station, J.A.U., Jamnagar during *kharif* 2024 for studies of variance for combining ability revealed that mean squares due to lines were significant for all the characters under studied except earhead diameter. Mean squares due to testers were significant for all the characters under studied. The mean squares due to lines $\times$ testers were significant for all the traits under studied except days to maturity. The variance ratio of gca and sca resulted less than unity, showed that the non-additive gene action was pre-dominant for the expression of all traits under studied except days to 50 per cent flowering and earhead length. Among the parents, two females JMSA₄ 20215 (5.62) and ICMA₁ 17555 (1.06), and two male parents like J-2604 (1.57) and J-2296 (1.02) were found good general combiners for grain yield per plant. Moreover, these parents possessed high concentration of desirable genes for a greater number of traits and should be utilized in various crop improvement programmes. Out of 45 crosses studied, 10 crosses exhibited significant and positive sca effect for grain yield per plant. The highest positive sca effect for grain yield per plant was manifested by ICMA₄ 18222 $\times$ J-2296 (6.16) followed by JMSA₄ 20215 $\times$ J-2604 (4.84) and JMSA₅ 20211 $\times$ J-2571 (4.09), which involved poor $\times$ good, good $\times$ good and poor $\times$ average general combiners, respectively.

Keywords: Pearl millet, Line $\times$ tester analysis, gene action, combining ability

Introduction

Pearl millet (*Pennisetum glaucum* (L.) R. Br.) is a key member of the Poaceae (Gramineae) family and the *Pennisetum* genus. Commonly known as bajra, bajri, cattail millet, spiked millet, and bulrush millet, this crop is highly cross-pollinated and features protogynous flowering with wind-borne pollination. These traits facilitate hybrid development and the commercial benefits of heterosis. In India, pearl millet is a major staple food, ranking fourth in acreage after rice, wheat, and sorghum, and it is the sixth most important cereal globally. Believed to have originated in tropical Western Africa around 4000 years ago, pearl millet is diploid, with a chromosome number of $2n=2x=14$. The selection of appropriate parents for hybridization programme can be made on the basis of their ability to transmit desirable performance to their progenies (Yadav *et al.* 2005) [16]. The combining ability analysis helps in the evaluation of inbreds in terms of their genetic value, and in the selection of suitable parents for hybridization (Nambiar *et al.*, 2011) [12]. It also helps in the identification of superior cross combinations which may be utilized for commercial exploitation of heterosis (Singh and Sharma 2014) [14].

Materials and Methods

The experimental material comprised of nine CGMS (Female) lines viz., JMSA₁ 20208, JMSA₅ 20211, JMSA₄ 20215, JMSA₄ 20221, JMSA₄ 20223, ICMA₁ 17555, ICMA₄ 18222, ICMA₁ 93333, ICMA₁ 97111; five restorer (male) lines of pearl millet viz., J-2296, J-2480, J-2571, J-2576, J-2604 and their 45 F₁s hybrids developed by line $\times$ tester design and one standard check hybrid (GHB 1129). They were evaluated in randomized block design (RBD) with three replications at Main Pearl Millet Research Station, J.A.U., Jamnagar during *kharif* 2023. Row to row and plant to plant spacing was 60 cm $\times$ 15 cm. The observations were recorded on five randomly selected plants expect the plot basis from parents and crosses for 12 characters viz.,

days to 50% flowering, days to maturity, plant height, number of effective tillers per plant, earhead length, earhead diameter, dry earhead weight per plant, 1000-grain weight, dry fodder yield per plant, grain yield per plant, threshing index and harvest index. Mean data were used for statistical analysis. The total variation among F_1 hybrids was partitioned further into variance due to females, males and their interaction effects, which were used for combining ability analysis (Kempthorne, 1957) [7].

Results and Discussion

The analysis of variance for combining ability revealed that mean squares due to lines, testers and lines $\times$ testers were tested against the error mean squares. If lines $\times$ testers interaction component was significant, the mean squares due to lines and testers were further tested against their respective interaction mean squares. The result revealed that the mean squares due to lines and testers were significant for all the characters under studied except earhead diameter due to lines. The result indicates that significant contribution of both line and tester toward total variation (Table 1).

The mean squares due to lines $\times$ testers were found significant for all characters under study except days to maturity. The mean squares due to lines were also found significant for characters viz., days to 50 per cent flowering, plant height, earhead length, dry fodder yield per plant and grain yield per plant when tested against mean squares due to lines $\times$ testers interaction. Similarly, the mean squares due to testers were also found significant for days to 50 per cent flowering, earhead length, 1000-grain weight, threshing index and harvest index when tested against mean squares due to lines $\times$ testers interaction (Table 1).

The estimated variance due to lines (σ^2_l) was higher than the corresponding variance due to testers (σ^2_t) for all the traits except days to 50 per cent flowering, days to maturity, earhead length, earhead diameter, 1000-grain weight, threshing index and harvest index. The estimated variance due to sca (σ^2_{sca}) was greater than the corresponding variance due to gca (σ^2_{gca}) for all characters under studied except days to 50% flowering, days to maturity and earhead length. Hence, variance ratio ($\sigma^2_{gca}/\sigma^2_{sca}$) of all the characters except days to 50 per cent flowering and earhead length were resulted less than unity, suggesting the preponderance of non-additive gene action for all characters except days to 50 per cent flowering and earhead length (Table 1). These results were in connection to the results obtained by Chaudhary *et al.* (2022) [3], Keerthana *et al.* (2022) [6], Choudhary *et al.* (2023) [5], Maheswari *et al.* (2023) [10], Solanki *et al.* (2023) [15], Surendhar *et al.* (2023), Chinthakuntla *et al.* (2024) [4], Moghariya *et al.* (2024) [11] and Pipariya *et al.* (2025) [13].

The parents were characterized for their ability to transmit desirable genes to their progenies. Among the parents, two females JMSA₄ 20215 (5.62) and ICMA₁ 17555 (1.06), and two male parents like J-2604 (1.57) and J-2296 (1.02) were found good general combiners for grain yield per plant (Table 2).

The two female parent JMSA₄ 20215 (5.62) and ICMA₁ 17555 (1.06) displayed good general combiners for grain yield per plant

JMSA₄ 20215 also found good general combiners for plant height, number of effective tillers per plant, earhead length, dry earhead weight per plant, dry fodder yield per plant, threshing index and harvest index and the other female parent ICMA₁ 17555 displayed good general combiners for grain yield per plant also found good general combiners for plant height, 1000-grain weight, and harvest index. Moreover, if we discuss about general combining of male parents, J-2296 found good combiner for grain yield was also recorded good gca effects in favorable direction for days to 50 per cent flowering, days to maturity, threshing index and harvest index. Likewise, parent J-2604 was noted to have greater potential to transmit useful genes for grain yield per plant, plant height, number of effective tillers per plant, dry fodder yield per plant and threshing index. Thus, the parents were good general combiners for grain yield per plant also showed good general combining ability for one or more component traits. These findings are in concurrence with results of Badurkar *et al.* (2018) [1], Kumawat *et al.* (2019) [8], Madane *et al.* (2023) [9] and Moghariya *et al.* (2024) [11] in pearl millet.

Out of 45 crosses, 10 crosses manifested positive and significant sca effect for grain yield per plant (Table 3). The highest positive sca effect was observed in cross ICMA₄ 18222 $\times$ J-2296 (6.16) followed by JMSA₄ 20215 $\times$ J-2604 (4.84) and JMSA₅ 20211 $\times$ J-2571 (4.09) for grain yield per plant. Hence, these crosses were identified as good specific combinations for grain yield per plant. The highest sca effect for grain yield per plant was manifested by ICMA₄ 18222 $\times$ J-2296, which also exhibited significant sca effect in desired direction for earhead diameter, dry earhead weight per plant, threshing index and harvest index. This cross was involved poor $\times$ good general combining parents for grain yield per plant, fourth rank in *per se* performance and standard heterosis for grain yield per plant. The second highest sca effect in desired direction was recorded by cross, JMSA₄ 20215 $\times$ J-2604 involved good $\times$ good general combiners parents for grain yield per plant, which also exhibited significant sca effect in desired direction for dry earhead weight per plant and dry fodder yield per plant. This cross was also manifested first rank in *per se* performance and in standard heterosis for grain yield per plant. Likewise, third highest significant sca effect in desired direction for grain yield per plant was recorded by cross JMSA₅ 20211 $\times$ J-2571 had involved poor $\times$ average general combiners for grain yield per plant. The sca effect of grain yield per plant in this cross combination was also accompanied by sca effect for yield attributing traits viz., dry earhead weight per plant and dry fodder yield per plant.

However, Chaudhary *et al.* (1974) [3] stated that high sca effect would not necessarily mean a high performance by the cross and the estimation of sca effect seemed to be superfluous, as no additional information was obtained by doing so. Therefore, it is suggested that the selection of parents for further breeding programme should be based on gca effect and due consideration should be given to mean value of the cross combination while selecting crosses for specific combining ability effect.

Table 1: Analysis of variance for combining ability and variance components for different characters in pearl millet

Source	d. f.	Days to 50% flowering	Days to maturity	Plant height (cm)	Number of effective tillers/plant	Earhead length (cm)	Earhead diameter (cm)
Replications	2	1.70	0.62	83.07	0.04	3.74	0.06
Lines	8	19.88****	19.78*	1536.00****	0.59**	28.43****	0.12
Testers	4	51.06****	51.53**	397.57**	0.17**	60.55****	0.52**
Lines x Testers	32	3.67**	3.58	295.80**	0.29**	5.60**	0.32**
Error	88	2.01	7.79	81.85	0.02	1.42	0.07

Estimates of genetic components of Variance							
σ^2_l	-	1.19	0.80	96.94	0.04	1.80	0.003
σ^2_t	-	1.82	1.62	11.69	0.01	2.19	0.02
$\sigma^2_{lt} (\sigma^2_{sca})$	-	0.55	-1.40	71.31	0.09	1.40	0.08
σ^2_{gca}	-	1.59	1.32	42.14	0.02	2.05	0.01
$\sigma^2_{gca} / \sigma^2_{sca}$	-	2.88	-0.95	0.59	0.19	1.47	0.14

Table 1: Cont...

Source	d. f.	Dry earhead weight/plant (g)	1000-grain weight(g)	Dry fodder yield/plant(g)	Grain yield / plant(g)	Threshing index(%)	Harvest index(%)
Replications	2	15.40	0.25	1.99	1.75	19.58	6.14
Lines	8	114.36**	7.27**	161.82***++	87.50***+	371.54**	145.96**
Testers	4	61.54**	23.77***++	93.61**	47.37**	671.36***+	279.33***+
Lines x Testers	32	58.28**	3.79**	44.38**	29.73**	181.58**	80.83**
Error	88	8.50	0.41	4.25	3.51	37.61	10.90
Estimates of genetic components of Variance							
σ^2_l	-	7.06	0.46	10.50	5.6	22.26	9.00
σ^2_t	-	1.96	0.87	3.31	1.62	23.47	9.94
$\sigma^2_{lt} (\sigma^2_{sca})$	-	16.59	1.13	13.38	8.74	47.99	23.31
σ^2_{gca}	-	3.78	0.72	5.88	3.04	23.04	9.60
$\sigma^2_{gca} / \sigma^2_{sca}$	-	0.23	0.64	0.44	0.35	0.48	0.41

*, ** Significant at 5% and 1% levels, respectively, when tested against error mean square.

+, ++ Significant at 5% and 1% levels, respectively, when tested against lines × testers interaction means, respectively

Table 2: Estimates of general combining ability effect of parents for different characters in brinjal

Sr. No.	Parents	Days to 50% flowering	Days to maturity	Plant height (cm)	Number of effective tillers/plant	Earhead length (cm)	Earhead diameter (cm)
Lines							
1	JMSA ₁ 20208	-1.45**	-1.38	-13.41**	-0.07**	-1.47**	-0.04
2	JMSA ₅ 20211	0.28	0.26	-5.61**	0.14**	-0.09	-0.13**
3	JMSA ₄ 20215	1.55**	1.62**	13.13**	0.16**	2.03**	0.08
4	JMSA ₄ 20221	0.28	0.26	9.07**	0.30**	1.92**	-0.10
5	JMSA ₄ 20223	1.75**	1.74**	10.60**	-0.10**	0.57	0.09
6	ICMA ₁ 17555	0.28	0.19	7.84**	-0.28**	0.17	0.04
7	ICMA ₄ 18222	-1.39**	-1.41**	-8.65**	-0.25**	-1.09**	0.13**
8	ICMA ₁ 93333	-0.52	-0.55	-9.67**	-0.04	-1.91**	-0.04
9	ICMA ₁ 97111	-0.79**	-0.73	-3.31	0.13**	-0.15	-0.02
	SE ±	0.27	0.52	1.61	0.02	0.23	0.05
Testers							
1	J-2296	-1.51**	-1.53**	-1.98	0.01	0.46	-0.20**
2	J-2480	-0.07	-0.09	-0.37	0.06**	-0.96**	0.12**
3	J-2571	-1.10**	-1.07**	-2.52	-0.06**	2.27**	0.11**
4	J-2576	0.86**	0.85	-1.84	-0.10**	-1.64**	-0.09
5	J-2604	1.82**	1.85**	6.71**	0.08**	-0.12	0.06
	SE ±	0.36	0.70	2.16	0.03	0.31	0.07

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

Table 2: Cont...

Sr. No.	Parents	Dry earhead weight/plant (g)	1000-grain weight(g)	Dry fodder yield/plant(g)	Grain yield / plant(g)	Threshing index(%)	Harvest index(%)
Lines							
1	JMSA ₁ 20208	-2.99**	-0.35**	-2.58**	-0.02	6.23**	4.07**
2	JMSA ₅ 20211	-2.40**	-0.74**	-1.77**	-1.75**	-1.27	-1.01
3	JMSA ₄ 20215	5.31**	0.31	5.70**	5.62**	6.09**	2.49**
4	JMSA ₄ 20221	-0.11	-0.88**	4.65**	-1.73**	-4.11**	-5.49**
5	JMSA ₄ 20223	3.24**	0.43**	1.47**	0.51	-3.76**	-1.80**
6	ICMA ₁ 17555	0.12	1.42**	0.30	1.06**	2.70	1.85**
7	ICMA ₄ 18222	0.64	-0.30	-2.86**	-2.08**	-7.66**	-2.65**
8	ICMA ₁ 93333	-1.88**	-0.08	-2.52**	-1.82**	-2.42	-0.60
9	ICMA ₁ 97111	-1.92**	0.19	-2.38**	0.22	4.22**	3.14**
	SE ±	0.51	0.12	0.38	0.32	1.12	0.60
Testers							
1	J-2296	-0.86	-1.08**	-2.50**	1.02**	4.79**	4.08**
2	J-2480	1.56**	0.02	1.80**	-1.78**	-7.44**	-4.85**
3	J-2571	0.95	0.97**	-1.06**	-0.28	-2.64**	-0.43
4	J-2576	-2.18**	0.88**	-0.05	-0.53	2.42**	0.23
5	J-2604	0.53	-0.79**	1.81**	1.57**	2.88**	0.97
	SE ±	0.69	0.16	0.51	0.43	1.51	0.81

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

Table 3: Five best specific cross combinations for sca effect for grain yield per plant along with their desirable sca effect of component characters including gca effect of their parents in pearl millet

Crosses	sca effect for grain yield/ plant	gca effect for grain yield/plant		Heterosis (%) over		Significant desirable sca effect for component traits
		Female	Male	Better parent	Standard check (GHB 1129)	
ICMA ₄ 18222 × J-2296	6.16**	-2.08** (P)	1.02** (G)	52.30**	23.39**	6,7,10,11
JMSA ₄ 20215 × J-2604	4.84**	5.62** (G)	1.57** (G)	114.68**	58.64**	7,9
JMSA ₅ 20211 × J-2571	4.09**	-1.75** (P)	-0.28 (A)	20.20**	7.93	7,9
JMSA ₄ 20221 × J-2480	3.87**	-1.73** (P)	-1.78** (P)	115.44**	-0.68	5,7,8
JMSA ₁ 20208 × J-2480	3.43**	-0.02 (A)	-1.78** (P)	129.41**	5.76	1,4,8,10,11

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

1	=	Days to 50 per cent flowering	2	=	Days to maturity	3	=	Plant height (cm)
4	=	Number of effective tillers/plants	5	=	Earhead length (cm)	6	=	Earhead diameter (cm)
7	=	Dry earhead weight/plant (g)	8	=	1000-grain weight (g)	9	=	Dry fodder yield/plant (g)
10	=	Threshing index (%)	11	=	Harvest index (%)			

Conclusion

In the present study the mean squares due to lines × testers were significant for all the traits under studied except days to maturity. The non-additive genetic variance was important in the inheritance of various traits. The variance ratio of gca and sca showed that the non-additive gene action was pre-dominant for the expression of all traits studied except days to 50 per cent flowering and earhead length. From ongoing discussion, it could be concluded that the best two promising crosses namely ICMA₄ 18222 × J-2296 and JMSA₄ 20215 × J-2604 manifested significant and high desirable sca effect for grain yield per plant and some components traits. Therefore, these three best crosses could be further evaluated over years and locations to exploit for commercial cultivation through heterosis breeding or utilized in future breeding programme to obtain desirable transgressive segregants and to identify high yielding superior inbreds.

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