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Assessment of combining ability and gene action for grain yield and its component traits in pearl millet [*Pennisetum glaucum* (L.) R. Br.]

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Abstract
A line x tester analysis using 10 male sterile lines (female parents) and six testers (male parents) was carried out to study the combining ability and gene action for grain yield and 10 quantitative traits in pearl millet. Both GCA and SCA variances were highly significant for all characters. The ratio of GCA and SCA variance indicated the predominance of non-additive gene action for the characters studied except grain yield per plant. The estimates of general combining ability (GCA) effects indicated that the parents RMS 7A, ICMA 843-22, ICMA 04999, ICMA 93333 and JMSA 20042 (females) and BIB-40, BIB-75 and BIB-186 (males) emerged as good general combiners for grain yield and its components. The cross combinations such as RMS 21A X BIB-186, ICMA92777 X BIB- 65, ICMA 04999 X BIB- 76 and ICMA 06999 X BIB- 40, RMS 7A X BIB- 75, ICMA 92777 X BIB- 40, ICMA 92777 X BIB-66, ICMA 97111 X BIB- 186, ICMA 04999 X BIB- 65, JMSA 20042 X BIB- 40 and JMSA 20042 X BIB-66, RMS 7A X BIB-76, ICMA 06999 X BIB-76,RMS 6A X BIB-186 showed significant and positive specific combining ability (SCA) effects for grain yield and other yield attributing characters.

Keywords: Combining ability, gene action, line x tester analysis, Pearl millet

Introduction
Pearl millet (*Pennisetum glaucum* (L.) R. Br.) is the world's sixth important and widely grown drought tolerant, warm-season potential food cereal crop. In India pearl millet is the fourth most important food grain after rice, wheat and sorghum. In India, it is grown on about 7.3 million hectares with an annual production of 8.74 million tones and productivity of 1198 kg/ha (Anonymous, 2015-16) [1, 2]. It is widely cultivated in the states of Rajasthan, Maharashtra, Gujarat, Uttar Pradesh and Hariyana. Pearl millet is highly cross pollinated crop with the advantages of huge genetic variability, protogyny and availability of efficient cytoplasmic genetic male sterility system. These characteristics, offer great possibilities of crop improvement through hybridization. Selection of suitable parent is an important step in a crop improvement programme. The principal aim of any breeding programme is to increase the yield potential. The yield is a complex character comprising of a number of components each of which is genetically controlled and susceptible to environmental fluctuations. The concept of combining ability is gaining importance in plant breeding as it provides valuable genetic information about the parents and the characters under study. It helps in assessing the breeding value of parental lines in terms of their superiority in hybrid combinations and also provides the information regarding the nature and extent of gene action involved in controlling the inheritance of characters in question, like yield and yield attributing characters, thus helps in deciding upon the future breeding strategy. Hence the present investigation based on line x tester analysis helps in testing a large number of genotypes to assess the gene action and combining ability.

Materials and Methods
The material for study consisted of ten male sterile lines, viz., RMS 6A, RMS 7A, RMS 21A, ICMA 843-22, ICMA 92777, ICMA 93333, ICMA 97111, ICMA 04999, ICMA 06999 and JMSA 20042 and six testers viz., BIB- 40, BIB-65, BIB-66, BIB-75, BIB-76 and BIB-186. Crosses were attempted using line x tester mating design at International Crop Research Institute for Semi-Arid Tropics (ICRISAT) Patancheru, Hyderabad during *summer* 2016. Resulted 60 F_1 hybrids and two standard checks HHB-67 Improved and RHB-177 were grown in randomized block design with three replications in each of the environments at Agricultural Research Station, Beechhwal, Bikaner during *kharif* 2016. Each plot consisted of two rows each of 4 meter length with row spacing of 60 cm.

Plant to plant distance was maintained at 15 cm. All the recommended cultural practices were followed to raise agronomically good crop. The observations were recorded on five randomly selected plants for seven characters *viz*., plant height, number of effective tillers per plant, ear head length, ear head diameter, test weight, dry stover yield per plant and grain yield per plant. The characters like days to 50% flowering and days to maturity were recorded on whole plot basis. The data were statistically analyzed for combining ability as per the method suggested by Kempthorne (1957) [6].

Results and Discussion

Analysis of variance for combining ability (Table 1) indicated that the mean squares due to lines were found to be highly significant for all the characters except days to 50 per cent flowering and ear head diameter. In case of testers significant values were obtained for plant height, ear head diameter and test weight, whereas the mean squares due to line x tester were found highly significant for all the characters studied, thus indicating the existence of considerable amount of genetic variability in the experimental material. Estimates of general combining ability (GCA) and specific combining ability (SCA) variance were highly significant for almost all the characters indicating the importance of additive and non-additive components of variation in the inheritance of these characters in pearl millet (Table 2). The estimate of variance SCA were higher in magnitude than their respective GCA components for all the characters expect grain yield per plant suggesting predominant role of non-additive gene action for yield and yield attributing characters. However, GCA/SCA ratio was less than unity for all the characters expect grain yield per plant which confirmed the role of non-additive type of gene effects. The present study confirmed the finding of Chaudhary *et al*., (2012) [5], Parmer *et al.,* (2013), Bhadalia *et al.,* (2014) [3], Bhardwaj *et al.,* (2015) [4] and Nandaniya *et al*., (2016) [8].

An overall appraisal of *gca* effects (Table 3) indicated that none of the parents was good general combiner simultaneously for all the characters studied. However, among the lines, ICMA 93333 was found to be good general combiner for seven characters *viz.,* for days to maturity, plant height, number of effective tillers per plant, ear head length, dry stover yield per plant, grain yield per plant and harvest index followed by ICMA 04999 for six characters *viz*., number of effective tillers per plant, ear head length, ear head diameter, dry stover yield per plant, grain yield per plant and harvest index, RMS 7A for five characters namely, days 50 per cent flowering, days to maturity, ear head diameter, test weight and dry stover yield per plant, JMSA 20042 for four characters like, number of effective tillers per plant, test weight, dry stover yield per plant and grain yield per plant, ICMA 843-22 for four characters *viz*., plant height, number of effective tillers per plant, ear head diameter and dry stover yield per plant, ICMA 06999 for test weight and harvest index, RMS 6A for days to 50 per cent flowering and days to maturity, ICMA 97111 for ear head length and harvest index. Among the testers BIB-40 was good general combiner for the five characters namely, ear head diameter, test weight, dry fodder yield per plant, grain yield per plant and harvest index, BIB-75 for days to 50% flowering, days to maturity, ear head diameter, grain yield per plant and harvest index followed by BIB-186 for three characters like, ear head length, test weight, dry stover yield per plant, BIB-66 for ear head diameter, BIB-65 for test weight and BIB- 76 for harvest index in all over the environments. Thus these good combiner parents could be used in hybridization programme to exploit their GCA effects for grain yield and some important yield contributing characters.

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

		Mean squares									
Source of variation	**d.f.**	**Days to 50% Flowering**	**Days to maturity**	**Plant height**	**Number of effective tillers / plant**	**Ear head length**	**Ear head diameter**	**Test weight**	**Dry Stover yield / plant**	**Grain yield / plant**	**Harvest index**
Replication (r)	2	2.206	1.302	0.334	0.049*	0.389	0.001	0.401	3.133	0.375	104.595**
Crosses	59	32.393**	41.767**	1497.909**	3.651**	84.056**	1.366**	22.875**	1452.682**	277.358**	358.957**
line (l)	9	55.600	113.461**	2842.731**	10.768**	158.923*	1.343	49.363**	4488.984**	717.015**	653.602*
tester (t)	5	41.644	58.100	6108.677**	2.215	144.713	4.213**	87.662**	189.357	235.586	396.670
Error	354	0.881	1.753	13.048	0.012	0.613	0.014	0.647	3.107	1.291	3.966

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

Table 2: Estimates of combining ability variances for various traits in pearl millet.

Source of variation	**Days to 50% flowering**	**Days to maturity**	**Plant height**	**Number of effective tillers / plant**	**Ear head length**	**Ear head diameter**	**Test weight**	**Dry Stover yield / plant**	**Grain yield / plant**	**Harvest index**
$\sigma^2 GCA$	0.294	0.727**	50.665***	0.057**	1.244*	0.023*	0.805***	18.790*	3.903*	3.179
$\sigma^2 SCA$	2.812**	2.200***	64.370***	0.261***	6.784***	0.112***	1.139***	109.456***	2.497**	32.754**
$\sigma^2 GCA / \sigma^2 SCA$	0.104	0.330	0.787	0.218	0.183	0.205	0.706	0.171	1.563	0.097

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

Table 3: General combining ability effects for different characters in pearl millet.

Sr. N0.	**Parents**	**Days to 50% flowering**	**Days to maturity**	**Plant height**	**Number of effective tillers / plant**	**Ear head length**	**Ear head diameter**	**Test weight**	**Dry Stover yield / plant**	**Grain yield / plant**	**Harvest index**
Lines											
1	RMS 6A	-1.856**	-1.809**	-6.032**	-0.186**	-1.054**	-0.064**	0.173	-4.730**	-2.431**	0.038
2	RMS 7A	-1.041**	-2.087**	-0.363	-0.013	-0.182	0.250**	0.610**	6.909**	0.166	-2.811**
3	RMS 21A	0.533**	0.524**	6.403**	-0.488**	-3.997**	-0.130**	-1.689**	-6.320**	-4.741**	-6.293**
4	ICMA 843-	1.293**	1.783**	7.808**	0.632**	0.296*	0.089**	0.124	11.536**	2.854	-1.490**

	22										
5	ICMA 92777	0.422**	0.172	9.121**	0.017	0.109	-0.071**	-0.852**	-2.523**	-0.820**	0.144
6	ICMA93333	0.719**	-0.957**	5.942**	0.179**	1.839**	0.118**	-0.596**	7.990**	3.451**	1.349**
7	ICMA 97111	-0.911**	-0.402**	-10.624**	-0.443**	1.170**	-0.044**	0.047	-8.063**	-1.168**	2.527**
8	ICMA 04999	0.774**	1.672**	1.344**	0.674**	2.081**	0.154**	-0.238*	2.438**	6.351**	6.211**
9	ICMA 06999	0.607**	1.839**	-8.914**	-0.616**	0.143	-0.296**	0.546**	-16.612**	-5.144**	2.648**
10	JMSA 20042	-0.541**	-0.735**	-4.625**	0.245**	-0.405**	-0.006	1.876**	9.376**	1.482**	-2.323**
	SE (g_i) ±	0.127	0.180	0.491	0.015	0.106	0.016	0.109	0.240	0.155	0.271
	SE (g_i-g_j) ±	0.180	0.254	0.695	0,021	0.150	0.023	0.120	0.672	0.219	0.754
Testers											
1	BIB – 40	0.889**	0.691**	-0.791*	0.091	0.333**	0.204**	0.512**	1.225**	1.532**	1.164**
2	BIB – 65	-0.544**	0.091	4.479**	-0.032	-1.016**	-0.407**	1.030**	-0.361	-0.702**	-0.928**
3	BIB – 66	-0.278**	-0.987**	-5.928**	-0.320	-0.540**	0.144**	-0.764**	0.067	-2.869**	-3.879**
4	BIB – 75	-0.811**	-0.820**	-4.912**	0.139	-0.639**	0.062**	0.161	0.168	0.902**	1.467**
5	BIB – 76	0.044	-0.020	-7.283**	0.022	-0.563**	0.034**	-1.586**	-2.581**	0.041	1.448**
6	BIB – 186	0.700**	1.046	14.334**	0.101	2.425**	-0.037**	0.648**	1.481**	1.095	0.727**
	SE (g_j) ±	0.099	0.140	0.380	0.012	0.082	0.012	0.084	0.186	0.120	0.209
	SE (g_i-g_j) ±	0.140	0.197	0.538	0.017	0.116	0.018	0.120	0.263	0.169	0.297

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

The SCA effect (Table 4) depicted that no specific cross combination had consistently high SCA effect for all the characters. Out of 60 cross combinations 19 showed significant and positive SCA effect for grain yield per plant. The highest SCA effect for grain yield per plant was observed by cross RMS 21A X BIB-186 proved to be the best specific combiner over all the environments for as much as seven characters viz., number of effective tillers per plant, ear head length, ear head diameter, test weight, dry stover yield per plant, grain yield per plant and harvest index and ICMA 06999 X BIB- 40 for seven characters viz., days to 50 per cent flowering, plant height, number of effective tillers per plant, ear head diameter, test weight, dry stover yield per plant and grain yield per plant followed by ICMA 92777 X BIB- 65 for six character viz., days to maturity, plant height, number of effective tillers per plant, ear head length, dry stover yield per plant and grain yield per plant. ICMA 04999 X BIB- 76 for six characters viz., plant height, number of effective tillers per plant, ear head length, dry stover yield per plant and grain yield per plant and harvest index followed by RMS 7A X BIB-75 for number of effective tillers per plant,

Table 4: Hybrids showing significant positive specific combining ability effects for grain yield and their performance in other traits in pearl millet.

Sr. No.	Cross	SCA effects	Traits showing useful and significant sca effects
1	RMS 21 A X BIB-186	9.469**	Number of effective tillers/plant, ear head length, ear head diameter, test weight, dry stover yield/plant, harvest index.
2	ICMA 06999 X BIB-40	3.348**	Days to 50% flowering, plant height, number of effective tillers/plant, ear head diameter, test weight, dry stover yield/plant.
3	ICMA 92777 X BIB-65	2.430**	Days to maturity, plant height, number of effective tillers/plant, ear head length, dry stover yield/plant.
4	ICMA 04999 X BIB-76	6.222**	Plant height, number of effective tillers/plant, ear head length, dry stover yield/plant, harvest index.
5	RMS 7A X BIB-75	7.656**	Number of effective tillers/plant, ear head diameter, dry stover per plant, harvest index.
6	ICMA 92777 X BIB-40	5.940**	Number of effective tillers/plant, ear head length, test weight, harvest index.
7	ICMA 92777 X BIB-66	8.308**	Number of effective tillers/plant, ear head length, ear head diameter, dry stover yield / plant.
8	ICMA 97111 X BIB-186	5.772**	Number of effective tillers/plant, ear head diameter, dry stover yield / plant, harvest index.
9	ICMA 04999 X BIB-65	3.480**	Number of effective tillers/plant, ear head length, ear head diameter, dry stover yield / plant.
10	JMSA 20042 X BIB-40	7.271**	Plant height, number of effective tillers/plant, dry stover per plant, harvest index.
11	JMSA 20042 X BIB-66	2.048**	Number of effective tillers/plant, ear head diameter, test weight, harvest index.

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

ear head diameter, dry stover yield per plant and grain yield per plant and harvest index. ICMA 92777 X BIB-40 for number of effective tillers per plant, ear head length, test weight, grain yield per plant and harvest index. ICMA 92777 X BIB-66 for number of effective tillers per plant, ear head length, ear head diameter, dry stover yield per plant and grain yield per plant. ICMA 97111 X BIB-186 for number of effective tillers per plant, ear head diameter, dry stover yield

per plant and grain yield per plant and harvest index. ICMA 04999 X BIB- 65 for number of effective tillers per plant, ear head length, ear head diameter, dry stover yield per plant and grain yield per plant. JMSA 20042 X BIB- 40 for plant height, number of effective tillers per plant, dry stover yield per plant and grain yield per plant and harvest index. JMSA 20042 X BIB-66 for number of effective tillers per plant, ear head diameter, test weight, grain yield per plant and harvest index. Result in consonance of these finding were reported by Khandagale *et al*., (2014) [7], Bhardwaj *et al*., (2015) [4] and Patel *et al*., (2016) [10].

High SCA effects from good x good general combiners indicate additive x additive type of gene interaction and superiority of favorable genes, contributed by parents, while those involving good x poor or poor x poor combiners indicate interaction of additive x dominance or dominance x dominance, respectively. Thus cross combinations involving good x good general combiner parents are of more relevance in cross pollinated crops such as pearl millet, because, genes controlling these effects may be fixed in the end product of a breeding programme. In the present study, cross with high SCA effects involving good x good general combiners were RMS 7A X BIB-75, ICMA 93333X BIB-186, ICMA 04999X BIB-65 and JMSA 20042 X BIB-40 for grain yield per plant and related traits. These crosses offer good promise for improvement of respective component traits and ultimately grain yield. The transgressive segregants could be isolated in higher frequency from these cross and utilize to generate inbreds lines using conventional breeding methods for further crop improvement programmes. Bhadalia *et al*., (2014) [3], Shinde and Mehetre (2014) [11] and Nandaniya *et al*., (2016) [8] also reported similar findings.

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