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Research Article

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 six lines and eleven testers was carried out to study the combining ability and gene action for grain yield and 14 quantitative traits in pearl millet. Analysis of variance for combining ability revealed that significant differences among the mean squares was observed for lines, testers and lines x testers for all the characters except for mean squares due to lines for number of productive tillers per plant, ear head weight per plant, grain yield per plant, harvest index and threshing index and due to testers for ear head weight per plant, days to maturity, dry fodder yield per plant, grain yield per plant, harvest index and threshing index, which indicated the importance of both additive and non-additive genetic variances in the expression of these characters. The ratio of GCA variance and SCA variance indicated the predominance of non-additive gene action for the characters days to 50% flowering, length of protogyny, number of nodes per plant, plant height, number of productive tillers per plant, ear head weight per plant, days to maturity, 1000-grain weight, dry fodder yield per plant, grain yield per plant, harvest index and threshing index and additive gene action for ear head girth and ear head length. Among the lines, ICMA-04111, ICMA-92777 and ICMA-05333 and the testers J-2534, J-2454 and J-2507 displayed high *gca* effect for grain yield per plant and for some desirable traits. Significant and positive *sca* effect for grain yield per plant was displayed by the cross ICMA-05333 x J-2527 followed by ICMA-05333 x J-2340, JMSA-20064 x 283-SB-11, ICMA-92777 x STPT-115, ICMA-04999 x J-2539 and JMSA-20071 x J-2507. These crosses involved either average x average, good x poor, poor x poor or good x good general combining parents. These crosses have been identified as best hybrids for improving grain yield per plant and could be further evaluated to confirm their stable superior performance.

Key words:
Pearl millet**,** combinig ability, gene action, line x tester analysis

Introduction

Pearl millet (*Pennisetum glaucum* (L.) R. Br.) is a member of the family Poaceae with chromosome number 2n=14. It is an important member of the genus *Pennisetum*, which has high importance for both food and fodder and it is the most drought tolerant major cereal. The grain is the main purpose of cultivation of pearl millet in India and other countries. However, it is also grown on small scale as high quality forage crop in India, USA, Australia, South America and South Africa. The share of pearl millet in total food grain production is to the tune of 10.7 %. 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 (Annon., 2013). It is widely cultivated in the states of Rajasthan, Maharashtra, Gujarat, Uttar Pradesh and Hariyana (Annon., 2013). Commercial hybrid seed in pearl millet is possible mainly through the development of hybrids by the utilization of cytoplasmic genetic male sterility system. Burton (1951) was the first to develop cytoplasmic male sterile line, Tift 23A. This opened up a new field for hybrid seed production in pearl millet. The use of CMS in pearl millet paved the way for grain yield augmentation with the development and release of the high yielding hybrids.

An understanding of the combining ability and gene action is a pre-requisite for any successful plant breeding programme. Testing the parents for their combining ability is very important because many times the high yielding parents may not combine well to give good hybrids. Line x tester analysis helps in testing a large number of genotypes to assess the gene action and combining ability. The present experiment was, therefore planned to study combining ability and gene action in pearl millet.

Material and Methods

The present study on pearl millet was conducted at Department of Genetics and Plant Breeding, Junagadh Agricultural University, Junagadh, Gujarat. Six diverse male sterile lines (cytoplasm A1 & A4) *viz.,* ICMA-04111, JMSA-20071, ICMA-92777, ICMA-04999, JMSA-20064, ICMA-05333 were crossed with eleven testers *viz.,* J-2534, J-2527, 334-SB-11, 283-SB-11, STPT-115, J-2290, J-2454, J-2507, J-2539, J-2340 and 285-SB-11 in a line x tester mating design during *kharif* 2012 to produce 66 hybrids. The resulted 66 hybrids along with 17 parents were evaluated during summer-2013 in a Randomized Block Design with three replications. Each plot with a spacing of 60 x 15 cm consisted of single row of 5.0 m length. All need based agronomic practices were followed during the crop growth period to raise a good crop. Observations were recorded on randomly selected five plants in each replication and entry for 14 quantitative traits *viz.*, days to 50% flowering, length of protogyny, number of nodes per plant, plant height (cm), ear head girth (cm), ear head length (cm), number of productive tillers per plant, ear head weight per plant (g), days to maturity, 1000-grain weight (g), dry fodder yield per plant (g), grain yield per plant (g), harvest index (%) and threshing index (%). The mean values were used for the analysis of variance for experimental design. The data were statistically analyzed for combining ability as per the method suggested by Kempthorne (1957).

Results and Discussion

Analysis of variance for combining ability (Table 1) showed significant differences among mean squares due to lines, testers and line x tester for all the characters except for mean squares due to lines for number of productive tillers per plant, ear head weight per plant, grain yield per plant, harvest index and threshing index and due to testers for ear head weight per plant, days to maturity, dry fodder yield per plant, grain yield per plant, harvest index and threshing index, which indicated the existence of genetic diversity among the parents. However, mean squares due to testers were larger than those due to lines for all the characters except days to 50% flowering, length of protogyny, number of nodes per plant, plant height, ear head weight per plant and dry fodder yield per plant indicating more diversity among the testers for these characters. Estimates of genetic component of variance revealed that the variances due to lines (σ^2l) were higher than the variances due to testers (σ^2t) for all the characters except days to 50% flowering, length of protogyny, plant height, ear head girth, ear head length, number of productive tillers per plant, ear head weight per plant, days to maturity, 1000-grain weight, grain yield per plant, harvest index and threshing index indicating the greater role of lines towards total additive genetic variance. Estimates of GCA variance and SCA variance revealed that the magnitude of GCA variance was higher than those of SCA variance for ear head girth and ear head length. The ratio between GCA and SCA variance was also more than unity for ear head girth and ear head length suggesting involvement of additive gene action in the inheritance these characters. Whereas, this ratio was less than unity for days to 50% flowering, length of protogyny, number of nodes per plant, plant height, number of productive tillers per plant, ear head weight per plant, days to maturity, 1000-grain weight, dry fodder yield per plant, grain yield per plant, harvest index and threshing index suggesting that these characters were predominately under the genetic control of non-additive gene action. The findings of the present investigation for grain yield per plant and its attributing traits are in close conformity with the findings of Rasal and Patil (2003), Dangaria *et al*. (2004), Vaghasiya *et. al.* (2008), Chaudhary *et al.* (2012) and Bhadalia *et al.* (2014).

An overall appraisal of *gca* effects (Table 2) indicated that none of the parents was good general combiner simultaneously for all the characters studied. However, among the lines, ICMA-04111 was found to be good general combiner for eight characters *viz.*, length of protogyny, number of nodes per plant, plant height, ear head length, ear head weight per plant, 1000-grain weight, dry fodder yield per plant and grain yield per plant followed by ICMA-92777 for six characters *viz.*, days to 50% flowering, number of nodes per plant, number of productive tillers per plant, grain yield per plant, harvest index and threshing index and ICMA-05333 for four characters *viz.*, length of protogyny, ear head girth, ear head length and 1000-grain weight. Among the testers, J-2534 was good general combiner for eleven characters *viz.*, length of protogyny, number of nodes per plant, plant height, ear head girth, number of productive tillers per plant, ear head weight per plant, 1000-grain weight, dry fodder yield per plant, grain yield per plant, harvest index and threshing index followed by J-2454 for eight characters *viz.*, days to 50% flowering, number of productive tillers per plant, ear head weight per plant, days to maturity, dry fodder yield per plant, grain yield per plant, harvest index and threshing index and J-2507 for eight characters *viz.*, days to 50% flowering, plant height, ear head girth, number of productive tillers per plant, ear head weight per plant, days to maturity, 1000-grain weight and dry fodder yield per plant. Hence the parents viz., J-2534, ICMA-04111, J-2454, ICMA-92777, J-2507 and J-2340 which are good general combiners for maximum number of characters are considered as the potential parents and could be utilized in further breeding programme in order to combine more number of characters by involving fewer numbers of parents in a crossing programme.

The study indicated that the parents exhibiting good *gca* effect for different traits like, number of nodes per plant, plant height, ear head girth, ear head length, number of productive tillers per plant, days to maturity, 1000-grain weight, dry fodder yield per plant and threshing index were also having desirable *per se* performance, which suggested that the *per se* performance can be considered as a reliable criterion for selecting parents for hybridization. High general combining ability effects mostly contribute either additive gene effect or additive x additive interaction effect or both and represent fixable portion of genetic variation. Accordingly, ICMA-04111, ICMA-92777, ICMA-05333, J-2534, J-2454 and J2507 offer the best possibilities of exploitation for the development of improved lines with enhanced yielding ability. Further, the lines showing good general combining ability for particular components may be utilized in component breeding programme for improving specific trait of interest.

The best specific combination was observed in cross ICMA-05333 x J-2527 for grain yield per plant and involved average x average combining parents (Table 3). This cross was also expressed good specific combining ability for days to 50 % flowering, number of productive tillers per plant, ear head weight per plant, 1000-grain weight, dry fodder yield per plant and grain yield per plant. The cross combinations *viz.*, ICMA-05333 x J-2340, JMSA-20064 x 283-SB-11, ICMA-92777 x STPT-115 and ICMA-04999 x J-2539 also showed high, significant and positive *sca* effects for grain yield per plant and some other yield attributing characters. This indicated that the high *sca* effect observed for grain yield per plant was associated with desirable sca effect manifested by its component characters like plant height, ear head girth, ear head length, number of productive tillers per plant, ear head weight per plant and 1000-grain weight.

The good general combiners when crossed may not always produce the best hybrid. Marked negative effects in crosses between good x good were noteworthy, which could be attributed to the lack of complementation between favourable alleles of the parents involved. Marked positive *sca* effects in crosses between good x poor and poor x poor could be ascribed to better complementation between favourable alleles of parents involved. These findings are in agreement with the earlier findings of Pethani *et al.* (2004), Bhanderi *et al.* (2007), Vagadiya *et al.* (2010), Lakshmana *et al.* (2011) and Parmar *et al.* (2013).

From the present findings it can be concluded that for the characters like, days to 50% flowering, length of protogyny, number of nodes per plant, plant height, number of productive tillers per plant, ear head weight per plant, days to maturity, 1000-grain weight, dry fodder yield per plant, grain yield per plant, harvest index and threshing index displayed higher *sca* effect than *gca* effect indicated that there was substantial role played by dominance gene action. Such characteres could be improve through heterosis breeding or through segregants in the segregating generations, which the breeder can handle through pedigree method for developing high yielding types in pearl millet. While for characters like, ear head girth and ear head length, the *gca* effect was higher than *sca* effect so these was governed by additive gene action. The presence of additive effects would enhance the chances of making improvement through simple selection. The most of the crosses exhibiting high sca effect involved either good x poor, poor x poor or good x good general combiners, for majority of the characters studied. The results suggested the presence of additive x dominance, dominance x dominance and additive x additive type of gene interactions. When epistasis is present, the recurrent selection followed by pedigree or biparental mating or diallel selective mating systems may prove to be effective in improvement of grain yield and its attributes in pearl millet.

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

Source	d.f.	Days to 50 % flowering	Length of protogyny	No. of nodes per plant	Plant height (cm)	Ear head girth (cm)	Ear head length (cm)	No. of productive tillers per plant
Replications	2	0.702	0.021	0.221	138.540*	0.423	2.642	0.583**++
Lines	5	78.223**++	2.506**++	3.450**++	3151.997**++	12.258**++	130.331**++	1.124
Testers	10	48.250**++	1.412**+	1.113*+	2152.629**++	12.719**++	303.202**++	3.216**++
Lines x Testers	50	11.814**	0.566**	0.506**	474.765**	1.051**	17.546**	0.718**
Error	130	0.882	0.040	0.121	43.711	0.141	1.452	0.081
Variance components								
σ^2l		2.344	0.075	0.101	94.191	0.367	3.905	0.032
σ^2t		2.632	0.076	0.055	117.162	0.699	16.764	0.174
σ^2lt		3.644	0.176	0.128	143.685	0.304	5.364	0.212
σ^2GCA		2.445	0.075	0.085	102.298	0.484	8.444	0.082
σ^2SCA		3.644	0.176	0.128	143.685	0.304	5.364	0.212
σ^2GCA/σ^2SCA		0.671	0.429	0.660	0.712	1.596	1.574	0.386

Table 1. Contd..

Source	d.f.	Ear head weight per plant(g)	Days to maturity	1000-grain weight (g)	Dry fodder yield per plant (g)	Grain yield per plant (g)	Harvest index	Threshing index
Replications	2	105.741	5.515*+	0.021	267.997	57.736	7.043	0.397
Lines	5	1359.810	54.918*+	11.281**++	5249.940*+	881.034	30.251	192.173
Testers	10	949.320	37.120	13.733**++	2621.161	908.572	43.360	471.302
Lines x Testers	50	1318.893**	21.403**	3.264**	1957.849**	740.342**	68.660**	277.427**
Error	130	38.185	1.305	0.210	107.609	54.940	5.526	25.809
Variance components								
σ^2l		40.049	1.625	0.336	155.828	25.033	0.749	5.041
σ^2t		50.619	1.990	0.751	139.642	47.424	2.102	24.750
σ^2lt		426.903	6.699	1.018	616.747	228.467	21.045	83.873
σ^2GCA		43.780	1.754	0.482	150.115	32.936	1.227	11.997
σ^2SCA		426.903	6.699	1.018	616.747	228.467	21.045	83.873
σ^2GCA/σ^2SCA		0.103	0.262	0.474	0.243	0.144	0.058	0.143

*, ** Significant at 5 and 1 % levels, respectively
+,++ Significant at 5 and 1 % levels, respectively against lines x testers interaction

Table 2. General combining ability effect of parents for different characters in pearl millet

Sr. No.	Parents	Days to 50% flowering	Length of protogyny	No. of nodes per plant	Plant height(cm)	Ear head girth (cm)	Ear head length(cm)	No. of productive tillers per plant
Lines								
1	ICMA-04111	2.37**	-0.08*	0.49**	15.59**	-0.65**	2.75**	0.15**
2	JMSA-20071	-1.66**	0.02	-0.17**	-11.63**	0.10	-1.62**	-0.12*
3	ICMA-92777	-0.51**	0.34**	0.27**	0.97	-0.15*	-2.60**	0.29**
4	ICMA-04999	-1.51**	0.22**	-0.34**	-5.87**	-0.08	-0.64**	-0.01
5	JMSA-20064	0.85**	-0.03	0.02	6.10**	-0.35**	1.36**	-0.18**
6	ICMA-05333	0.46**	-0.46**	-0.27**	-5.15**	1.14**	0.75**	-0.13**
	SE(g_i)	**0.163**	**0.035**	**0.061**	**1.151**	**0.065**	**0.210**	**0.050**
	SE(g_i-g_j)	**0.231**	**0.049**	**0.086**	**1.63**	**0.092**	**0.297**	**0.070**
Testers								
1	J-2534	-0.22	-0.20**	0.17*	7.68*	0.42**	-2.41**	0.15*
2	J-2527	2.01**	0.03	0.07	-1.30	0.50**	0.90**	0.42**
3	334-SB-11	3.51**	-0.11*	0.21*	21.34**	-0.88**	10.62**	-0.37**
4	283-SB-11	0.01	-0.06	0.04	-3.36*	1.05**	0.17	-0.57**
5	STPT-115	-0.16	0.24**	-0.56**	-23.86**	0.45**	2.42**	-0.47**
6	J-2290	-0.11	0.43**	0.05	-2.90	0.88**	-2.80**	-0.17*
7	J-2454	-1.66**	0.44**	-0.32**	-5.98**	-1.34**	-4.53**	0.77**
8	J-2507	-0.50*	0.01	0.010	5.54**	0.22*	-1.64**	0.22**
9	J-2359	-2.72**	-0.05	-0.14	-1.56	-0.76**	1.14**	-0.17*
10	J-2340	0.01	-0.32**	0.30**	4.67**	-1.05**	-3.23**	0.41**
11	285-SB-11	-0.16	-0.43**	0.08	-0.27	0.51*	-0.64*	-0.22**
	SE(g_i)	**0.221**	**0.047**	**0.082**	**1.558**	**0.088**	**0.284**	**0.067**
	SE(g_i-g_j)	**0.313**	**0.066**	**0.116**	**2.204**	**0.125**	**0.402**	**0.095**

*, ** Significant at 5% and 1% levels, respectively

Contd…

Table 2. Contd….

Sr. No.	Parents	Ear head weight(cm)	Days to maturity	1000-grain weight(g)	Dry fodder yield(g)	Grain yield (g)	Harvest index	Threshing index
Lines								
1	ICMA-04111	11.84**	1.44**	0.41**	21.44**	7.95**	-1.41**	0.20
2	JMSA-20071	-7.37**	-0.96**	-0.02	-16.57**	-7.52**	0.83*	-2.32**
3	ICMA-92777	-1.73	1.68**	-0.54**	4.13*	2.98*	1.05*	4.21**
4	ICMA-04999	0.94	-1.50**	0.21**	-6.33**	-1.82	-0.09	-2.19*
5	JMSA-20064	-1.17	-0.47**	-0.81**	-2.02	-0.38	0.41	0.83
6	ICMA-05333	-2.53*	-0.20	0.74**	-0.66	-1.21	-0.79	-0.73
	SE(g_i)	**1.076**	**0.199**	**0.080**	**1.806**	**1.290**	**0.409**	**0.884**
	SE(g_i-g_j)	**1.521**	**0.281**	**0.113**	**2.554**	**1.825**	**0.579**	**1.251**
Testers								
1	J-2534	5.20**	-0.49	0.60**	7.82**	10.36**	3.21**	7.08**
2	J-2527	1.66	0.79**	-0.94**	13.19**	3.27	-0.85	1.99
3	334-SB-11	-13.52**	1.01**	-0.49**	-1.87	-7.47**	-1.03	2.40*
4	283-SB-11	-3.30*	1.73**	0.39	-7.97**	-3.37	-0.18	-2.81*
5	STPT-115	-6.22**	1.79**	0.75**	-24.81**	-11.03**	-0.86	-9.43**
6	J-2290	-3.46*	-0.21	0.98**	-5.36*	0.28	2.12**	3.26**
7	J-2454	7.59**	-1.32**	-1.12**	12.22**	9.49**	1.21*	3.69**
8	J-2507	5.34**	-2.55**	0.97**	14.78**	3.09	-1.38*	1.08
9	J-2359	7.88**	0.79**	-1.47**	-8.67**	-3.61*	-1.40*	-8.86**
10	J-2340	6.64**	0.34	-0.04	6.10*	5.99**	0.33	0.98
11	285-SB-11	-7.81**	-1.88**	0.37**	-5.45*	-7.02**	-1.15*	0.64
	SE(g_j)	**1.457**	**0.269**	**0.108**	**2.445**	**1.747**	**0.554**	**1.197**
	SE(g_i-g_j)	**2.060**	**0.381**	**0.153**	**3.458**	**2.471**	**0.784**	**1.693**

*, ** Significant at 5% and 1% levels, respectively

Table 3. Sca effect of selected crosses for grain yield per plant and component characters in pearl millet

Characters	Hybrids									
	ICMA-05333 x J-2527	ICMA-05333 x J-2340	JMSA-20064 x 283-SB-11	ICMA-92777 x STPT-115	ICMA-04999 x J-2539	JMSA-20071 x J-2507	ICMA-04111 x J-2534	ICMA-92777 x J-2340	JMSA-20064 x 334-SB-11	ICMA-04999 x J-2507
Grain yield per plant	38.72**	25.47**	22.27**	21.10**	17.81**	17.54**	17.27**	15.14**	14.97**	14.91**
Days to 50% flowering	1.21*	0.54	1.48*	-0.32	2.57**	1.50**	1.52**	0.18	1.98**	4.01**
Length of protogyny	-0.46*	-0.27*	-0.16	-0.10	-0.22	0.06	0.29*	-0.01	-0.25*	-0.81**
Number of nodes per plant	0.15	0.40*	0.36	0.18	-0.05	-0.44*	-0.05	-0.14	0.33	0.05
Plant height(cm)	-6.68	15.49**	7.60*	24.90**	-0.49	3.63	1.60	-9.57*	-1.10	22.54**
Ear head girth(cm)	-0.14	0.01	-0.39	0.91**	1.99**	0.29	-0.19	-0.69**	-0.62**	0.68**
Ear head length(cm)	0.65	0.41	-1.96**	1.02	-1.39*	-1.24	-1.03	3.19**	1.52*	6.59**
Number of productive tillers per plant	0.96**	-0.29	0.34*	0.50**	0.17	-0.52**	0.15	0.76**	0.47**	0.38*
Ear head weight(g)	53.63**	29.72**	22.13**	20.24**	18.38**	31.16**	21.60**	14.89**	20.29**	7.54*
Days to maturity	-1.64*	3.14**	1.36*	-1.85**	2.00**	0.12	-1.00	0.93	-1.25	-1.33*
1000-grain weight(g)	1.39**	0.27	-0.89**	1.11**	0.10	-2.24**	0.11	-0.39	0.33	0.25
Dry fodder yield per plant(g)	49.38**	12.60*	39.76**	27.89**	17.80**	-0.07	27.02**	10.08	34.26**	1.75
Harvest index	1.99	5.71**	0.72	2.82*	2.30	2.20	-0.85	3.27*	-1.96	5.28**
Threshing index	1.32	4.91	7.57**	9.25**	5.10	-5.23	-0.66	4.14	-0.05	7.33*

*, ** Significant at 5% and 1% levels, respectively