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Combining ability and heterosis for grain yield, fodder yield and other agronomic traits in sorghum [*Sorghum bicolor* (L.) Moench]

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Abstract: Forty five hybrids derived from a diallel mating design of ten parents and one standard check PUSA CHARI-121 were evaluated for general and specific combining ability effects and standard heterosis for grain yield/plant, dry fodder yield/plant, days to 50 per cent flowering, plant height, number of leaves/plant, leaf length, leaf breadth and 100- seed weight of *Sorghum bicolor*. The mean square due to general and specific combining ability was significan for Days to 50% flowering, Days to maturity, Plant height (cm),No of Leaves/plant, Leaf length (cm), Leaf width (cm), seed yield/plant (g), Fodder yield/plant (q/ha) and 100-seed weight (g) for all the characters. Both additive and non additive genetic effects were present in the material under study. However the ratio of σ^2gca/ σ^2sca suggested that the preponderance of non additive gene action in expression of all the characters under study. Out of the nine parents PUSA CHARI-121, PANT CHARI-4, MP CHARI, PANT CHARI-6 and PANT CHARI-5 identified as good general combiner for grain yield/plant, dry fodder yield/plant and other agronomical traits. The hybrid HC-136 x PANT CHARI-4 and PANT CHARI-4 x PUSA CHARI-121 for grain yield/plant and hybrid MP CHARI x PANT CHARI -6, PANT CHARI-5 x SPV 1616 and HC-136 x PANT CHARI-4 for dry fodder yield/plant exhibited higher magnitude of positive significant specific combining ability effect with highest standard heterosis and *per se* performance. These hybrids were also found suitable for two or three yield contributing traits. In general, close association between specific combining ability effects and standard heterosis was observed among the best hybrids identified on the basis of specific combining ability effects for grain and dry fodder yield.

Keywords: Combining ability, Diallel analysis, Gene action,, Sorghum, Standard heterosis

INTRODUCTION

Sorghum [*Sorghum bicolor* (L.) Moench] is an often self-pollinating, diploid (2n = 2x = 20) crop with a genome, about 25% the size of maize or sugarcane. It is a C4 plant with higher photosynthetic efficiency and higher abiotic stress tolerance (*Nagy et al.*, 1995; *Reddy et al.*, 2009). Sorghum is fifth most important cereal crop globally and is the dietary staple of more than 500 million people in 30 countries. It is grown on 40 m ha in 105 countries of Africa, Asia, Oceania and the Americas. Africa and India account for the largest share (> 70%) of global sorghum area while USA, India, Mexico, Nigeria, Sudan and Ethiopia are the major sorghum producers (Kumar *et al.*, 2011; Kumar and Chopra, 2013). It is the third most important grain crop in India, next only to rice (*Oryza sativa*) and wheat (*Triticum aestivum*). Maharashtra, Karnataka, Madhya Pradesh, Andhra Pradesh, Rajasthan Gujarat and UP are the major sorghum growing states of India. Besides being an important food, feed and forage crop, sorghum also provides raw material for the production of starch, fiber, dextrose syrup, biofuels, alcohol, and other products (Kumar and Chopra, 2013). Classical plant breeding has resulted in the successful development of high yielding, highly adapted sorghum cultivars. Vast diversity is available in sorghum and it is distributed among different sorghum races. Therefore, further enhancement of yield potential and the productivity of newly developed varieties needs urgent attention. The traits like grain and fodder yield are governed by polygenes with complex gene action and hence understanding the nature and magnitude of gene action help the breeder in selection of an appropriate breeding method such as biparental mating and recurrent selection was suggested. by Hayes and Garber in 1919. For improvement in such an important crop, the most important prerequisite is the selection of suitable parents, which could combine well and produce desirable hybrids and segregants. In the present study, an attempt has been made to estimate the heterosis in F1 hybrids with respect to yield, the combining ability and gene action governing the quantitative traits in sorghum, *S. bicolor* using *diallel mating* designs.

MATERIALS AND METHODS

The ten genetically diverse lines of sorghum presented in table 1 were crossed in diallel mating design exclud-

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Table 1. Origin and pedigree of sorghum genotypes used for the diallel cross.

Cultivar	Origin/Source	Pedigree
1-PANT CHARI-5	GBPUA&T Pantnagar (U.K)	CS 3541 X IS 6953
2-PUSA CHARI-1002	IARI New Delhi	xxxxxxxxxxxxxx
3-SPV 1616	DSR Hyderabad (Andra Pradesh)	SPV 946 x Kh 89-246
4-PUSA CHARI-615	IARI New Delhi	xxxxxxxxxxxxxxxx
5-HC-136	GBPUA&T Pantnagar (U.K)	IS 3214 (biolor) x PC 7R
6-PANT CHARI-4	GBPUA&T Pantnagar (U.K)	IS 4776 x Rio
7-PUSA CHARI-121	IARI New Delhi	xxxxxxxxxxxxxxxx
8-MP CHARI	GBPUA&T Pantnagar (U.K)	xxxxxxxxxxxxxxx
9-PANT CHARI-6	GBPUA&T Pantnagar (U.K)	Selection from SDSL 92140
10-HC-171	GBPUA&T Pantnagar (U.K)	SPV 8 x IS 4776

ing reciprocals to produce 45 experimental hybrids during *kharif* 2012. The 45 F_{1s} including Ten parents and a popular local check PUSA CHARI-121 were grown at the Crop Research Center of Sardar Vallabhbhai Patel University of Agriculture & Technology, Meerut (U.P.) during *kharif* 2012. University is situated at latitude of 29.5° N and longitude 77.45° E and at an elevation of 237 M above the Mean Sea Level. The experiment was laid out in randomized block design with three replication in a single-row plot of 6.75 m long, spaced at 0.45 m apart. NPK 120:40:00 fertilizers was applied as half basal dose of nitrogen and full dose of phosphorus at the time of sowing and half nitrogen applied after one month of sowing. Plots were thinned down after two weeks of crop emergence and plant-to-plant distance of 0.15 m was maintained. All other recommended agronomical practices were followed to raise a good crop. The biometrical observations recorded on grain yield/plant (g), dry fodder yield/plant (g), plant height (cm), number of leaves/ plant, leaf length (cm), leaf breadth (cm) and 100- seed weight (g) on five randomly selected competitive plants of each genotype and each replication. The observation for days to 50% flowering and days to maturity were recorded on the plot basis. The mean values of observations were subjected to diallel analysis to estimate general combining ability (gca) and specific combining ability (sca) effects as per procedure given by Griffing method 2 Model I (Griffing, 1956) and standard heterosis was calculated as per standard procedure given by Meredith and Bridge (1972). Analysis of variance (ANOVA) was performed to test the significance of differences among the genotypes including crosses and parents as per standard procedure given by Panse and Sakhatme **(**1964).

RESULTS AND DISCUSSION

The analysis of variance revealed significant variability among the parents and hybrids for all the nine characters studied. For efficient selection, presence of variability among the genotypes for the traits of interest is a prerequisite. The analysis of variance for combining ability revealed the significant mean square due to general and specific combining ability for all the characters under study (Table 2). This indicates that all the characters contribute much for genetic variability among the parents and hybrids and both additive and none additive gene effects were important for the expression of these traits. However the variance due to specific combining ability was greater than the variance due to general combining ability, which indicated the predominant role of non additive gene action in the expression of these traits. Predominance of non-additive gene action for these traits in sorghum was observed by Pillai *et al.* (1995), Badge and Patil (1997), Baghel *et al.* (2005), Premlatha *et al.* (2006), Solanki *et al.* (2007), Mohamed and Talib (2008) and Aruna *et al*. (2010), Vinaykumar (2011). Harer and Bapat (1982) stated that the *per se* performance of the parents with high general combining ability provide the criteria for the choice of parents for hybridization. On this basis, those parents which performed well for *per se* performance and general combining ability effects can be considered as desirable parents. Further the parents with high gca effects are desirable for obtaining useful segregants in early generations. The potentiality of parents to produce better offspring's with superior genes was evaluated based on their general combining ability effect. To get desirable recombinants in segregation generations, the parents of the hybrids must be good general combiner for the characters to which improvement is sought Kulkarni *et al.* (2007), Gravois and McNew, 1993). The estimate of general combining ability effects for different diverse parents revealed that none of the nine lines showed desirable significant general combining ability effects for all the traits together indicating that different parent should be used for genetic improvement of different yield components (Table 3). In the present study, different parental lines have been identified with good general combining ability for different yield and yield related traits. Considering the both general combining ability effects and *per se* performance, the parental lines PUSA CHARI-121, PANT CHARI-4 and MP CHARI with moderate to high *per se* performance and high significant positive general combining effect for grain yield and 100- seed weight indicate that these lines are good for grain yield/plant. While the parental lines PANT CHARI-6, PUSA CHARI-121, PANT CHARI-5 and MP CHARI showed high per se performance and high significant positive general combining effect for dry fodder yield. Apart from grain and fodder yield some parents also registered significant general combining ability effect in desirable direction

Table 2. Analysis of Variance for combining ability in diallel crosses for nine characters in sorghum.

Source of Variation	DF	Days to 50 % Flowering	Days to Maturity	Plant height (cm)	No of Leaves/plant	Leaf Length(cm)	Leaf Width(cm)	Seed yield/plant(g)	Fodder yield/plant(q/ha)	100- Seed Weight(g)
gca	8	24.50**	32.02**	2195.69**	5.35**	460.87**	6.99**	371.15**	15940.91**	0.20**
Sca	36	20.04**	28.48**	2278.51**	5.44**	181.87**	4.39**	332.84**	12995.36**	0.12**
Error	88	0.44	1.08	77.02	0.08	1.50	0.05	3.31	12.57	0.00
σ^2gca		0.40	0.32	-	-	25.36	0.23	3.48	267.77	0.01
σ^2sca		19.60	27.40	2201.49	5.36	180.37	4.34	329.53	12982.79	0.12
σ^2gca σ^2sca		0.02	0.01	-	-	0.14	0.05	0.01	0.02	0.06

**Significant at 1 % level respectively; Negative values of gca variances are not indicated in Table; Note-gca= General Combining ability sca= Specific Combining ability

Table 3. Estimates of general combining ability effects (gca) and *per se* (P) performance of parents for nine characters.

Characters		Days to 50 % Flowering	Days to Maturity	Plant Height(cm)	No of Leaves/plant	Leaf Length(cm)	Leaf Width(cm)	Seed yield/plant(g)	Fodder yield/plant(q/ha)	100- Seed Weight(g)
PANT CHARI-5	gca	0.58**	-0.653**	-4.943**	-0.02	7.89**	0.89**	-2.80**	19.88**	0.02
	P	70.00	111.00	173.00	11.73	81.57	7.63	42.33	258.00	3.07
PUSA CHARI-1002	gca	-1.02**	-1.13**	-10.39**	-0.19	-3.86**	0.01	-6.41**	-26.47**	-0.08**
	P	69.00	105.00	163.00	10.17	76.67	7.10	45.00	205.00	2.97
SPV 1616	gca	0.22	0.92**	5.81**	-0.36*	-0.97**	-0.53**	0.20	-4.75**	-0.04*
	P	71.00	107.00	188.00	9.27	66.83	6.73	52.00	195.00	3.03
PUSA CHARI-615	gca	-1.17**	-1.04**	4.96**	-0.14	0.67**	-0.36**	-0.67	-35.17**	0.01
	P	70.00	106.00	202.00	11.30	85.33	6.28	53.67	127.00	3.13
HC-136	gca	0.13	0.34*	2.66**	0.35*	2.30**	-0.32*	-0.26	4.88**	0.10**
	P	70.00	106.00	204.00	12.23	86.30	7.35	15.60	173.00	3.10
PANT CHARI-4	gca	0.82**	0.95**	-13.91**	-0.68**	-3.78**	-0.11	3.45**	-0.05	0.05*
	P	71.00	106.00	174.00	10.23	71.70	7.10	54.33	264.00	2.87
MP CHARI	gca	-0.77**	-1.02**	2.12**	0.070	-3.33**	-0.02	3.07**	-10.53**	0.05*
	P	71.00	106.00	174.00	10.23	71.70	7.10	54.33	264.00	2.87
PANT CHARI-6	gca	1.34**	1.40**	2.24**	0.56**	1.46**	0.58**	-0.84*	28.27**	-0.11**
	P	76.00	112.00	174.00	11.30	80.90	8.10	54.00	287.00	2.87
PUSA CHARI-121 (c)	gca	-0.14	0.22	11.45**	0.42**	-0.39**	-0.12	4.27**	23.94**	0.10**
	P	68.00	105.00	215.00	11.23	65.50	6.38	55.67	255.00	3.07
SE G(I)		0.10	0.17	1.44	0.04	0.20	0.03	0.29	0.58	0.01
SE G(I)-G(J)		0.16	0.25	2.16	0.07	0.30	0.05	0.44	0.87	0.01

*,**Significant at 5 % and 1 % level of significant respectively; Note- gca= General Combinig ability, P= *per se performance* for traits

Table 4. Estimates of specific combining ability effects (sca), standard heterosis (SH) and per se performance (P) for various traits.

Crosses	Combining abiity efects	Seed yield/plant(gm)	Fodder yield/plant(q/ha)	100- Seed Weight(gm)	Days to 50 % flowering	Days to maturity	Plant Height(cm)	No of leaves/plant	Leaf Length(cm)	Leaf Width(cm)
HC-136 x PANT CHARI-4	sca	18.17**	135.84**	0.298**	-2.05**	0.38	34.61**	2.74**	3.51**	0.12
	SH	34.72**	36.08**	16.29**	-	-	4.65**	15.76**	19.69**	12.07**
	P	75.00	347.00	3.57	69.00	112.00	225.00	13.00	78.40	7.15
PANT CHARI-4 x PUSA CHA-RI-121	sca	11.17**	86.12**	0.370**	4.89**	6.83**	8.82	1.42**	2.27**	-0.98**
	SH	28.74**	23.92**	18.24**	10.29**	-	-	13.71**	13.69**	-
	P	71.67	316.00	3.63	65.00	119.00	208.00	12.77	74.47	6.25
PANT CHARI-5 x MP CHARI	sca	13.97**	-111.67**	0.116**	0.43	-0.31	-10.81*	-0.39*	0.99	-0.72**
	SH	4.78**	-	4.23*	-	-	-	-	25.08	19.59**
	P	58.33	104.00	3.20	70.00	109.00	188.00	11.27	81.93	70.63
MP CHARI x PANT CHARI-6	sca	12.01**	42.60**	0.485**	0.01	1.62**	26.01**	3.89**	6.89**	2.09**
	SH	4.78	4.31*	11.73**	-	-	7.91**	43.63**	24.27**	58.78**
	P	58.33	266.00	3.43	71.00	113.00	232.00	16.13	81.40	10.13
PANT CHARI-5 x SPV 1616	sca	-6.50**	145.87**	0.04	-0.56	-1.25*	17.82**	1.84**	2.94**	10.79**
	SH	-	43.92**	-	-	-	2.33	16.38**	31.65**	50.94**
	P	35.00	367.00	3.13	70.00	110.00	220.00	13.07	86.23	9.63
HC-136 x PUSA CHARI-121	sca	1.06	82.84**	-0.048	2.58**	1.11*	35.91**	0.84**	-1.88**	-0.39**
	SH	-	24.71**	6.51**	-	6.67*	16.74**	17.81**	16.64**	-
	P	49.17	318.00	3.27	70.00	112.00	251.00	13.23	76.40	6.63
PUSA CHARI-121 x PANT CHARI-6	sca	-2.53	68.12**	-0.266**	-5.29**	-4.62**	7.34	-2.36**	13.85**	2.29**
	SH	-	27.84**	-	-2.94**	-	-	-	39.33**	60.34**
	P	15.00	326.00	2.83	66.00	108.00	222.00	10.23	91.30	10.23
Check										
GJ-39 (Check)	P	55.67	255.00	3.07	68.00	105.00	215.00	11.23	65.50	6.38

*,**Significant at 5 % and 1 % level of significant respectively; Note- sca= Specific Combining ability, SH= Standard heterosis, P= *per se performance* for traits

for other traits like days to 50% flowering and maturity (PUSA CHARI-615, PUSA CHARI-1002 and MP CHARI), number of leaves (HC-136, PUSA CHARI-121 and PANT CHARI-6), leaf length and width (PANT CHARI-5 and PANT CHARI-6) (Table 3). Thus, it would be worthwhile to use above parents in breeding programme for exploiting additive gene effects. Similar results were reported by earlier workers in sorghum (Prakash *et al.*, 2010; Mahdy *et al.*, 2011).

A perusal of best hybrids on the basis of significant positive specific combining ability effects and standard heterosis for grain and dry fodder yield revealed that hybrid HC-136 x PANT CHARI-4 exhibits highest magnitude of positive significant specific combining ability effect for grain yield/plant along with the highest magnitude of standard heterosis for grain yield/plant against the popular local check PUSA CHARI-121 (Table 4). This hybrid also exhibited positive significant specific combining ability effect and standard heterosis for dry fodder yield/plant, 100-grain weight, plant height, number of leaves/plant and leaf length. It was in fact a cross of poor x good general combining ability effect parent for seed yield/plant. A high x high general combining ability effect hybrid PANT CHARI -4 x PUSA CHARI-121 showed significant high positive specific combining ability effects and standard heterosis for grain yield/plant, fodder yield/plant, 100-grain weight, number of leaves/plant, leaf length. Other important hybrids for grain yield/plant was PANT CHARI-5 x MP CHARI and MP CHARI x PANT CHARI-6 which exhibited significant high positive specific combining ability effects and standard heterosis for grain yield/plant and 100-seed weight (Table 4). Both the hybrid involved one good combiner and one poor combiner for grain yield. Such occurrence of good hybrids by the combination of one good combiner and one poor combiner may be due to accumulation of favorable genes and partly due to dominance and recessive interaction.

On the basis of higher significant positive specific combining ability effect in relation to standard heterosis for dry fodder yield/plant revealed that hybrid PANT CHARI-5 x SPV 1616 recorded the high specific combining ability effects for dry fodder yield/plant. This hybrid also exhibited positive significant specific combining ability effect for plant height, number of leaves/plant, leaf length and leaf width. It was derived from high x low parental combinations for dry fodder yield/plant and exhibited highest positive standard heterosis and per se performance for dry fodder yield/plant.

Another important hybrid for dry fodder yield/plant was HC-136 x Pusa Chari-121 and PUSA CHARI-121 x PANT CHARI-6 (Table 4). Both hybrids were a derivative of high x high parental combinations in terms of general combining ability and these hybrids might produce desirable segregants. Hence, these hybrids might be desirable for biparental selection or intermating. These hybrids appeared in the top ranking hybrids with high specific combining ability effects and exhibited highest positive standard heterosis and per se performances for dry fodder yield/plant. High specific combining ability and standard heterosis for grain yield/plant and dry fodder yield and their related traits were observed in Sorghum by Prakash et al. (2010) and Mahdy et al. (2011). In general parental lines and all the hybrids possessed good per se performance and combining ability effects for grain and dry fodder yield and other agronomic traits. The result indicated that the heterosis for grain and dry fodder yield can be exploited commercially. It is apparent the good x poor, poor x good and good x good general combiners depicted high specific combining ability effect indicating the role of the dominance gene action.

Conclusion

Thus, it can be concluded that both inter and intra allelic interactions were involved in the expression of plant height, number of leaves/plant, leaf length and leaf width. The parental lines in this study were having diverse genetic background of their source populations, and hence their hybrids exhibited high specific combining ability effects along high standard heterosis for grain and dry fodder yield/plant. Hence, the heterosis for grain and dry fodder yield can be exploited commercially in forage sorghum.

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