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Study on combining ability and gene action for yield and its component traits in fodder sorghum (*Sorghum bicolor* L)

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Abstract
Combining ability analysis was conducted for yield and its attributes in fodder sorghum. It revealed that variances due to hybrids and parents interaction were significant for all characters. The estimate of variances due to specific combining ability (6^2_{SCA}) and general combining ability (6^2_{GCA}) and their ratio ($6^2_{GCA}/6^2_{SCA}$) indicated the importance of non-additive type of gene action for fodder yield and its component. The parents, AKMS 14A, 2219A, GFS 3, GFS 4, GFS 5 and CSV 21F were found good general combiners for green and dry fodder yield with one or more yield attributing traits. The SRF 305 reported as good combiner for earliness with green fodder yield and TSS%. GFS 4, CSV 21F, and PANT CHARI 23 also depicted as good combiners for quality parameters like TSS and average combiner for HCN content. The hybrids, 2219A x SSG 59-3, AKMS 14A x SRF 283, AKMS 14A x GFS 3, AKMS 14A x CSV 21F and 296A x PANT CHARI 23 were emerged as most specific cross combinations for green fodder yield per plant.

Keywords: Combining ability, GCA, SCA, gene action, fodder sorghum

Introduction
Sorghum (*Sorghum bicolor* L. Moench) plays a very important role in providing nutrition to human race along with wheat, rice, maize and barley in many countries of the world. It is one of the most important food and feed crops of India. Thus, improvement of sorghum is much emphasized owing to its importance as food and fodder crop. The demand for fodder sorghum is fast increasing. To meet the demand increase in the production should come from same or even less area in the present situation of shrinking agricultural land. Improvement of the genetic potential of the crop in order to maximize the economic yield per unit of input remains the most possible means of increasing the production. It is necessary to improve the fodder sorghum yield with nutritionally superior qualities in order to obtain better animal performance.

The knowledge of combining ability gives information regarding the selection of parents in terms of the performance of their hybrids. Besides, estimates of combining ability indicate about both nature and magnitude of gene action and selection of parents for various characters of economic importance. Line x tester mating design (Kempthorne, 1957) [7] is an appropriate technique for evaluation relatively large number of genotypes for genetic worth and gathering valuable information regarding their combining ability.

Materials and Methods
Three male sterile lines (AKMS 14A, 296A, and 2219A) were crossed with 12 testers (GFS 3,GFS 4, GFS 5, CSV 21F, GJ 39, HC 308, SRF 305, PANT CHARI 23, SSG 59-3, SRF 283, SRF 289 and SRF 335) in a Lx T mating design during *Rabi*-2014. Thirty six F_1 hybrids along with their 15 parents and one standard check (CSH-13) were grown in a randomized block design with three replications during *kharif* 2015 at Main Sorghum Research Station, Navsari Agricultural University, and Surat. Both parents and F_1 were raised each in one row with spacing of 30cm. The biometrical observations on fodder yield and other related components *viz.*, days to 50% flowering, plant height, number of leaves, leaf length, leaf width, stem diameter, leaf: stem ratio, TSS%, HCN content, green and dry fodder yield were recorded on five randomly selected plants from each of the three replications at the time of harvesting. The mean values of observations were subjected to L x T analysis (Kempthorne, 1957) [7] to estimate combining ability effects. Analysis ofvariance was performed to test thesignificance of differences among the genotypesincluding crosses and parents (Panse and Sukhatme, 1978) [11].

Results and Discussion

The ANOVA indicated that the variance due togenotypes were highly significant for all the traits studied indicating the existence of widevariability among the genotypes. Considerable genetic variation both among parents and hybrids was found for green dry fodder yield and their component traits indicated by high and significant mean square values for most of these characters (Table 1). This implies that choice of the parents was appropriate and the genetic information obtained on the present materials could form the basis for exploiting it in fodder sorghum hybrid breeding programme.

Analysis of variance for combining ability revealed (Table 2) that the variances due to female were found significant for number of leaves per plant, leaf length, stem diameter and total soluble sugar (TSS %) and due to male were for number of leaves per plant, leaf length, total soluble sugar (TSS %) and dry fodder yield per plant. The GCA variances were depicted significant for all the traits except plant height and HCN content while, variances for SCA were observed significant for all the traits. The variance due to specific combining ability was greater than the variance due to general combining ability and their ratio ($6^2_{GCA}/6^2_{SCA}$) indicated the predominant role of non-additive gene action in the expression of these traits and heterosis breeding is most appropriate for the improvement of fodder yield and its component.Non-additive gene action for these traits was earlier reported by Patel *et al.* (2012a) [14], Jain and Patel (2014) [5], Padmashree *et al*. (2014) [10]; Aruna *et al.* (2015) and Sushil and Pooran Chand (2015) [14]

Table 1: Analysis of variance (mean squares) for parents and hybrids for various traits in fodder sorghum

Source of Variation	d. f.	Days to 50% flowering	Plant height (cm)	Number of leaves per plant	Leaf length (cm)	Leaf width (cm)	Stem diameter (cm)	Leaf: stem ratio	TSS %	HCN content (ppm)	Green fodder yield per plant (g)	Dry fodder yield perPlant (g)
Replications	2	61.02	190.00	1.06	0.07	0.47	1.57	0.00	0.26	175.80	1592.88**	190.25*
Genotypes (G)	50	174.89**	2586.99**	17.42**	924.93**	4.88**	2.69**	0.02**	5.23**	168.20**	5606.26**	1137.05**
Parents (P)	14	179.31**	8065.65**	2.82**	382.90**	5.31**	1.87**	0.01**	8.68**	296.27**	1898.74**	128.31**
Females (f)	2	18.77	3268**	0.49	129.33*	3.31**	5.56**	0.01**	2.93**	364.66**	1623.44**	49.78
Males (m)	11	222.98**	5964.79**	2.57*	425.09**	6.13**	1.37*	0.02**	9.39**	306.28**	2112.06**	154.03**
Hybrids (H)	35	139.45**	323.52**	20.07**	1025.55**	4.72**	2.67**	0.02**	3.90**	120.11*	5681.23**	761.46**
Parents *Vs* Hybrids	1	1353.55**	5106.90**	128.90**	4991.51**	4.57**	14.80**	0.17**	3.54**	58.29	54887.56**	28405.00**
Error	100	27.75	122.54	1.20	33.65	0.59	0.61	0.00	0.39	70.23	132.03	47.50

* Significant at 5% and** Significant at 1% probability level d. f.: degree of freedom, TSS: Total soluble sugar

Table 2: Analysis of variance (mean squares) and variance components for combining ability for various traits in sorghum

Source of variation	D.F	Days to 50% flowering	Plant height	Number of leaves per plant	Leaf length	Leaf width	Stem diameter	Leaf: stem ratio	TSS %	HCN content	Green fodder yield per plant	Dry fodder yield per Plant
Replications	2	70.33	194.89	0.76	2.45	0.87	0.68	0.00	0.06	54.80	1959.29**	303.40**
Females (f)	2	72.33	10.62	67.32**	4218.50**	5.65	14.86**	0.06	12.71**	27.02	12512.15	440.48
Males (m)	11	197.53	228.87	35.84**	1617.45**	5.67	2.45	0.01	5.95*	87.75	8297.04	1633.91**
Females X Males	22	116.51**	399.29**	7.89**	439.34**	4.17**	1.67**	0.02**	2.08**	144.75*	3752.33**	354.41**
Error	70	30.87	151.75	1.13	37.81	0.63	0.55	0.00	0.38	68.64	148.99	51.14
Estimates												
σ^2f		-1.22	-10.79	1.65**	104.97**	0.04	0.37**	0.001	0.30*	-3.27	243.33	2.39
σ^2m		9.00	-18.93	3.10**	130.90**	0.16	0.09	-0.001	0.43*	-6.33	504.97	142.17**
σ^2GCA		0.36*	-1.19	0.19**	9.22**	0.008*	0.02**	0.000*	0.03*	-0.39	30.37**	6.41**
σ^2SCA		29.58**	92.25**	2.23**	135.22**	1.19**	0.35**	0.006**	0.56**	25.37**	1206.77**	102.30**
σ^2GCA / σ^2SCA		0.01	-0.01	0.08	0.06	0.007	0.057	0.00	0.05	-0.015	0.025	0.062

* Significant at 5% and ** Significant at 1% probability level**.**

General Combining Ability Effects

The gca effects of the parents for various traits were estimated and accordingly the parents were classified as good, average and poor combiners (Table 3 and Table 4). The parents AKMS 14A, 2219A, GFS 3, GFS 4, GFS 5 and CSV 21F were found good general combiners for green and dry fodder yield with one or more yield component. The parents GFS 4, CSV 21F, SRF 305 and PANT CHARI 23 were good combiners for quality parameters like total soluble sugar and average combiner for HCN content. The SRF 305 was good combiner parent for early flowering and green fodder yield. The good general combiner parents can be utilized in future breeding programme for the development of higher yielding hybrid as well as stable variety. Thus, it would be worthwhile to use above parents in breeding programme for exploiting non-additive gene effects. Similar results were reported by Iyanar and Khan (2005) [4]; Patel and Patel (2010) [12]; Bhatt and Baskheti (2011) [2]; Mungra *et al.* (2011)

Table 3: Estimates of general combining ability effects of parents for different characters in sorghum

Parents	Days to 50% flowering	Plant height	Number of leaves per plant	Leaf length	Leaf width	Stem diameter	Leaf: stem ratio	TSS %	HCN content	Green fodder yield per plant	Dry fodder yield per Plant
Females [Lines]											
AKMS 14A	1.61	-0.04	0.84**	4.64**	-0.19	-0.61**	0.03**	-0.09	0.95	13.37**	3.80**
296A	-1.05	-0.51	0.73**	7.72**	0.45**	0.67**	0.01*	-0.54 **	-0.73	-21.30**	-3.09**
2219A	-0.55	0.56	-1.57**	-12.37**	-0.26 *	-0.06	-0.05**	0.63 **	-0.22	7.93**	-0.70
S.E. (g_i)	0.87	1.84	0.18	0.96	0.12	0.13	0.01	0.10	1.38	1.92	1.15
Males [Testers]											
GFS 3	5.75 **	9.78 **	3.78**	24.64**	-1.11**	-0.10	0.01	-0.99 **	5.17	29.12**	20.96**
GFS 4	2.19	4.45	0.16	3.26	-0.44	-0.21	0.02	0.97 **	3.73	24.68**	11.74**
GFS 5	-1.80	-6.76	2.18**	4.35*	0.52*	0.12	0.01	-0.81**	-2.14	29.23**	7.30**
CSV 21F	11.52**	-1.54	2.31**	9.08**	-0.54 *	-0.27	0.07**	0.60 **	-1.57	25.01**	14.63**
GJ 39	-3.36	0.56	-0.28	-12.24**	0.38	-0.18	-0.06**	-0.94 **	4.17	-47.44**	-19.70**
HC 308	-3.25	2.45	-0.95 *	12.62**	0.45	0.55*	-0.02	-0.51 *	-1.83	32.90**	14.52**
SRF 305	-4.13 *	-6.76	-1.68**	-0.91	1.28**	0.65*	0.02	0.47 *	2.02	13.01**	-6.04*
PANT CHARI 23	-0.13	5.89	1.62**	13.64**	-1.24**	1.05**	-0.06**	1.14 **	-3.73	1.68	-3.82
SSG 59-3	-2.02	-4.10	-1.79**	-17.24**	0.71 **	-0.21	0.01	-0.33	0.45	-46.66**	-18.37**
SRF 283	-3.02	-2.99	-1.95**	-11.93**	-0.10	-0.24	-0.01	0.12	-0.38	-33.21**	-9.82**
SRF 289	-3.47	-1.65	-1.81**	-13.51**	-0.61 *	-0.24	0.03**	0.98 **	-4.13	-11.10**	-4.37
SRF 335	1.75	0.67	-1.59**	-11.77**	0.68 **	-0.92**	-0.02	-0.70 **	-1.74	-17.21**	-7.04**
S.E. (g_j)	1.75	3.69	0.36	1.93	0.25	0.26	0.01	0.21	2.76	3.83	2.30

* Significant at 5% and ** Significant at 1% probability level

Table 4: Summarized account of GCA effects of parents for different characters in sorghum

Parents	Days to 50 per cent flowering	Plant height	Number of leaves per plant	Leaf length	Leaf width	Stem diameter	Leaf: stem ratio	TSS %	HCN content	Green fodder yield per plant	Dry fodder yield per Plant
Females											
AKMS 14A	A	A	G	G	A	G	G	A	A	G	G
296A	A	A	G	G	G	P	G	P	A	P	P
2219A	A	A	P	P	P	A	P	G	A	G	A
Males:											
GFS 3	P	G	G	G	P	A	A	P	A	G	G
GFS 4	A	A	A	A	A	A	A	G	A	G	G
GFS 5	A	A	G	G	G	A	A	P	A	G	G
CSV 21F	P	A	G	G	P	A	G	G	A	G	G
GJ 39	A	A	A	P	A	A	P	P	A	P	P
HC 308	A	A	P	G	A	P	A	P	A	G	G
SRF 305	G	A	P	A	G	P	A	G	A	G	P
PANT CHARI 23	A	A	G	G	P	P	P	G	A	A	A
SSG 59-3	A	A	P	P	G	A	A	A	A	P	P
SRF 283	A	A	P	P	A	A	A	A	A	P	P
SRF 289	A	A	P	P	P	A	G	G	A	P	A
SRF 335	A	A	P	P	G	G	A	P	A	P	P

Pecific Combining Ability Effects

Perusal of Table 5 revealed that the crosses exhibiting high positive SCA effects for green fodder yield with one or more yield attributing traits. For the most economical character i.e. green fodder yield per plant, total twelve crosses manifested highly significant positive SCA effects. Among them, 2219A x SSG 59-3 exhibited highest SCA effects and followed by AKMS 14A x SRF 283, AKMS 14A x GFS 3, AKMS 14A x CSV 21F and 296A x PANTCHARI 23. There was some degree of relationship between heterosis and SCA effects, as most of the best specific cross combinations manifested positive heterobeltiosis and standard heterosis. From the bestspecific cross combinations, four cross combinations involved G x G, three G x P, and one P x A parental combinations. P x A general combiners also produced good specific cross combinations; this might have resulted from interaction of dominant or epistatic interaction. These indicate that good general combiner might not necessarily produce good specific combinations for all the characters, however, it was observed that at least one good general combining parent was involved in desirable specific combination for majority of the crosses. It is interesting to note that the cross 2219A x GFS 4 was superior to the cross combination 2219A x SRF 289 in SCA effects and heterobeltiosis, even though it was remains behind in *per se* performance. This might be due to higher *per se* performance of parent (SRF 289) involved in the later cross combinations. This suggested that estimates of SCA and heterobeltiosis alone may not always lead to correct evaluation of hybrids. The best specific cross combinations, AKMS 14A x CSV 21F, AKMS 14A x GFS 3, 2219A x GFS 4 and 2219A x SRF 289 recorded high *per se* performance with highly significant heterotic effect for green fodder yield; these hybrids also involved G x G and G x P parental cross combinations. Hence these hybrids may be further tested to increase the green fodder yield in sorghum. The findings are in agreement with the response of Agarwal *et al.* (2005) [1];

Monteiro *et al*. (2008) [8]; Prakash *et al.* (2009) [13]; and Kalpande *et al.* (2015) [6] who have also observed significant sca effects for high green fodder yielding hybrids. The present study suggested that the good combining parents may be utilized in different cross combinations and the crosses having high sca effects for fodder yield may further be tested in multi-location trails over large area before their recommendation for commercial cultivation

Table 5: Estimates of specific combining ability (sca) effects of Best ten cross and their *per pe*rformance for green fodder yield in sorghum

S. No.	Hybrids	GFY/P (g) *Per se*	SCA	GCA female	GCA male	Useful and significant SCA effects for other traits	Heterosis BP	Heterosis SH
1	2219 A x SSG 59-3	107	53.85**	7.93** G	-46.66** P	NLP, LL, TSS% & DFY	-24.35**	-8.83
2	AKMS 14A x SRF 283	147	42.3**	13.37** G	-33.21** P	PH, NLP, LL & L:S	1.38	25.36**
3	AKMS 14A x GFS 3	245	34.85**	13.37** G	29.12** G	L:S	69.59**	109.69**
4	AKMS 14A x CSV 21F	249	33.3**	13.37** G	25.01** G	NLP & LL	44.85**	112.54**
5	296 A x PANT CHARI 23	146	32.3**	-12.30** P	1.68 A	LL	42.21**	24.79**
6	296 A x HC 308	144	30.85**	-12.30** P	32.90** G	L:S	7.69	23.65**
7	2219 A x GFS 4	208	28.96**	7.93** G	24.68** G	L:S	47.52**	77.78**
8	296 A x GFS 4	130	27.74**	-12.30** P	24.68** G	DF, NLP, LL & LW	27.27**	11.68
9	2219 A x SRF 289	218	24.19**	7.93** G	-11.10** P	DF & DFY	55.08**	86.89**
10	AKMS 14A x SRF 305	159	23.41**	13.37** G	13.01** G	L:S	9.91	35.90**

GCA: general combining ability, SCA: specific combining ability, BP: better parent, SH: standard heterosis, A: average, G: good, P: poor, DF=days to 50 % flowering, PH=plant height, NLP=number of leaves per plant, LL=leaf length, LW=leaf width, L: S=leaf: stem ratio, TSS%=total soluble sugar, GFY/P=green fodder yield per plant, DFY/P=dry fodder yield per plant

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