Available online at www.ijpab.com

DOI: http://dx.doi.org/10.18782/2320-7051.5830

ISSN: 2320 – 7051

Int. J. Pure App. Biosci. **5 (5):** 493-502 (2017)

International Journal of Pure & Applied Bioscience

Research Article

OPEN ACCESS

Studies on Combining Ability for Yield and Its Component Traits in Forage Sorghum

Ashok Kumar Dehinwal[1*], S. K. Pahuja[1], M. Shafiqurrahaman[1], Anil Kumar[1] and Priyanka Sharma[2]

[1]Department of Genetics and Plant Breeding, CCSHAU, Hisar, Haryana - 125004, India

[2]Faculty of Agricultural Sciences, SGT University, Gurugram, Delhi-NCR, India-122505

*Corresponding Author E-mail: ashokdehinwalccshau@gmail.com

Received: 4.09.2017 | Revised: 7.10.2017 | Accepted: 10.10.2017

ABSTRACT

The study envisaged assessing the general combining ability of the parents and specific combining ability of the hybrids, using line x tester mating design. Twenty four hybrids (derived from mating four testers with six lines in L x T design) along with their parents and checks ((SSG 59-3 and MFSH 4)) were evaluated at two locations with two date of sowing (Early and late sowing) during the kharif season of 2015-16. Data on five randomly taken plants from each genotype in each replication were recorded on different quantitative characters at first cut (55 days after sowing) and second cut (45 days after first cut). The ratio of σ^2 GCA/σ^2 SCA was less than unity for all the characters indicating preponderance of non-additive gene action (dominance and epistasis). Among female parents 9A and 14A was the best combiner for green fodder yield and 14A for dry fodder yield in more than two different environments. Among male parents, HJ 513 and G 46 were found to be the best general combiner for green fodder yield and dry fodder yield. The cross combination of 465A × HJ 513 and 9A × IS 2389 exhibited high and positive sca effects for green fodder yield as well as for dry fodder yield. This suggests the usefulness of heterosis breeding or any breeding plan which makes use of specific combining ability effects for improvement in these traits.

Key words: *Forage sorghum, Combining ability, Variance and Gene action*

INTRODUCTION

Sorghum is popular as a dual purpose crop and is next to rice and wheat in its acreage and importance in India. Sorghum grain is used as staple food by millions of people and is grown in Northern states of the country it is mainly grown as fodder during summer and *kharif* seasons as a single as well as multicut crop. Combining ability refers to the ability of a parent to transmit its desirable performance to its progeny in crosses. General combining ability is average performance of a genotype in cross combinations involving a set of other genotypes.

Cite this article: Dehinwal, A.K., Pahuja, S.K., Shafiqurrahaman, M., Kumar, A. and Sharma, P., Studies on Combining Ability for Yield and Its Component Traits in Forage Sorghum, *Int. J. Pure App. Biosci.* **5(5):** 493-502 (2017). doi: http://dx.doi.org/10.18782/2320-7051.5830

Specific combining ability is average performance of a specific cross combination expressed as deviation from the population mean. Combining ability analysis helps in selection of suitable parents for hybridization, evaluation of inbreds in terms of their genetic value and identification of superior specific cross combinations[1]. Like green revolution, India is contemplating for white revolution which is possible only with adequate supply of nutritious feeds and fodder. It is well known that the animal industry in any country revolves around sufficient quantity of good quality feed and fodder[2]. To study the combining ability of a number of parents, Line x Tester analysis is the most appropriate procedure. The Line x Tester analysis[3] is one of the simplest and efficient methods of evaluating large number of inbreds/parents for their combining ability. Based on the information from Line x Tester analysis, development of commercially viable hybrids is possible.

MATERIALS AND METHOD

The study envisaged assessing the general combining ability of the parents and specific combining ability of the hybrids, using line x tester mating design. Twenty four hybrids derived from mating four testers with six lines in L x T design along with their parents and checks ((SSG 59-3 and MFSH 4)) were evaluated at two locations *i.e*. research area of Forage Section, Department of Genetics and Plant Breeding, Chaudhary Charan Singh Haryana Agricultural University, Hisar and Regional Research Station Uchani, Karnal with two date of sowing (Early and late sowing) during the *kharif* season of 2015-16. All the thirty six genotypes were grown in a randomized block design in three replications of a two-row plot of 4.0 m length. All the recommended cultural package of practices was followed from sowing to harvesting of the crop. Data on five randomly taken plants from each genotype in each replication were recorded on different quantitative characters *viz.* Plant height (cm), number of tillers per plant, leaf length (cm), leaf breadth (cm), stem diameter (cm), green fodder yield (g/plant) and dry fodder yield (g/plant) in all the four environments (Table 2 and 3) at first cut (55 days after sowing) and second cut (45 days after first cut).

RESULTS AND DISCUSSION

Estimates of variances due to general and specific combining ability for all the characters under study are presented in Table 1. General combining ability variances for female parents were highly significant for all the characters. The general combining ability variances of males were highly significant for all the seven traits except number of tillers per plant which were non-significant.

The SCA variances (σ^2 SCA) were higher than GCA variance (σ^2 GCA) for almost all the characters (Table 4). The ratio of σ^2 GCA/σ^2 SCA was less than unity for all the thirteen characters indicating preponderance of non-additive gene action (dominance and epistasis). Similar results have been reported[4,5].

General combining ability effects

The data obtained from the crosses and parental lines were subjected to line x tester analysis. The estimates of general combining ability (GCA) effects of all the parents comprising six female and four male parents for all the characters in all the four environments have been presented in Table 2. The brief description of different characters for general combining ability analysis is as follows:

Plant height up to the base of flag leaf

In case of female parents, 31A (9.60) and 14A (8.01) exhibited positive significant GCA effects for plant height in E_1 while 9A (5.51) and 31A (5.39) showed positive effects in E_2. On the other hand, the female 56A (15.20) showed positive significant GCA effects in E_3 while 31A (11.64) in E_4. However, the other good combining lines were 56A (4.18) in E_1, 14A (4.93) in E_2 and E_3, respectively and 467A (7.56) in E_4 indicating their suitability as good general combiner for plant height. In case of male parents, G 46 (8.71 and 10.15) exhibited positive significant GCA effects for plant height in E_1 and E_2 respectively. On the other hand the male parent IS 2389 (2.51 and 6.64) recorded positive significant GCA effects in E_3 and E_4, respectively for this character. However, the other good combining male parents were HJ 513 (2.45 and 6.17) and in E_3 and E_4, respectively indicating their suitability as good general combiner for plant height.

Number of tillers per plant

Line 31A (0.46) exhibited positive significant GCA effects in E_1 indicating its suitability as good general combiner for this character. Female parent 56A (-0.31) in E_2 showed significant negative GCA effects which indicated its poor general combining ability for this character. As far as testers are concerned, the genotypes IS 2389 (0.49) and HJ 541 (0.51) were found to be good general combiner in E_1 and in E_2, respectively.

Table 1: Analysis of variance for combining ability for different morphological characters in different environments in forage sorghum

SV	D.F.	Env.	PH	TT	LL	LB	SD	GFY	DFY
Replication	2	E_1	96.01	0.05	39.18	0.98	0.23	1110.76	96.88
		E_2	83.34	0.45	95.84	0.14	1.05	317.63	96.18
		E_3	50.13	0.32	43.92	0.31	1.55	337.56	38.54
		E_4	113.92	0.13	24.19	0.10	0.03	2295.68	210.76
Hybrids	23	E_1	914.28**	0.36**	162.35**	2.58**	20.57**	13881.51**	843.71**
		E_2	575.53**	0.27*	198.28**	1.39**	7.41**	13472.47**	728.97**
		E_3	405.42**	0.11	121.63**	1.19**	13.41**	7472.20**	281.34**
		E_4	483.40**	0.23	88.37**	1.68**	17.00**	9689.81**	517.38**
Lines	5	E_1	1030.18**	0.15	314.91**	5.43**	22.56**	2207.85**	80.63**
		E_2	484.07**	0.58**	462.03**	2.78**	18.45**	5804.50**	254.51**
		E_3	904.43**	0.11	102.17**	2.19**	19.39**	4846.68**	196.67**
		E_4	875.23**	0.34*	117.60**	2.45**	19.77**	12175.85**	591.18**
Tester	3	E_1	977.16**	0.90**	138.99**	2.92**	9.53**	31212.38**	1652.20**
		E_2	1210.43**	0.39*	28.41	1.07**	5.45**	6048.76**	287.38**
		E_3	256.52**	0.14	185.62**	1.49**	8.85**	5941.05**	198.61**
		E_4	985.23**	0.20	24.79	0.81	8.89**	8859.38**	401.27**
Lines x Testers	15	E_1	863.06**	0.32	116.17**	1.56**	22.11**	14306.55**	936.37**
		E_2	479.03**	0.14	144.33**	0.99**	4.12**	17513.20**	975.44**
		E_3	268.86**	0.10	115.32**	0.80**	12.32**	8653.61**	326.11**
		E_4	252.43**	0.20	91.35**	1.60**	17.69**	9027.22**	516.00**
Error	46	E_1	30.17	0.17	11.13	0.21	1.22	223.81	32.02
		E_2	41.52	0.13	16.76	0.29	0.98	404.94	33.50
		E_3	28.31	0.12	13.01	0.34	1.23	300.45	34.56
		E_4	47.47	0.13	9.85	0.33	0.91	170.39	21.27

D.F. = Degree of freedom * Significant at 5% level **Significant at 1% level
E_1 = Early sowing at Hisar E_2 = Early sowing at Karnal
E_3 = Late sowing at Hisar E_4 = Late sowing at Karnal
PH = Plant height (cm) TT = Total number of tillers per plant
LL = Leaf length (cm)
LB = Leaf breadth (cm) SD = Stem diameter (cm)
Env. = Environments
GFY = Green fodder yield per plant (g) DFY = Dry fodder yield per plant (g)

Leaf length

In case of leaf length, the lines 14A (4.99) and 467A (2.49) in E_1, 56A (8.79) and 467A (4.08) in E_2, 14A (2.83) and 31A (2.74) in E_3, and 56A (2.83) and 465A (2.79) in E_4 exhibited positive significant GCA effects, respectively. However, the other good combining lines were 56A and 465A (2.36) in E_1, and 31A (2.41) in E_4 which indicated their suitability as good general combiner for leaf length. In case of testers, genotype G 46 was found to be the best combiner for this character in all the four environments *i.e*. E_1 (2.89), E_2 (1.29), E_3 (4.26) and E_4 (1.76), respectively. However, the other good combining tester was IS 2389 (1.36) in E_1 considered as good general combiner for leaf length.

Leaf breadth

Lines with significant positive GCA for leaf breadth include 465A (0.56) and 56A (0.42) in E_1, 9A (0.40) in E_2, 56A (0.60) in E_3 and 467A (0.62) in E_4 whereas the significant negative GCA values were recorded for this trait in lines 9A (-1.16) in E_1, 467A (-0.94) in E_2, 465A (-0.64) in E_3 and 31A (-0.54) in E_4. Other female parents which showed significant positive GCA effects were 14A (0.39) in E_1 and 31A (0.39) in E_2, respectively indicated their suitability as good general combiners for this character.

Among testers, HJ 541 (0.52) in E_1, HJ 513 (0.36 and 0.34) in E_2, and E_3, respectively exhibited positive significant GCA effects for this character.

Stem diameter

In forage sorghum, thin stem is desirable trait so far preference of livestock is concerned. The highest negative GCA effects were recorded for 31A (-1.36) in E_1, 56A (-1.50) in E_2, 31A (-1.43) in E_3 and 56A (-2.00) in E_4 which indicated their suitability as source material for thin stem girth. Lines 14A (2.49) in E_1, 9A (2.19) in E_2, 56A (2.22) in E_3 and 465A (1.59) in E_4, respectively recorded significant positive GCA effects for stem diameter. In case of testers, IS 2389 (-0.70) in E_2 and G 46 (-0.67) in E_4 were found to be the best general combiner for thin stem diameter.

Green fodder yield per plant

Lines 9A (15.90) in E_1, 9A (24.00) and 14A (23.75) in E_2, 467A (26.01) and 465A (25.35) in E_3 and 467A (54.51) in E_4 were found to be good general combiners for green fodder yield. However, the other good combining lines were 14A (9.65) in E_1 and 9A (20.18) in E_4. As far as testers are concerned, genotypes HJ 513 (36.32 and 17.75) showed highest positive significant GCA effects for this character in E_1 and E_2 respectively. On the other hand the male G 46 (16.01) exhibited highest positive significant GCA effects in E_3 while HJ 541 (32.26) in E_4 for this trait. However, the other testers, G 46 (33.26) in E_1 and HJ 513 (15.29) in E_3 were found to be good general combiners for this character.

Dry fodder yield per plant

Among lines, 14A (4.38) exhibited positive significant GCA effects for dry fodder yield in E_1, 14A (8.26) in E_2, 465A (4.58) and 467A (4.58) in E_3 while 467A (12.43) in E_4 indicated their suitability as source material for dry fodder yield. Other female parents which showed significant positive GCA effects were 56A (2.15) and 467A (2.15) in E_2 and 9A (3.68) in E_4. Among the testers G 46 (7.99 and 4.03) in E_1 and E_3, and HJ 541 (6.74) in E_4, respectively exhibited positive significant GCA effects for dry fodder yield. Similar results have been reported[6, 7, 8].

Two good combining female and male parents in all the four environments for various traits have been presented in Table 5a and Table 5b, respectively. The perusal of tables revealed that among female parents 9A and 14A was the best combiner for green fodder yield and 14A for dry fodder yield in more than two different environments. Among lines, 31A was the best general combiner for plant height in three different environments and 31A is also better for numbers of tillers. 14A, 56A and 467A were good combiners for leaf length in two different environments and 56A was also better for leaf breadth. 31A and 56A were better for stem diameter in two environments. Among male parents, HJ 513 and G 46 were found to be the best general combiner for green fodder yield and dry fodder yield. G 46 was the best combiner for leaf length in three environments while HJ 513 and HJ 541 were found to be better for leaf breadth and stem diameter whereas HJ 541 and IS 2389 were better combiner for number of tillers. Similar results have been reported by Agarwal and Shrotria[9], Prabhakar *et. al*[10] and Rani *et. al*[11].

Table 2: General combining ability effects of parents in different characters in different environments in forage sorghum

Female parents	Plant height				Number of tillers per plant				Leaf length				Leaf breadth			
	E_1	E_2	E_3	E_4	E_1	E_2	E_3	E_4	E_1	E_2	E_3	E_4	E_1	E_2	E_3	E_4
9A	0.43	5.51*	1.70	-10.94**	0.04	-0.06	0.11	-0.23	-3.39**	-2.63	1.66	-4.01**	-1.16**	0.40*	0.19	-0.48*
14A	8.01**	4.93*	-1.09	1.43	0.04	0.19	-0.06	-0.10	4.99**	-3.55*	2.83*	-3.30**	0.39*	0.08	0.07	-0.09
31A	9.60**	5.39*	-10.80**	11.64**	0.46*	0.19	0.03	0.19	-8.81**	-8.67**	2.74*	2.41*	-0.45**	0.39*	0.09	-0.54*
56A	4.18*	-5.32*	15.20**	-3.53	-0.05	-0.31*	0.11	0.15	2.36*	8.79**	-3.92**	2.83*	0.42*	0.07	0.60**	0.23
465A	-9.07**	-1.11	-5.01*	-6.15*	-0.01	-0.19	-0.10	0.10	2.36*	1.99	-0.34	2.79*	0.56**	0.06	-0.64**	0.24
467A	-13.15**	-9.40**	-0.01	7.56	-0.17	0.19	-0.10	-0.10	2.49*	4.08**	-2.97*	-0.72	0.25	-0.94**	-0.31	0.62**
SE (d)	**2.24**	**2.63**	**2.17**	**2.81**	**0.17**	**0.15**	**0.14**	**0.15**	**1.36**	**1.67**	**1.47**	**1.28**	**0.18**	**0.22**	**0.24**	**0.23**
Male parents																
HJ 513	-9.24**	-0.01	2.45	6.17**	-0.31*	-0.19	0.08	-0.15	-0.72	0.67	0.51	-0.52	-0.20	0.36*	0.34*	-0.03
HJ 541	-0.63	-9.93**	-5.49**	-6.17**	0.13	0.51*	0.06	0.02	-3.53**	-0.38	-3.16**	-0.55	0.52**	-0.14	0.09	0.28
IS 2389	1.15	-0.21	2.51	6.64**	0.49*	0.17	-0.03	0.02	1.36	-1.58	-1.60	-0.69	0.10	-0.10	-0.07	-0.24
G 46	8.71**	10.15**	0.54	-6.64**	-0.01	0.01	-0.11	0.10	2.89**	1.29	4.26**	1.76*	-0.41**	-0.13	-0.35*	-0.02
SE (d)	**1.83**	**2.15**	**1.77**	**2.29**	**0.14**	**0.12**	**0.11**	**0.12**	**1.11**	**1.36**	**1.20**	**1.04**	**0.15**	**0.18**	**0.19**	**0.19**

Female parents	Stem diameter				Green fodder yield per plant				Dry fodder yield per plant			
	E_1	E_2	E_3	E_4	E_1	E_2	E_3	E_4	E_1	E_2	E_3	E_4
9A	-0.30	2.19**	-0.60	1.10**	15.90**	24.00**	-14.82*	20.18**	0.63	-0.49	-2.08	3.68*
14A	2.49**	-0.13	0.41	-0.59	9.65*	23.75**	-14.40*	-26.49**	4.38*	8.26**	-5.83**	-7.15**
31A	-1.36**	-0.43	-1.43**	-0.31	-11.18*	-3.50	-14.82*	-26.07**	-1.88	1.60	0.00	-3.40
56A	1.00*	-1.50**	2.22**	-2.00**	5.90	2.33	-7.32	-5.24	-0.63	2.15*	-1.25	-2.99
465A	-0.28	0.39	-0.75	1.59**	0.07	-13.92*	25.35**	-16.90**	-3.13	-5.07*	4.58*	-2.57
467A	0.45	-0.53	0.15	0.22	-20.35**	-32.67**	26.01**	54.51**	0.63	2.15*	4.58*	12.43**
SE (d)	**0.45**	**0.40**	**0.45**	**0.39**	**6.11**	**8.22**	**7.07**	**5.32**	**2.31**	**2.36**	**2.39**	**1.88**
Male parents												
HJ 513	-0.25	-0.16	0.95**	0.99**	36.32**	17.75**	15.29**	-18.29**	6.60**	2.99	1.25	-2.99*
HJ 541	1.09*	0.73*	-0.54	-0.13	-48.13**	-23.36**	-13.43*	32.26**	-12.85**	-5.63**	3.47*	6.74**
IS 2389	-0.42	-0.70*	0.10	-0.18	-21.46**	-5.31	-17.88**	-8.29*	-1.74	-0.07	-1.81	-0.21
G 46	-0.42	0.33	-0.51	-0.67*	33.26**	10.92	16.01**	-5.68	7.99**	2.71	4.03*	-3.54*
SE (d)	**0.36**	**0.33**	**0.37**	**0.32**	**4.98**	**6.71**	**5.77**	**4.35**	**1.88**	**1.93**	**1.95**	**1.54**

Specific combining ability effects

Specific combining ability is the average performance of a specific cross combination expressed as deviation from the population mean. SCA effect is the main cause for superiority of a cross. It is inferred that superiority of a cross cannot be fixed through selection. The estimates of specific combining ability effects are provided in Table 3 and the description of different characters is as under:

Plant height up to the base of flag leaf

The maximum SCA effects were recorded by crosses 14A × IS 2389 [(34.43) (good x poor GCA)] followed by 56A × G 46 (18.04) (good x good) and 465A × G 46 (13.96) (good x good) in E_1 and crosses 467A × HJ 513 (16.26) (good x poor) followed by 467A × IS 2389 (15.79) (good x poor) and 9A × HJ 541 (15.26) (good x good) in E_2. On the other hand, highest SCA effects were exhibited by the crosses 14A × IS 2389 (11.62) (good x good) and 465A × HJ 541 (8.70) (good x good) for this character in E_3 and the crosses 9A × G 46 (19.39) (good x good) followed by 14A × IS 2389 (9.57) (good x good) and 467A × HJ 513 (9.42) (good x good) in E_4 were found to be the best cross combinations for plant height.

Number of tillers per plant

In case of number of tillers per plant, the crosses 9A × HJ 541 (0.78) (poor x poor GCA) in E_1; crosses 467A × HJ 541 (0.52) (poor x poor) in E_2; crosses 467A × HJ 541 (0.57) (poor x poor) in E_3 recorded significant positive SCA effects. The high SCA effects are desirable as number of tillers per plant is directly proportional to fodder yields.

Leaf length

In case of leaf length, the highest SCA effects were recorded for crosses 56A × HJ 541 (7.44) (good x good GCA) followed by 31A × HJ 513 (5.47) (good x poor) and 9A × G 46 (4.94) (good x good) in E_1 and crosses 9A × G 46 (8.88) (poor x good) followed by 467A × IS 2389 (8.37) (good x poor) and 31A × HJ 541 (7.42) (good x poor) in E_2. On the other hand, maximum SCA effects were recorded for crosses 14A × HJ 541 (7.87) (good x good) followed by 465A × IS 2389 (7.48) (poor x poor) and 465A × HJ 541 (6.87) (poor x good) for this character in E_3 and crosses 9A × G 46 (7.37) (good x good) followed by 467A × HJ 541 (6.05) (poor x poor) and 31A × HJ 513 (4.40) (good x poor) in E_4 had positive SCA effects for this character.

Leaf breadth

The maximum SCA effects were shown by crosses 14A × HJ 541 (1.16) (good x good GCA) followed by 9A × HJ 513 (1.15) (good x poor) and 467A × HJ 513 (0.90) (poor x poor) for leaf breadth in E_1 while crosses 14A × HJ 513 (1.67) (poor x good) and 467A × HJ 513 (1.29) (good x good) had higher positive sca effects in E_2. On the other hand, maximum SCA effects were shown by crosses 14A × HJ 513 (1.39) (poor x good) and 31A × HJ 541 (1.11) (poor x poor) in E_3 and crosses 31A × HJ 541 (1.38) (good x poor) and 9A × G 46 (4.40) (good x poor) in E_4.

Stem diameter

Negative sca effects are desirable for a character like stem diameter. The maximum negative SCA effects were observed by the crosses, 467A × IS 2389 (-3.65) (poor x poor GCA) and 14A × G 46 (-3.29) (good x poor) in E_1; crosses 31A × HJ 541 (-1.13) (poor x good) and 465A × IS2389 (-1.09) (poor x poor) in E_2. On the other hand, maximum negative SCA effects were shown by crosses 467A × IS 2389 (-3.16) (poor x poor) and 56A × HJ 513 (-1.95) (poor x poor) in E_3 while crosses 465A × G 46 (-3.11) (good x good) followed and 9A × HJ541 (-2.19) (good x poor) in E_4 were found to be good specific combiner for this character.

Table 3: Specific combining ability effects of hybrids in different characters in different environments in forage sorghum

Hybrids	Plant height				Number of tillers per plant				Leaf length				Leaf breadth			
	E_1	E_2	E_3	E_4	E_1	E_2	E_3	E_4	E_1	E_2	E_3	E_4	E_1	E_2	E_3	E_4
9A × HJ 513	0.57	6.01	2.38	-6.92	-0.15	-0.60*	-0.77**	-0.02	-8.28**	-3.01	2.54	1.81	-1.15**	-0.15	-0.14	0.39
9A × HJ 541	-0.88	15.26**	-6.51	0.08	0.78*	0.04	0.03	-0.02	0.36	0.55	-2.97	-7.9**	0.36	0.29	0.02	-0.71
9A × IS 2389	7.85*	-7.63	0.33	-12.56*	-0.31	-0.13	-0.66*	-0.02	2.97	-6.42*	4.81	-1.19	0.58	0.45	0.00	-0.70
9A × G 46	-7.54*	-13.65**	3.80	19.39**	0.38	0.20	0.19	0.06	4.94*	8.88**	-4.38	7.37**	0.22	-0.59	0.12	1.02
14A × HJ 513	-0.18	-13.74**	-14.66**	-5.46	-0.31	-0.19	0.17	0.02	2.68	1.91	-3.80	0.60	0.43	1.67**	1.39**	0.54
14A × HJ 541	-1.46	1.85	5.29	-1.63	0.41	-0.05	-0.14	0.02	-0.68	-5.54	7.87**	3.63	1.16**	-0.03	-0.90*	0.06
14A × IS 2389	34.43**	-2.04	11.62**	9.57*	0.35	0.29	0.11	-0.15	4.60*	-0.51	-8.35**	-1.40	0.63*	-0.34	0.38	0.21
14A × G 46	-32.79**	13.93**	-2.24	6.51	-0.45	-0.05	-0.14	0.10	-6.60**	4.13	4.29	-2.84	0.10	-0.30	0.90*	-0.81*
31A × HJ 513	4.40	-3.53	6.88	4.50	0.23	0.31	0.25	-0.27	5.47*	3.37	1.29	4.40*	-0.66*	-0.45	0.39	-0.85*
31A × HJ 541	-0.71	-2.28	-3.01	-1.00	-0.38	-0.22	-0.06	0.40	-6.39*	7.42*	-3.22	1.42	0.52	0.22	1.11*	1.38**
31A × IS 2389	-2.49	-4.50	-11.01**	1.19	0.06	-0.22	0.03	0.06	-0.78	-9.22**	0.06	2.90	-0.10	-0.42	-0.01	-0.27
31A × G 46	-1.21	10.31*	7.13	-4.69	0.09	0.12	-0.22	-0.19	1.69	-1.58	1.87	-8.7**	0.24	0.65	-0.49	-0.26
56A × HJ 513	13.15**	-5.82	6.88	-4.00	0.27	0.15	0.00	0.44	-4.19	-5.76	0.79	2.48	0.43	-0.06	-0.55	0.22
56A × HJ 541	-15.63**	7.26	8.16*	-2.50	-0.01	-0.22	0.19	-0.40	7.44**	-2.54	-5.38*	-5.99*	-0.13	0.64	0.30	-0.25
56A × IS 2389	-15.57**	0.04	-9.67*	7.69	-0.40	0.12	-0.22	-0.23	2.56	3.33	-0.27	2.98	0.00	0.11	-0.15	0.10
56A × G 46	18.04**	-1.49	-2.37	-1.19	0.13	-0.05	0.03	0.19	-5.81*	4.97	4.87	0.54	-0.30	-0.69	0.40	-0.06
465A × HJ 513	-10.43	0.81	1.76	2.46	0.06	-0.15	0.04	-0.69*	-0.19	4.87	-3.30	-5.98*	0.05	-0.31	0.59	-0.82*
465A × HJ 541	8.46*	-9.61*	8.70*	-2.88	0.12	0.33	-0.10	0.15	-5.22	-4.41	6.87*	2.88	0.43	0.84*	0.31	0.00
465A × IS 2389	-11.99**	-1.67	4.04	3.32	-0.10	-0.17	-0.01	0.31	2.06	4.45	7.48**	3.02	-1.01**	0.59	-0.34	0.25
465A × G 46	13.96**	10.47	-14.49**	-2.90	-0.08	-0.01	0.07	-0.27	3.36	-4.91	-11.05**	0.08	0.53	0.56	-0.55	0.57
467A × HJ 513	-7.51*	16.26**	-3.24	9.42*	-0.10	-0.02	-0.29	0.02	4.51	-1.38	2.49	-3.31	0.90**	1.29**	0.09	0.53
467A × HJ 541	10.21*	-12.49*	-9.63*	7.92	-0.22	0.52*	0.57*	-0.15	4.49	4.51	-3.17	6.05*	-0.02	-0.28	0.17	-0.48
467A × IS 2389	-12.24**	15.79**	4.70	-0.22	0.40	0.12	0.15	0.02	-11.40**	8.37**	-3.73	-6.3**	-0.10	-0.39	0.12	0.40
467A × G 46	9.54*	-19.57**	8.17*	-17.11**	-0.08	-0.22	0.07	0.10	2.40	-11.49**	4.41	3.58	-0.79	0.38	-0.39	-0.45
SE (d)	**4.48**	**5.26**	**4.34**	**5.62**	**0.34**	**0.29**	**0.29**	**0.29**	**2.72**	**3.34**	**2.95**	**2.56**	**0.37**	**0.44**	**0.48**	**0.47**
5% significant value	7.48	8.78	7.25	9.39	0.57	0.48	0.48	0.48	4.54	5.58	4.93	4.28	0.62	0.73	0.80	0.78
1% significant value	10.80	12.68	10.46	13.54	0.82	0.70	0.70	0.70	6.56	8.05	7.11	6.17	0.89	1.06	1.16	1.13

Table 3 contd…..

Hybrids	Stem diameter				Green fodder yield per plant				Dry fodder yield per plant			
	E_1	E_2	E_3	E_4	E_1	E_2	E_3	E_4	E_1	E_2	E_3	E_4
9A × HJ 513	-1.84*	-0.30	2.67**	-1.48*	-106.7**	-100.6**	6.38	29.54**	-25.35**	-20.07**	1.25	4.65
9A × HJ 541	-0.58	1.48*	1.77*	-2.19**	-5.63	-52.89**	-3.24	75.65**	-10.90	-21.46**	-0.69	16.60**
9A × IS 2389	4.13**	-0.43	-0.61	-0.18	52.71**	154.06**	4.54	-40.46**	21.32**	34.65**	0.97	-6.46*
9A × G 46	-1.71*	-0.45	-0.30	3.85**	59.65**	-0.50	-7.68	-64.74**	14.93**	6.88	-1.53	-14.70**
14A × HJ 513	2.91**	-0.95	-0.27	3.14**	-50.49**	-53.75**	-5.71	-37.13**	-12.43**	-13.82**	-3.33	-7.85*
14A × HJ 541	0.84	-0.21	-0.61	-0.30	7.29	52.36**	34.68**	13.99	7.01	19.79**	8.06*	2.43
14A × IS 2389	-0.45	2.16**	2.52**	-2.52**	0.63	-49.03**	0.79	-28.79**	0.90	-9.10*	-0.28	-10.60**
14A × G 46	-3.29**	-1.00	-1.64*	-0.33	42.57**	50.42**	-29.76*	51.93**	4.51	3.13	-4.44	16.04**
31A × HJ 513	-0.91	1.03	0.17	0.06	28.68*	90.17**	-6.96	15.79	2.15	17.85**	4.17	3.40
31A × HJ 541	-0.44	-1.13	0.57	-2.18**	56.46**	6.28	56.76**	-56.43**	13.26**	-0.21	8.89*	-17.90**
31A × IS 2389	2.13*	-0.60	1.57	3.03**	16.46	-31.78*	58.79**	72.46**	7.15	-2.43	16.11**	22.29**
31A × G 46	-0.78	0.71	0.84	-0.91	101.60**	-64.67**	8.99	-31.82**	-22.57**	-15.21**	3.06	-7.71*
56A × HJ 513	3.29**	1.76*	-1.95*	-1.21	18.26	-29.00	-12.79	43.29**	10.90*	-1.74	-4.58	7.99*
56A × HJ 541	-2.48**	-0.33	-0.45	1.34*	16.04	55.44**	-70.74**	11.07	5.35	16.88**	-14.8**	4.93
56A × IS 2389	-1.00	-0.10	1.08	-1.21	-48.96**	-35.94*	85.38**	-15.04	-19.10**	-13.68**	21.81**	-3.13
56A × G 46	0.19	-0.33	1.32	1.08	14.65	9.50	-1.85	-39.32**	2.85	-1.46	-2.36	-9.79**
465A × HJ 513	-1.49	-0.16	-0.75	-1.84*	130.76**	120.58**	81.88**	-46.71**	28.40**	24.51**	11.25*	-12.40**
465A × HJ 541	0.24	-0.73	-1.52*	2.82**	-18.13	-48.31**	9.93	4.40	1.18	-8.54*	2.64	-2.15
465A × IS 2389	-1.15	-1.09	1.74*	2.13**	-39.79**	-48.03**	-45.63**	41.63**	-14.93**	-14.10**	-10.69*	8.13*
465A × G 46	2.41**	1.98**	0.52	-3.11**	-72.85**	-24.25	-46.18**	0.68	-14.65**	-1.88	-3.19	6.46*
467A × HJ 513	-1.95*	-0.38	0.12	1.33*	-20.49*	-27.33	-62.79**	-4.79	-3.68	-6.74	-8.75*	4.24
467A × HJ 541	2.42**	1.23	3.78**	0.52	-56.04**	-12.89	-27.40*	-48.68**	-15.90**	-6.46	-4.03	-3.82
467A × IS 2389	-3.65**	0.06	-3.16**	-1.27	18.96	10.72	13.71	-29.79**	4.65	4.65	4.31	-10.20**
467A × G 46	3.18**	-0.90	-0.75	-0.58	57.57**	29.50*	76.49**	83.26**	14.93**	8.54	8.47*	9.79**
SE (d)	**0.90**	**0.81**	**0.91**	**0.78**	**12.21**	**16.43**	**14.15**	**10.65**	**4.62**	**4.73**	**4.79**	**3.76**
5% significant value	1.50	1.35	1.52	1.30	20.39	27.44	23.63	17.79	7.72	7.90	8.00	6.28
1% significant value	2.17	1.95	2.19	1.88	29.43	39.60	34.10	25.67	11.13	11.40	11.54	9.06

Table 4: Genetic variance for different characters under different environments in forage sorghum

Environment	E_1			E_2			E_3			E_4		
Characters	σ^2 GCA	σ^2 SCA	σ^2 GCA / σ^2 SCA	σ^2 GCA	σ^2 SCA	σ^2 GCA / σ^2 SCA	σ^2 GCA	σ^2 SCA	σ^2 GCA / σ^2 SCA	σ^2 GCA	σ^2 SCA	σ^2 GCA / σ^2 SCA
PH	9.37	2592.42	0.004	24.55	1558.03	0.016	20.77	929.41	0.022	45.19	1066.73	0.042
TT	0.01	0.57	0.025	0.02	0.26	0.089	0.00	-0.06	-0.033	0.01	0.26	0.019
LL	7.39	388.98	0.019	6.73	449.98	0.015	1.91	325.98	0.006	-1.34	231.05	-0.006
LB	0.18	5.80	0.030	0.06	2.74	0.023	0.07	2.08	0.033	0.00	3.82	0.001
SD	-0.40	58.61	-0.007	0.52	14.63	0.036	0.12	34.48	0.003	-0.22	48.12	-0.005
GFY	0.03	3.18	0.008	0.01	0.49	0.016	-0.04	3.61	-0.011	0.05	3.67	0.015
DFY	160.24	43850.61	0.004	-772.43	43600.40	-0.018	-217.32	22886.30	-0.009	99.36	27564.08	0.004

PH = Plant height TT =Number of tillers per plant LL = Leaf length (cm) LB = Leaf breadth (cm)

SD = Stem diameter (cm) GFY = Green fodder yield per plant (g) DFY = Dry fodder Yield per plant (g)

σ^2 GCA = GCA variance σ^2 SCA = SCA variance

E_1 = Early sowing at Hisar E_2 = Early sowing at Karnal

E_3 = Late sowing at Hisar E_4 = Late sowing at Karnal

Table 5a: Promising general combining female parents for different characters in forage sorghum

Environments / Characters	Female parents							
	Early sowing (Hisar) (E_1)		Early sowing (Karnal) (E_2)		Late sowing (Hisar) (E_3)		Late sowing (Karnal) (E_4)	
Plant height (cm)	31A (9.60**)	14A (8.01**)	9A (5.51*)	31A (5.39*)	56A (15.20**)	-	31A (11.64**)	467A (7.56)
Number of effective tillers per plant	31A (0.46*)	-	-	-	-	-	-	-
Leaf length (cm)	14A (4.99**)	467A (2.49*)	56A (8.79**)	467A (4.08**)	14A (2.83*)	31A (2.74*)	56A (2.83*)	465A (2.79*)
Leaf breadth (cm)	465A (0.56**)	56A (0.42*)	9A (0.40*)	31A (0.39*)	56A (0.60**)	-	-	-
Stem diameter (cm)	31A (-1.36**)	-	56A (-1.50**)	-	31A (-1.43**)	-	56A (-2.00**)	-
Green fodder yield (g/plant)	9A (15.90**)	14A (9.65**)	9A (24.00**)	14A (23.75**)	467A(26.01**)	465A(25.35**)	467A (54.51**)	9A (20.18**)
Dry fodder yield (g/plant)	14A (4.38*)	-	14A (8.26**)	56A (2.15*)	465A (4.58*)	467A (4.58*)	-	-

Table 5b: Promising general combining male parents for different characters in forage sorghum

Environments / Characters	Male parents							
	Early sowing (Hisar) (E_1)		Early sowing (Karnal) (E_2)		Late sowing (Hisar) (E_3)		Late sowing (Karnal) (E_4)	
Plant height (cm)	G 46 (8.71**)	-	G 46 (10.15**)	-	-	-	IS 2389 (6.64**)	HJ 513 (6.17**)
Number of effective tillers per plant	IS 2389 (0.49*)	-	HJ 541 (0.51*)	-	-	-	-	-
Leaf length (cm)	G 46 (2.89**)	-	-	-	G 46 (4.26**)	-	G 46 (1.76*)	-
Leaf breadth (cm)	HJ 541 (0.52**)	-	HJ 513 (0.36*)	-	HJ 513 (0.34*)	-	-	-
Stem diameter (cm)	-	-	IS 2389 (-0.70*)	-	-	-	G 46 (-0.67*)	-
Green fodder yield (g/plant)	HJ 513 (36.32**)	G 46 (33.26**)	HJ 513 (17.75**)	-	G 46 (16.01**)	HJ 513 (15.29**)	HJ 541 32.26(**)	-
Dry fodder yield (g/plant)	G 46 (7.99**)	HJ 513 (6.60**)	-	-	G 46 (4.03*)	HJ 541 (3.47*)	HJ 541 (6.74**)	-

Table 6: Promising specific combining hybrids for different characters in forage sorghum

Environments / Characters	Hybrids							
	Early sowing (Hisar) (E_1)		Early sowing (Karnal) (E_2)		Late sowing (Hisar) (E_3)		Late sowing (Karnal) (E_4)	
Plant height (cm)	14A × IS 2389 (34.43**)	56A × G 46 (18.04**)	467A × HJ 513 (16.26**)	467A × IS 2389 (15.79**)	14A × IS 2389 (11.62**)	465A × HJ 541 (8.70**)	9A × G 46 (19.39**)	14A × IS 2389 (9.57*)
Number of effective tillers per plant	9A × HJ 541 (0.78*)	14A × HJ 541 (0.41)	467A × HJ 541 (0.52*)	465A × HJ 541 (0.33)	467A × HJ 541 (0.57*)	31A × HJ 513 (0.25)	56A × HJ 513 (0.44)	31A × HJ 541 (0.40)
Leaf length (cm)	56A × HJ 541 (7.44**)	31A × HJ 513 (5.47*)	9A × G 46 (8.88**)	467A × IS 2389 (8.37**)	14A × HJ 541 (7.87**)	465A × IS 2389 (7.48**)	9A × G 46 (7.37**)	467A × HJ 541 (6.05*)
Leaf breadth (cm)	14A × HJ 541 (1.16**)	467A × HJ 513 (0.90**)	14A × HJ 513 (1.67**)	467A × HJ 541 (1.29**)	14A × HJ 513 (1.39**)	31A × HJ 541 (1.11*)	31A × HJ 541 (1.38**)	9A × G 46 (1.02)
Stem diameter (cm)	467A × IS 2389 (-3.65**)	14A × G 46 (-3.29**)	31A × HJ 541 (-1.13**)	465A × IS 2389 (-1.09**)	467A × IS 2389 (-3.16**)	56A × HJ 513 (-1.95**)	465A × G 46 (-3.11**)	9A × HJ 541 (-2.19**)
Green fodder yield (g/plant)	465A × HJ 513 (130.76**)	31A × G 46 (101.60**)	9A × IS 2389 (154.06**)	465A × HJ 513 (120.58**)	56A × IS 2389 (85.38**)	465A × HJ 513 (81.88**)	467A × G 46 (83.26**)	9A × HJ 541 (75.65**)
Dry fodder yield (g/plant)	465A × HJ 513 (28.40**)	9A × IS 2389 (21.32**)	9A × IS 2389 (34.65**)	465A × HJ 513 (24.51**)	56A × IS 2389 (21.81**)	31A × IS 2389 (16.11**)	31A × IS 2389 (22.29**)	9A × HJ 541 (16.60**)

GCA value in parenthesis

**Significant at 1% level of significance *Significant at 5% level of significanc

Green fodder yield per plant

The highest SCA effects were observed by the crosses 465A × HJ 513 (130.76) (poor x good GCA) followed by 9A × G 46 (59.65) (good x good) and 467A × G 46 (57.57) (poor x good) for green fodder yield in E_1 while crosses 9A × IS 2389 (154.06) (good x poor) followed by 465A × HJ 513 (120.58) (good x good) and 31A × HJ 513 (90.17) (poor x good) had higher positive sca effects in E_2. The maximum SCA effects were observed by the crosses 56A × IS 2389 (85.38) (poor x good) followed by 465A × HJ 513 (81.88) (good x good) and 467A × G 46 (76.49) (good x good) in E_3 while crosses 467A × G 46 (83.26) (good x poor) followed by 9A × HJ 541 (75.65) (good x good) and 31A × IS 2389 (72.46) (good x good) in E_4 had higher positive sca effects for this character. Hybrids 31A × HJ 541 (56.46) and 9A × IS 2389 (52.71) in E_1; crosses 56A × HJ 541 (55.44) and 14A × HJ 541 (52.36) in E_2; 31A × IS 2389(58.79) and 31A × HJ 541 (56.76) in E_3 and crosses 14A × G 46 (51.93) and 56A × HJ 513 (43.29) in E_4 had significant SCA effects for this character.

Dry fodder yield per plant

The highest SCA effects were recorded by the crosses 465A × HJ 513 (28.40) (poor x good GCA) followed by 9A × IS 2389 (21.32) (poor x poor), 9A × G 46 (14.93) (poor x good) and 467A × G 46 (14.93) (poor x good) for dry fodder yield in E_1 and crosses 9A × IS 2389 (34.65) (poor x poor) followed by 465A × HJ 513 (24.51) (good x poor) and 14A × HJ 541 (19.79) (good x good) in E_2. The crosses 56A × IS 2389 (21.81) (poor x poor) recorded highest SCA effects followed by 31A × IS 2389 (16.11) (poor x poor) and 465A × HJ 513 (11.25) (good x poor) in E_3 while crosses 31A × IS 2389 (22.29) (poor x poor) followed by 9A × HJ 541 (16.60) (good x good) and 14A × G 46 (16.04) (poor x good) in E_4 showed high SCA effects. The crosses 31A × HJ 541 (13.26) and 56A × HJ 513 (10.90) in E_1; crosses 31A × HJ 513 (17.85) and 56A × HJ 541 (16.88) in E_2 ; 31A × HJ 541 (8.89) and 467A × G 46 (8.47) in E_3 and cross 467A × G 46 (9.79) and 465A × IS 2389 (8.13) in E_4 also showed significant SCA effects. Similar results have been reported[9, 10, 11].

Best specific cross combinations for different characters have been presented in Table 6. Read-through of this table revealed that for plant height, the cross combination 14A × IS 2389 exhibited high and positive SCA effects and cross 467A × HJ 541exhibited positive sca effects for number of tillers. The cross combination of 465A × HJ 513 and 9A × IS 2389 exhibited high and positive sca effects for green fodder yield as well as for dry fodder yield. Hybrids 14A × HJ 513 and 31A × HJ 541 for leaf breadth and 9A × G 46 for leaf length were found to be the best specific combiner. Similar results have been reported [12, 13]. Thus, the study reveals that there is lot of scope for the use of these lines in future breeding programmes in the development of either base populations or hybrids.

REFERENCES

1. Sprague, G.F. and Tatum, L.A., General and specific combining ability in single crosses in corn. *Journal of the American Society of Agronomy*, **34(1)**: 923-932 (1942).
2. Siddiqui, M.A. and Baig, K.S., Combining ability analysis for yield and its components characters in sorghum [*Sorghum bicolor* (L.) Moench]. The *Journal of Research*, ANGRAU, **29**: 27-34 (2001).
3. Kempthorne, O., An Introduction to Genetic Statistics, New York, John Wiley and Sons, 1st Edn., pp: 456-471 (1957).
4. Grenier, C.P.J., Bramel, M., Noirot. K.E., Prasada Rao and Hamon, P., Assessment of genetic diversity in three subset constituted from the ICRISAT sorghum collection using random *vs* non-random sampling procedures. *Theoretical and Applied Genetics*, **101**: 190-196 (2001).
5. Tariq, A., Sattar., A.Z., Ghulam, S., Muhammad, G., Khalid, S., Khan, M., Shahid, I. and Talat, M., Character association and inheritance studies of different sorghum genotypes for fodder yield and quality under irrigated and rainfed conditions. *African Journal of Biotechnology*, **11(38)**: 9189-9195 (2012).
6. Reddy, B.V.S., Sharma, H.C., Thakur, R.P. and Ramesh, S., Characterization of ICRISAT-bred sorghum hybrid parents (set I). *International Sorghum and Millets Newsletter*, **47**: 138 (2006).
7. Joshi, D.C., Shrotria, P.K., Singh, R. and Chawla, H.S., Morphological characterization of forage sorghum (*Sorghum bicolor* (L.) Moench) varieties for DUS testing. *Indian Journal of Genetics and Plant Breeding*, **69(4)**: 383-393 (2009).
8. Singh, S., Dwivedi, V.K., Sherotria, P.K. and Pandey, S., Genetic divergence in sorghum (*Sorghum bicolor* (L.) Moench). *Forage Res*, **36(1)**: 48-51 (2010).
9. Agarwal M. and Shrotria P.K., Heterosis and inbreeding depression in forage sorghum [*Sorghum bicolor* (L.) Moench]. *Indian J. Genet. Plant. Breed.*, **65(1)**: 12-14 (2005).
10. Prabhakar, S., Elangovan, M. and Bahadure, D.M., Combining ability of new parental lines for flowering, maturity and grain yield in Rabi sorghum. *Electronic Journal of Plant Breeding*, **4(3)**: 1214-1218 (2013).
11. Rani, C., Umakanth, A.V., Vemanna, I. and Tanmay, V.K., Heterosis studies for ethanol yield and its related traits in F_1 hybrids of sweet sorghum [*Sorghum bicolor* (L.) Moench]. *Madras Agricultural Journal*, **100(1/3)**: 1-8 (2013).
12. Bibi, A., Sadaqat, H.A., Tahir, M.H.N., Usman, B.F. and Ali, M. Genetic analysis of forage quality traits in sorghum-sudangrass hybrids under water stress. *J. Anim. Plant Sci*, **22(4)**: 1092-1100 (2012).
13. Kamdi, S.R., Manjare, M.R. and Sushir, K.V., Combining ability analysis for forage yield and yield contributing characters in sweet sorghum (*Sorghum bicolor* (L.) Moench). *Mysore Journal of Agricultural Sciences*, **45(4)**: 837-843 (2011).