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Combining ability and heterosis for fodder yield, quality and its component traits in forage sorghum [*Sorghum bicolor* (L.) Moench]

PR Patel, RM Chauhan, SK Jain and DG Patel

PR Patel
Sorghum Research Station
Sardarkrushinagar Dantiwada Agricultural University, Deesa, Gujarat, India

RM Chauhan
Sorghum Research Station
Sardarkrushinagar Dantiwada Agricultural University, Deesa, Gujarat, India

SK Jain
College of Agriculture, Sri Karan Narendra Agricultural University, Lalsot, Dausa, Rajasthan, India

DG Patel
Sorghum Research Station
Sardarkrushinagar Dantiwada Agricultural University, Deesa, Gujarat, India

Abstract

The aim of this study was to estimate the general combining ability (GCA) of the parents and specific combining ability (SCA) of hybrids considered for the development of high yielding and better quality cultivars of forage sorghum. Nineteen parents and 60 F_1 hybrids obtained by crossing 4 male sterile lines and 16 fertile lines in line x tester matting system during *Kharif* 2012 were sown in randomized block design in three replication during summer and *Kharif* 2013 with two different date of sowing. Analysis of variance revealed significant differences among genotypes, parents and hybrids for all the traits on pooled basis. Combining ability analysis revealed presence of both additive and non-additive gene effects. The SCA variance was found to be more important to gca variance for green and dry fodder yield per plant, plant height, stem diameter, leaf width, leaf: stem ratio, shoot fly dead heart percentage, quality characters and days to flowering, which favored a hybrid breeding programme. The female parents 9A and 14A were found to be good general combiners for most of the characters under study. Among male parents, SRF 327 and SPV 2113 were found as good general combiners for fodder yield per plant, yield attributes and quality related traits. Out of 60 hybrids, 24 hybrids showed significant positive sca effects on pooled basis for green and dry fodder yield per plant. The best five hybrids based on significant positive sca effects for green fodder yield per plant were 104A x SPV 1616, 27A x SPV 1616, 9A x SRF 331, 14A x SRF 335 and 27A x SRF 317. These cross combinations involved poor x poor, good x poor, poor x average, good x poor and good x good GCA effects, respectively. Out of these five hybrids, 27A x SRF 317 and 14A x SRF 335 had high *per se* performance with significant positive heterosis and positive sca effects for fodder yield, its contributing traits and quality traits.

Keywords: General and specific combining ability, Line x tester analysis, HCN content, Brix per cent, Heterosis

Introduction

Sorghum [*Sorghum bicolor* (L.) Moench] is one of the most important cereals of the semi-arid tropics. Green fodder is the cheapest source of feed for milch, beef and draft animals. Therefore, development of fodder resources of the country becomes a high priority national programme. This could be achieved through bringing more area under fodder cultivation and improving productivity of fodder crop coupled with quality. But there is little scope of increasing area under cultivation of fodder crops due to urbanization, industrialization and traditional inclination among farmers. Only 4.4 per cent of the total cropped area of the country is under fodder crops cultivation. Hence, only optional strategy to meet fodder requirement is to exploit crop productivity through better yielding varieties/hybrids and efficient agronomic management. The major challenge facing in sorghum research in India is to evolve technologies that will enable transformation of subsistence farming into commercial and profitable production. For accomplishing these objectives, it is crucial to enhance the productivity of sorghum, diversification of the genetic base including hybrid cytoplasm, disease and pest resistance, fodder quality, acid and saline soil adaptability, *etc.*

Commercial exploitation of heterosis in crop plant is regarded as one of the major breakthrough in the field of plant breeding. The scope of exploitation of hybrid vigour depends on the direction and magnitude of heterosis, biological feasibility and type of gene action involved. After the development of male sterile lines in sorghum, exploitation of heterosis has become commercially feasible and considerable research has been done on the phenomena of hybrid vigour in sorghum crop (Quinby, 1963; Singhania and Rao, 1976 and Patel, 1990) [20, 22, 16]. However, as far as fodder sorghum is concerned,

Correspondence
SK Jain
College of Agriculture, Sri Karan Narendra Agricultural University, Lalsot, Dausa, Rajasthan, India

not much emphasis has been placed for the improvement of forage sorghum except through selection from the local materials and limited hybridization resulting into evolving of some improved cultivars and very few commercial hybrids.

Before initiating hybridization programme, the selection of suitable parents is one of the most important steps because selection of the parent on the basis of phenotypic performance alone is not a sound procedure since phenotypically superior lines may yield poor hybrids. The lines or parents which produce good progenies on crossing are of immense use to the breeder. This necessitates the testing of parents for their combining ability which in turn will help in identifying the best combiners which may be hybridized either to exploit heterosis or to accumulate desirable genes through selection. For the identification of parents having good potentials to transmit desirable characteristics to their progenies and also to help in sorting out of promising crosses for fodder yield and its related traits, combining ability analysis is powerful tool. The gca is attributed to additive genetic effects which are theoretically fixable. On the other hand, sca attributable to non additive gene action may be due to dominance, additive x dominance and dominance x dominance or higher order interactions and is unfixable. The presence of non additive genotypic variance is the primary justification for initiating the hybrid programme (Cockerham, 1961) [5]. At the time, it also elucidates the nature of gene action involved in the inheritance of the characters. Sprague and Tatum (1942) [23] proposed the concept of gca and sca as a measure of gene effects.

Therefore, the present investigation was undertaken with a view to study the performance of different hybrids, extent of heterosis, combining ability of genotypes (females, males, hybrids and checks together) for thirteen characters through line x tester mating design in fodder sorghum having diverse male sterile lines and pollen fertility restorers.

Material and methods

The experimental material comprised of 82 genotypes including fertile counter parts of four male sterile lines (9A, AKMS14A, 27A and 104A), 15 males (SRF 317, SRF 321, SRF 323, SRF 327, SRF 328, SRF 330, SRF 331, SRF 332, SRF 334, SRF 335, SRF 336, SRF 337,CSV 15, SPV 1616 and SPV 2113), 60 hybrids and three checks *viz.*, GFS 4, GFS 5 and CSV 21F, were grown in a randomized block design replicated thrice during summer-*kharif,* 2013 at Sorghum Research Station, S. D. Agricultural University, Deesa, Gujarat. The individual environments were created by sowing in two seasons *i.e.,* summer and *kharif* and each season having two different date of sowing with two different dose of fertilizers (Early sowing + 80: 40: 00, Late sowing + 100: 50: 00). Each genotype was represented by a single row plot of 4.0 metre length. The inter row and intra row distance was 30 cm and 7.5 to 10 cm, respectively. All the recommended agronomical practices and plant protection measures were followed as and when required to harvest a good crop. Observations were recorded on thirteen characters viz., Days to flowering, plant height (cm), number of leaves per plant, stem diameter (cm), leaf length (cm), leaf width (cm), leaf: stem ratio, green fodder yield per plant (g), dry fodder yield per plant (g), shoot fly dead heart percentage, brix (%), HCN content (ppm) and Crude protein (%). Five competitive plants were randomly selected and tagged from each plot of entry for recording observations and average value per plant was computed. The character days to flowering and maturity were recorded on plot basis. All the data of four environments subjected to estimation of heterosis and combining ability (Kempthorne 1957).

Results and Discussion

The analysis of variance for combining ability indicated that variances due to females, males and females x males were significant for all the characters in all four individual environment as well as pooled over the environments, suggesting the importance of both additive and non-additive components of genetic variance in controlling these traits. The analysis of variance for combining ability and the estimates of variance components (Table 1) revealed that the mean squares of variance due to males were significant for green and dry fodder yield per plant indicated the significant contribution of males towards gca variance component for this trait. The comparison of σ^2 f and σ^2 m revealed that the variance components due to males were higher than that of females for days to 50 per cent flowering, plant height, number of leaves per plant, stem diameter, leaf length, brix and HCN content, which showed greater contribution of males towards the σ^2 gca for these characters, while, the females variances were higher for leaf width, leaf: stem ratio, shoot fly dead heart percentage and crude protein content suggested role of female variance components towards gca variance. The mean squares due to female x male interactions were highly significant exhibited the presence of inter-allelic interaction and importance of sca variance in the inheritance of all the characters studied. Both additive and non-additive variances were important in the inheritance of green fodder yield per plant and its component could be improved by proper choice of the parents, their hybridization and by adopting suitable selection methods. However, comparison of relative magnitude of general and specific combining ability variance indicated that the additive genetic actions were predominant for number of leaves per plant and leaf length. The non-additive gene action was predominant for days to flowering, plant height, stem diameter, leaf width, leaf: stem ratio, green fodder yield per plant, dry fodder yield per plant, shoot-fly dead heart percentage, brix, HCN and crude protein content. The mean squares due to both female x environment, male x environment and females vs. males x environment were significant for all the traits except HCN and crude protein content suggested sensitivity of both kinds of gene effects to the environmental variation and this also indicating role of environment in the contribution of gca and sca variance for these traits.

The greater role of non-additive genetic variation in the inheritance of all these characters except number of leaves per plant and leaf length. It was evident from the ratio σ^2gca/σ^2sca found less than unity. The predominance of non-additive gene action for these traits was reported by earlier reporters (Yadav and Pahuja, 2014, Patil and Kute, 2015, Mohammed *et al.*, 2015 and Jain and Patel, 2016) [27, 18, 10, 7]. Population improvement methods like bi-parental mating or reciprocal recurrent selection or cyclic selection for improvement of yield could be utilized which may help in breaking the linkage blocks and additive portion would be generated over a time. Such recommendations were in line with Aruna and Padmaja (2009) [3], Aruna *et al*. (2010) [2], Mohammed *et al.* (2015) [10], Padmashree *et al*. (2014) [14] and Kumar and Chand (2015) [9]. Since the yield and most of the yield contributing characters involved major components as non-additive type of gene action heterosis breeding is most appropriate for the improvement of fodder yield. As male sterility is available since sixties, heterosis breeding would be most preferable for improvement in yield and some of the yield related parameters (Mohan *et al.*, 2007) [11]. The additive type of gene action was also important for crop duration, quality parameters and for fodder yield in some hybrids and hence hybridization followed by selection in advanced generation for better segregants or transgressive segregants would be more suitable (Pahuja *et al.*, 2003) [15].

Nature and magnitude of combining ability effects provide guidelines in identifying parents and their utilization. Based on the estimates of general combining ability effects on pooled basis, the parents were classified as good, average and poor combiners for thirteen traits (Table 4). Among females, 14A and 27A were good general combiners for green fodder yield per plant. These lines were also good or an average combiners for its contributing traits *viz.*, plant height, number of leaves per plant, stem diameter, leaf length, leaf width and leaf: stem ratio. Hence, these females may be considered as the best source of favorable genes for increasing green and dry fodder yield per plant in hybrid combinations (Yadav and Pahuja, 2007) [26]. On other hand, 27A was observed to possess genes for imparting earliness and tallness along with green fodder yield per plant. 9A as good combiner for increasing protein content (Khatri and Jatasara, 1988), HCN content and shoot fly dead heart percentage (Yadav and Pahuja, 2014 and Aruna *et al.*, 2015) [27, 4]. The parent14A showed sweetness with good general combiners for green and dry fodder yield per plant (Monapara and Sanghi, 1982) [12] while the parents 9A, 27A and 104A were good general combiners for shoot fly dead heart percentage. Out of these three, 27A was also good general combiner for plant height.

In the present study, parental lines SRF 317 followed by SRF 323, SRF 327, SRF 328, SRF 332 and SPV 2113 were found good general combiners for green and dry fodder yield per plant and related traits, while SRF 335 was good combiner for dry fodder yield per plant and rest of the yield attributing characters. The SRF 334 was average combiner for green and dry fodder yield per plant and related traits. The males SRF 321, SRF 327, SRF 337 and SPV 2113 also were good combiner for quality parameters like brix per cent, HCN content and crude protein content. The males SRF 321, SRF 327 and SRF 330 were good combiner for earliness, plant height and HCN content. The male SRF 335 was good general combiner for stem diameter, leaf length and leaf: stem ratio. The males SRF 321, SRF 323, SRF 330 and SRF 331 were good combiner for shoot fly dead heart percentage, also good general combiner for plant height (Table 2, Table 5). The parents *viz.*, SRF 317, SRF 327, SRF 332 and SPV 2113 were good general combiner for green and dry fodder yield per plant. These were also found good combiner for one or more yield attributes. These males could therefore, be utilized in breeding programme for improving these traits through hybridization followed by selection of transgressive segregants in desired direction. The good combining parents for yield, 14A, 27A, SRF 317, SRF 332 and SPV 2113 also expressed high sca effects in combinations with other parents for yield and its attributing traits (Table 2, Table 5). A number of earlier workers had also observed high sca effects with good combining parents for plant height, number of leaves per plant and leaf: stem ratio (Yadav and Pahuja, 2007; Singh *et al.*, 2010 and Jain and Patel, 2014) [26, 21, 6]. In such situation, it will be better to look for good transgressive segregants in further generation to make their use in breeding programme.

None of the hybrids recorded consistently significant and desirable sca effects for all the characters. Out of 60 hybrids, 24 showed significant positive sca effects on pooled basis for green and dry fodder yield per plant (Table 3, Table 5). The best five hybrids based on significant positive sca effects for green fodder yield per plant were 104A x SPV 1616 (126.59), 27A x SPV 1616 (86.16), 9A x SRF 331 (85.98), 14A x SRF 335 (84.25) and 27A x SRF 317 (77.57). These cross combinations involved poor x poor, good x poor, poor x average and good x good gca effects, respectively. This suggested that information on gca effects should be supplemented by sca effects and mean performance of hybrid for predicting the value of any hybrid. It is also desirable to sort out parental lines with high gca effects. The heterotic effects as well as significant positive sca effects appeared in hybrid 27A x SRF 317 for green fodder yield per plant as well as other yield contributing characters *viz.*, plant height and number of leaves per plant had good x good combining parents might have resulted from interaction of dominant gene contributed by both the parents. The findings were in agreement with the results of Agrawal *et al.* (2005) [1], Mohan *et al.* (2007) [11] and Prakash *et al.* (2010) [19] who had observed significant sca effects and non-additive genetic variance for high green fodder yielding hybrids. Normally sca effects do not contribute tangibly to the improvement of autogamous crops (directly as hybrid). But in case of sorghum, the commercial exploitation of heterosis is feasible with the use of male sterile lines. Hence, when high sca effects were observed in crosses involving atleast one good general combiner, the same may be exploited in heterosis breeding programme.

The hybrids 9A x SRF 327, 9A x SPV 2113, 14A x SRF 335, 14A x SRF 336, 27A x SRF 336, 27A x SRF 337, 27A x SPV 1616, 104A x SRF 328, 104A x CSV 15 and 104A x SPV 2113 which involved good x poor combining parent had significant and positive sca effects. The high sca effects in above crosses might be the result of dominant x additive gene interaction. The good x poor crosses besides exhibiting the favourable additive effects of the high parent manifest the complementary interaction effect and thus higher sca effects. The hybrids 9A x SRF 321, 9A x SRF 330, 9A x SRF 331, 9A x SRF 334, 104A x SRF 321, 104A x SRF 331 and 104A x SPV 1616 denoting significantly positive sca effects for green fodder yield per plant which were the results of both parents with poor or average x poor general combining ability (Mungra *et al.*, 2011) [13]. The high sca effects in these crosses might be due to epistatic gene interaction.

The crosses showing high sca effects for green fodder yield per plant also in general exhibited high sca effects for yield attributing traits. Out of the 24 crosses showing high positive sca effects, most of them showed high and significant sca effects for at least two yield components. Similar results were also reported by Agrawal *et al.* (2005) [1] Mohan *et al.* (2007) [11] and Mohammed *et al.* (2015) [10]. The information regarding the best *per se* performing parents, good general combiners and high yielding hybrids coupled with crosses possessing high sca effects (Table 6) revealed that high *per se* performance parents were generally good combiners for most of the characters. However, good general combiner might not necessarily produce good specific combinations for various characters. As it was clear for the trait green fodder yield per plant in which the highest sca effect crosses 104A x SPV 1616 (126.59) and 9A x SRF 331 (85.98) having both the parents either poor x poor or poor x average combination. This might be due to the non-additive gene effects of parent for yield characters. In such type of situation, for getting better segregants, bi-parental or cyclic breeding programme would be most appropriate methodology (Patil and Mistry, 1997 and Sumalini *et al*., 2005) [17, 24]. For other characters across the environments, significant and desirable sca effects on pooled basis were found for days to flowering (21), plant height (15), number of leaves per plant (8), stem diameter (12), leaf length (10), leaf width (15), leaf: stem ratio (23), shoot fly dead heart percentage (22), brix per cent (18), HCN content (26) and crude protein content (22). The importance of sca particularly in crosses involving diverse germplasm was brought out by the studies of Jain and Patel (2014) [6], Thakare *et al*. (2014) [25] and Patil and Kute (2015) [18].

The crosses exhibited high sca effect for yield characters had in general high sca effect for component traits *viz.*, plant height and number of leaves per plant and quality characters *i.e.*, brix per cent. The best *per se* performing parents were mostly good general combiners. The crosses exhibiting high sca effects did not always involve parents possessing high gca effects, thereby suggesting the importance of inter-allelic interactions and may directly exploited for commercial cultivation after multi-location testing. High *per se* performing hybrids with significant heterotic crosses may not always have significant sca effect.

Table 1: Analysis of variance (mean squares) for combining ability and estimates of variance components of different characters for pooled over the environments

Source of variations	d.f.	Days to 50 per cent Flowering	Plant height (cm)	NOL	SD (cm)	Leaf Length (cm)	Leaf Width (cm)	LSR	Green fodder yield (g)	Dry fodder yield (g)	SFDH %	Brix (%)	HCN (ppm)	Crude protein (%)
Replications in Environ.	8	1.86	159.9	0.40	0.742**	51.7*	0.181	0.001*	1752.5*	409.6**	1.160	0.96*	18.88	0.791**
Environments E)	3	2614.3**	42447.8**	240.8**	12.92**	4923.1**	72.78**	0.166**	261928.7**	24393.1**	1464.8**	91.51**	289.71**	2.333**
Females (F)	3	355.9**	13354.8**	5.3**	3.017**	980.5**	3.026**	0.123**	15258.4**	3531.0**	95.3**	180.6**	7980.1**	12.291**
Males (M)	14	766.9**	8077.9**	6.6**	2.003**	320.4**	3.003**	0.013**	80371.2**	8658.3**	36.2**	62.20**	4385.1**	6.514**
F vs. M	42	142.8**	5601.5**	2.3**	1.597**	127.2**	2.669**	0.014**	51525.9**	6805.7**	43.6**	25.79**	2452.0**	7.743**
F x E	9	101.3**	7182.7**	4.8**	4.240**	552.1**	1.377**	0.020**	98224.0**	10097.0**	12.5**	59.18**	28.267	0.133
M x E	42	104.3**	1625.6**	6.2**	1.458**	169.4**	2.419**	0.014**	26069.9**	2113.8**	5.3**	3.41**	16.051	0.173
(F vs. M) x E	126	69.1**	1324.9**	3.6**	1.249**	107.2**	2.031**	0.013**	25068.8**	2250.0**	9.6**	5.28**	18.785	0.279
Pooled Error	472	2.06	93.68	0.49	0.210	20.52	0.249	0.000	737.6	65.14	0.63	0.394	27.611	0.243
σ^2 f		1.00	10.53	0.01	-0.009	2.26	0.006	0.001	-607.9	-61.78	0.27	0.561	30.659	0.026
σ^2 m		12.26	45.32	0.03	0.004	2.72	-0.001	0.000	580.08	41.43	-0.067	0.797	40.330	-0.023
σ^2 fm		6.14	356.38	-0.10	0.029	1.66	0.053	0.001	2204.76	379.64	2.840	1.710	202.772	0.622
σ^2 fe		0.71	130.17	0.02	0.066	9.88	-0.015	0.000	1625.67	174.37	0.065	1.198	0.211	-0.003
σ^2 me		2.93	25.06	0.21	0.017	5.18	0.032	0.000	83.43	-11.34	-0.351	-0.155	-0.228	-0.009
σ^2 fme		22.37	410.41	1.04	0.346	28.90	0.594	0.004	8110.39	728.30	2.988	1.630	-2.942	0.012
σ^2 gca		3.37	17.85	0.015	-0.006	2.36	0.004	0.000	-357.80	-40.05	0.200	0.611	32.695	0.016
σ^2 sca		6.14	356.38	-0.10	0.029	1.66	0.053	0.001	2204.76	379.64	2.840	1.710	202.772	0.622
σ^2gca / σ^2sca		0.54	0.05	-0.14	-0.208	1.41	0.079	0.000	-0.162	-0.106	0.070	0.357	0.161	0.025

* and **: Significant at 5 and 1 per cent levels of significance, respectively.

Table 2: General combining ability effects of parents in pooled over the environments for days to flowering and plant height

Parents	DF	PH	NOL	SD	LL	LW	LSR	GFY	DFY	Brix %	HCN %	Protein %	SFDH %
Females													
9A	0.68**	0.98	-0.21**	-0.12**	3.18**	-0.06	0.02**	-10.04**	-1.66**	0.01	-9.29**	0.39**	-0.29**
14A	1.30**	-10.38**	0.20**	0.10*	-0.73	0.17**	0.02**	10.04**	6.51**	-0.51**	6.06**	-0.13**	1.07**
27A	-1.94**	10.60**	0.06	0.13**	-0.06	-0.13**	-0.03**	5.13*	-3.43**	-1.26**	0.08	-0.12**	-0.24**
104A	-0.05	-1.20	-0.05	-0.10**	-2.39**	0.02	-0.01**	-5.13*	-1.42*	1.77**	3.15**	-0.14**	-0.54**
S.Em.±	0.08	0.54	0.04	0.03	0.25	0.03	0.00	1.53	0.45	0.08	0.30	0.03	0.04
Males													
SRF 317	5.36**	10.42**	0.68**	0.29**	0.19	0.04	0.02**	44.59**	17.31**	-0.04	-2.36**	-0.39**	0.55**
SRF 321	-2.29**	5.**	-0.65**	-0.13	0.73	0.10	0.02**	-32.06**	-13.80**	-0.65**	-9.39**	0.24**	-1.97**
SRF 323	4.00**	7.65**	0.04	0.19**	-0.13	0.01	-0.03**	27.34**	9.97**	-0.68**	-14.05**	0.13	-0.79**
SRF 327	-2.35**	6.00**	-0.35**	-0.00	-0.79	0.22**	-0.01**	8.13*	4.41**	0.29**	-4.85**	-0.14	0.59**
SRF 328	-0.31	8.25**	-0.18	-0.12	2.01**	-0.15*	0.00	18.42**	6.64**	-0.20*	22.10**	0.08	0.96**
SRF 330	-1.31**	4.50**	-0.02	-0.04	1.07	0.15*	0.02**	0.94	-1.94	-0.57**	-7.48**	0.70**	-0.28*
SRF 331	1.57**	9.92**	0.12	0.06	3.30**	-0.14	0.02**	5.44	10.56**	0.52**	2.64**	0.03	-1.08**
SRF 332	3.21**	7.57**	0.50**	0.29**	-1.88*	0.02	-0.03**	49.75**	10.79**	-0.98**	3.00**	0.37**	0.79**
SRF 334	2.15**	1.44	0.18	0.09	-1.14	0.15*	-0.01**	-2.25	-1.86	-1.12**	13.79**	0.28**	0.28*
SRF 335	6.50**	1.71	0.32**	-0.14*	1.56*	-0.19*	0.00	-8.08*	13.64**	-0.80**	3.39**	-0.23**	-0.62**
SRF 336	0.21	3.38*	0.38**	-0.26**	-2.43**	-0.53**	0.02**	-67.48**	-10.07**	0.09	-4.64**	-0.23**	-0.06
SRF 337	-9.12**	-11.27**	-0.47**	-0.38**	-7.08**	-0.14	0.02**	-54.06**	-23.86**	3.39**	3.34**	0.21**	-0.45**
CSV 15	-3.47**	-12.27**	-0.32**	0.14*	0.75	-0.13	-0.03**	9.13*	-2.13	1.40**	8.20**	-0.54**	0.45**
SPV 1616	-0.91**	-39.68**	-0.09	-0.19**	0.38	-0.02	-0.01**	-67.50**	-26.90**	-0.39**	-4.77**	-0.68**	1.27**
SPV 2113	-3.25**	-3.14*	-0.13	0.20**	3.48**	0.62**	0.00	67.69**	7.24**	-0.25**	-8.93**	0.19*	0.35**
S.Em.±	0.17	1.18	0.09	0.06	0.55	0.06	0.02**	3.30	0.98	0.08	0.64	0.06	0.10

Table 3: Specific combining ability effects of crosses in pooled over the environments for different characters

Hybrids [1]	Days to flowering [2]	Plant height (cm) [3]	NOL/P [4]	SD [5]	LL [6]	LW [7]	LSR [8]	GFY [9]	DFY [10]	Brix % [11]	HCN (PPM) [12]	Protein % [13]	SFDH [14]
9A x SRF 317	-0.62	-13.23**	-0.31	-0.08	-0.17	-0.11	0.04**	1.50	23.08**	-1.22**	14.45**	-0.71**	1.61**
9Ax SRF 321	-5.22**	-12.14**	-0.05	0.01	-2.57	0.53**	-0.04**	23.14**	9.10**	-0.46*	19.74**	-0.38*	-0.51
9A x SRF 323	3.65**	7.29*	0.09	0.31*	1.74	-0.26	0.02**	-12.75	5.16*	-0.37	20.62**	-0.33	0.21
9A x SRF 327	1.84**	1.86	0.18	-0.03	3.08	-0.12	0.02**	-9.46	10.39**	1.14**	-1.32	0.49**	2.63**
9A x SRF 328	0.80	13.94**	-0.19	-0.03	2.26	-0.81**	-0.02**	43.91**	20.24**	-0.50*	-6.93**	0.16	2.86**
9A x SRF 330	1.13*	1.52	0.48*	0.03	-0.93	0.28	0.06**	39.31**	-8.42**	-0.17	0.37	-0.28	0.16
9A x SRF 331	4.42**	24.77**	0.43	0.29	3.75*	0.38*	-0.00	85.98**	40.58**	-0.48*	-20.26**	0.59**	0.09
9A x SRF 332	-0.89	2.79	-0.75**	-0.43**	2.75	0.49**	-0.02**	0.83	-10.32**	-0.18	2.35	-0.41*	1.33**
9A x SRF 334	-3.33**	38.00**	0.15	0.46**	4.12*	0.18	-0.04**	23.50**	-0.76	-0.27	-4.06*	-0.02	-0.34
9A x SRF 335	-1.68**	13.98**	-0.62*	-0.06	1.17	-0.23	-0.01**	12.41	2.24	0.34	-4.33*	0.27	-0.04
9A x SRF 336	-5.64**	1.32	-0.24	0.48**	-2.55	0.59**	-0.02**	-36.61**	-34.22**	-0.57**	-12.93**	0.52**	-2.16**
9A x SRF 337	-2.39**	4.21	0.10	-0.30*	-5.89**	-0.47**	-0.04**	2.89	-4.67	3.00**	-28.38**	0.24	-1.79**
9A x CSV 15	0.96*	0.63	0.06	-0.26	-1.49	0.07	-0.02**	-17.96*	-11.74**	0.19	-12.28**	0.25	-2.32**
9A x SPV 1616	10.07**	-96.37**	0.35	-0.51**	-4.68**	-0.78**	0.10**	-206.92**	-59.80**	-0.52*	19.88**	-0.27	0.07
9A x SPV 2113	3.10**	11.42**	0.30	0.12	-0.57	0.26	-0.02**	50.23**	19.14**	0.08	13.07**	-0.12	-1.80**
14A x SRF 317	0.76	-4.79	0.04	-0.21	3.49*	-0.33*	-0.01*	-40.75**	-6.42**	0.20	-5.88**	0.75**	-2.53**
14A x SRF 321	1.01*	15.38**	0.08	0.04	4.24**	0.06	0.02**	-21.10*	-16.82**	0.44*	-17.82**	-0.44**	-0.93**
14A x SRF 323	0.05	14.40**	-0.39	-0.49**	4.16*	0.01	0.02**	33.00**	-7.17**	0.37	-14.13**	-0.02	-1.63**
14A x SRF 327	-1.95**	4.30	-0.60*	-0.10	-2.85	-0.38*	0.05**	-46.96**	-19.19**	-2.75**	20.30**	-0.74**	-0.91**
14A x SRF 328	1.8**	-5.70	-0.35	-0.45**	-0.29	-0.14	0.03**	-53.66**	-2.01	0.07	-11.77**	0.01	-1.20**
14A x SRF 330	4.67**	2.46	-0.03	0.04	0.73	0.53**	-0.01**	51.73**	43.49**	0.79**	13.55**	-0.38*	1.90**
14A x SRF 331	0.55	-5.12	-0.56*	-0.37*	-5.51**	-0.04	-0.03**	-67.52**	-15.17**	-1.17**	5.14**	-0.79**	-1.43**
14A x SRF 332	1.65**	6.73*	0.61*	0.54**	-0.74	0.36*	-0.01	63.34**	10.35**	1.06**	-5.74**	0.60**	1.40**
14A x SRF 334	4.05**	-30.64**	-0.03	-0.14	-2.56	-0.06	0.02**	6.42	17.16**	0.48*	-6.20**	0.36*	1.37**
14A x SRF 335	1.11*	-8.66*	0.92**	0.45**	-2.10	0.45**	0.01	84.25**	22.08**	-0.01	-9.91**	0.04	2.17**
14A x SRF 336	0.07	-7.08*	0.05	0.07	-1.74	0.07	-0.01	38.15**	18.20**	3.16**	7.52**	1.05**	2.01**
14A x SRF 337	-2.85**	4.07	0.53*	0.49**	3.54*	0.63**	0.03**	7.48	-0.17	-2.58**	-6.20**	-0.32	2.78**
14A x CSV 15	-1.58**	-1.52	-0.12	-0.03	-0.71	-0.26	-0.03**	-26.96**	-7.74**	0.66**	21.42**	0.56**	-1.31**
14A x SPV 1616	-7.30**	28.57**	0.35	0.25	-1.50	-0.30	-0.03**	-5.83	-20.22**	-0.75**	15.20**	0.81**	0.043
14A x SPV 2113	0.03	-12.39**	-0.52*	-0.09	1.85	-0.59**	-0.03**	-21.60*	-16.36**	0.03	-5.48**	-1.49**	-0.90
27A x SRF 317	-2.25**	14.40**	0.21	0.68**	-4.70**	0.23	-0.04**		-1.57	1.66**	-5.97**	0.75**	1.84**
27A x SRF 321	1.32**	-16.60**	-0.44	-0.28	-3.20	-0.67**	0.01	-69.37**	6.45**	0.11	9.07**	-0.04	-0.80

Table 3: Contd...

[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	(11)	(12)	(13)	[14]
27A x SRF 323	-3.73**	-14.17**	0.47*	0.28	-1.57	0.06	-0.04**	31.2**	26.76**	1.10**	-4.95**	-0.09	-1.20**
27A x SRF 327	-1.21*	-9.35**	-0.09	-0.21	-3.28*	0.64**	-0.05**	40.37**	3.24	1.46**	-21.75**	1.06**	-0.10
27A x SRF 328	0.00	-5.35	0.07	-0.13	-2.06	-0.01	-0.01*	-49.26**	-25.99**	-0.58**	13.95**	-1.08**	0.82**
27A x SRF 330	-2.91**	3.65	-0.25	0.05	-0.45	-0.19	-0.01*	-44.20**	-16.57**	1.01**	-13.11**	0.23	-2.36**
27A x SRF 331	-3.87**	-13.19**	0.02	-0.09	3.74*	-0.14	0.02**	-38.53**	-22.57**	0.31	16.59**	-0.92**	1.16**
27A x SRF 332	-0.85	-0.50	0.27	0.05	0.44	-0.28	0.04**	-57.84**	-24.39**	0.01	-4.73**	-1.15**	-2.24**
27A x SRF 334	1.96**	13.29**	0.40	0.17	-2.42	0.12	0.00	51.32**	13.51**	1.26**	8.81**	0.36*	-0.62*
27A x SRF 335	1.36**	-9.98**	0.10	-0.33*	1.54	-0.12	0.03**	-49.84**	-9.32**	0.11	8.82**	-0.67**	0.21
27A x SRF 336	2.98**	2.94	0.48*	-0.07	0.53	-0.22	0.01	24.97**	13.30**	-1.55**	0.67	0.17	1.21**
27A x SRF 337	3.07**	4.67	-0.06	0.28	1.86	0.39*	0.02**	53.72**	12.51**	-3.21**	13.78**	0.76**	-1.17**
27A x CSV 15	1.09*	-0.08	-0.46	0.12	5.26**	-0.26	0.04**	16.37	2.36	-0.11	0.09	-0.15	2.39**
27A x SPV 1616	-0.06	32.00**	-0.55*	-0.08	4.11*	0.58**	-0.03**	86.16**	42.72**	0.02	-18.02**	0.07	-0.36
27A x SPV 2113	3.11**	-1.71	-0.18	-0.43**	0.21	-0.14	0.02**	-77.70**	-20.43**	-1.59**	-3.25	0.69**	-0.52
104A x SRF 317	2.11**	3.62	0.06	-0.39**	1.38	0.21	0.02**	-38.32**	-15.08**	-0.64**	-2.60	-0.79**	-1.64**
104A x SRF 321	4.92**	13.37**	0.40	0.24	1.53	0.09	0.02**	62.32**	1.28	-0.08	-10.99**	0.86**	1.20**
104A x SRF 323	0.13	-7.53*	-0.18	-0.10	-4.33**	0.19	0.00	-51.49**	-24.75**	-1.10**	-1.55	0.44**	2.62**
104A x SRF 327	1.32**	3.20	0.51*	0.33*	3.06	-0.14	-0.01**	16.05	5.57*	0.16	2.76	-0.81**	-1.61**
104A x SRF 328	-2.64**	-2.88	0.47	0.62**	0.09	0.95**	0.01	59.01**	7.75**	1.02**	4.75**	0.91**	-2.48**
104A x SRF 330	-2.89**	-7.63*	-0.20	-0.11	0.65	-0.62**	-0.03**	-46.85**	-18.50**	-1.62**	-0.81	0.43*	0.30
104A x SRF 331	-1.10*	-6.47	0.10	0.17	-1.98	-0.19	0.01	20.07*	-2.83	1.34**	-1.47	1.13**	0.18
104A x SRF 332	0.09	-9.03**	-0.14	-0.17	-2.45	-0.57**	-0.01*	-6.32	24.36**	-0.89**	8.12**	0.96**	-0.49
104A x SRF 334	-2.68**	-20.65**	-0.53*	-0.48**	0.87	-0.24	0.02**	-81.24**	-29.91**	-1.47**	1.45	-0.69**	-0.41
104A x SRF 335	-0.79	4.66	-0.41	-0.06	-0.60	-0.10	-0.02**	-46.83**	-15.00**	-0.44*	5.42**	0.36*	-2.34**
104A x SRF 336	2.59**	2.83	-0.29	-0.47**	3.76*	-0.45**	0.02**	-26.51**	2.71	-1.05**	4.74**	-1.74**	-1.07**
104A x SRF 337	2.17**	-12.94**	-0.57*	-0.47**	0.49	-0.56**	-0.01	-64.10**	-7.66**	2.79**	20.80**	-0.68**	0.18
104A x CSV 15	-0.48	0.97	0.53*	0.17	-3.05	0.45**	0.01*	28.55**	17.11**	-0.74**	-9.22**	-0.67**	1.24**
104A x SPV 1616	-2.70**	35.81**	-0.15	0.34*	2.07	0.50**	-0.04**	126.59**	37.30**	1.24**	-17.06**	-0.61**	2.91**
104A x SPV 2113	-0.04	2.68	0.39	0.40**	-1.49	0.48**	0.03**	49.07**	17.65**	1.49**	-4.34*	0.91**	1.39**
S.Em.±	0.30	2.04	0.15	0.10	0.95	0.11	0.00	5.72	1.70	0.13	1.11	0.10	0.17
No. of significant	44	32	16	23	16	26	49	48	49	40	48	41	43
Significant $^{+ve}$	23	15	8	11	10	15	23	24	24	18	22	22	21
Significant $^{-ve}$	21	17	8	12	6	11	26	24	25	22	26	19	22
Range	-7.30 to 10.07	-96.37 to 38.00	-0.75 to 0.92	-0.51 to 0.68	-5.89 to 5.26	-0.81 to 0.95	-0.05 to 0.10	-206.92 to 126.59	-59.80 to 43.49	-3.21 to 3.16	-28.38 to 21.42	-1.74 to 1.13	-2.62 to 2.91

*, ** Significant at 5 and 1 per cent levels of significance, respectively.

Table 4: Classification of parents with respect to their general combining ability effects for different characters based on pooled analysis in forage sorghum

Parents	DF	PH	NLPP	SD	LL	LW	LSR	GFY	DFY	SDHP	BRIX	HCN	CP
Female:													
9A	P	A	P	G	G	A	G	P	P	G	P	G	G
14A	P	P	G	P	A	G	G	G	G	P	G	P	P
27A	G	G	A	P	A	P	P	G	P	G	P	A	P
104A	A	A	A	G	P	A	P	P	P	G	G	P	P
Male:													
SRF 317	P	G	G	P	A	A	G	G	G	P	A	G	P
SRF 321	G	G	P	A	A	A	A	P	P	G	P	G	G
SRF 323	P	G	A	P	A	A	A	G	G	G	P	G	A
SRF 327	G	G	P	A	A	G	P	G	G	P	G	G	A
SRF 328	A	G	A	A	G	P	P	G	G	P	P	P	A
SRF 330	G	G	A	A	A	G	G	A	A	G	P	G	G
SRF 331	P	G	A	A	G	A	P	A	G	G	G	P	A
SRF 332	P	G	G	P	P	A	P	G	G	P	P	P	G
SRF 334	P	A	A	A	A	G	A	A	A	P	P	P	G
SRF 335	P	A	G	G	G	P	G	P	G	G	P	P	P
SRF 336	A	G	G	G	P	P	P	P	P	A	A	G	P
SRF 337	G	P	P	G	P	A	P	P	P	G	G	P	G
CSV 15	G	P	P	P	A	A	A	G	A	P	G	P	P
SPV 1616	G	P	A	G	A	A	G	P	P	P	P	G	P
SPV 2113	G	P	A	P	G	G	P	G	G	P	P	G	G

G = Good general combiner; P = Poor general combiner; A = Average general combiner; DF = Days to flowering; PH = Plant height; NLPP = Number of leaves per plant; SD = Stem diameter; LL = Leaf length; LW = Leaf width; LSR = Leaf: stem ratio; GFY = Green fodder yield per plant; DFY = Dry fodder yield per plant; SDHP = Shoot fly dead heart percentage and CP = Crude protein content.

Table 5: Best parents, general combiners, hybrids and hybrids with sca effects for different characters on pooled basis

Characters	Best Performing parents	Good General combiners	Best Performing hybrids	Hybrids with Highest sca effects	Characters	Best Performing parents	Good General combiners	Best Performing hybrids	Hybrids with Highest sca effects
Days to flowering	SRF 337	SRF 337	9A x SRF 317	14A x SPV 1616	Plant Height (cm)	SRF 336	27A	9A x SRF 334	9A x SRF 334
	SRF 330	CSV 15	14A x SRF 337	9A x SRF 336		SRF 332	SRF 317	9A x SRF 331	104A x SPV 1616
	SRF 332	SPV 2113	27A x SRF 337	9A x SRF 321		SRF 327	SRF 331	27A x SRF 317	27A x SPV 1616
	SRF 334	SRF 327	104A x SRF 337	27A x SRF 331		SRF 330	SRF 328	27A x SRF 334	14A x SPV 1616
	14A	SRF 321	14A x SPV 1616	27A x SRF 323		SPV 2113	SRF 323	9A x SRF 328	9A x SRF 331
Number of leaves per plant	SRF 317	SRF 317	14A x SRF 335	14A x SRF 335	Stem Diameter (cm)	SRF 337	SRF 337	104A x SRF 337	9A x SPV 1616
	SRF 323	SRF 332	14A x SRF 332	14A x SRF 332		SRF 334	SRF 336	104A x SRF 336	14A x SRF 323
	SPV 1616	SRF 336	27A x SRF 317	104A x CSV 15		SRF 327	SPV 1616	9A x SPV 1616	104A x SRF 334
	SPV 2113	SRF 335	14A x SRF 317	14A x SRF 337		SRF 331	SRF 335	9A x SRF 317	104A x SRF 336
	SRF 335	14A	27A x SRF 336	104A x SRF 327		SRF 330	9A	104A x SRF 334	104A x SRF 337
Leaf length (cm)	SRF 335	SPV 2113	9A x SRF 331	27A x CSV 15	Leaf Width (cm)	SPV 2113	SPV 2113	104A x SPV 2113	104A x SRF 328
	SRF 328	SRF 331	9A x SRF 328	14A x SRF 321		CSV 15	SRF 327	14A x SRF 330	27A x SRF 327
	SRF 323	9A	27A x SRF 331	14A x SRF 323		SRF 321	14A	9A x SPV 2113	14A x SRF 337
	SPV 2113	SRF 328	9A x SRF 334	9A x SRF 334		104A	SRF 330	104A x SRF 328	9A x SRF 336
	CSV 15	SRF 335	9A x SPV 2113	27A x SPV 1616		14A	SRF 334	27A x SRF 327	27A x SPV 1616
Leaf: stem ratio	SRF 323	SRF 335	9A x SPV 1616	9A x SPV 1616	Green fodder yield per plant (g)	SPV 2113	SPV 2113	27A x SRF 317	104A x SPV 1616
	14A	9A	9A x SRF 330	9A x SRF 330		SRF 323	SRF 332	14A x SRF 332	27A x SPV 1616
	9A	SPV 1616	9A x SRF 317	14A x SRF 327		SRF 317	SRF 317	104A x SPV 2113	9A x SRF 331
	104A	SRF 330	14A x SRF 335	9A x SRF 317		CSV 15	SRF 323	9A x SPV 2113	14A x SRF 335
	SRF 335	14A	9A x SRF 323	27A x SRF 332		SPV 1616	SRF 328	14A x SRF 335	27A x SRF 317
Dry fodder yield per plant (g)	CSV 15	SRF 317	9A x SRF 331	14A x SRF 330	Shoot fly dead heart percentage	CSV 15	SRF 321	104A x SRF 335	14A x SPV 1616
	SPV 2113	SRF 335	14A x SRF 330	27A x SPV 1616		SRF 327	SRF 331	27A x SRF 330	14A x SRF 317
	SRF 317	SRF 332	14A x SRF 335	9A x SRF 331		SRF 321	SRF 323	9A x SRF 321	104A x SRF 328
	SRF 321	SRF 331	9A x SRF 317	104A x SPV 1616		SPV 1616	SRF 335	9A x SRF 337	27A x SRF 330
	SRF 336	SRF 323	104A x SRF 332	27A x SRF 323		SRF 335	104A	9A x SRF 336	104A x SRF 335
Brix (%)	SRF 330	SRF 337	104A x SRF 337	14A x SRF 336	HCN (ppm)	SRF 317	SRF 323	9A x SRF 331	9A x SRF 327
	SPV 1616	CSV 15	9A x SRF 337	9A x SRF 337		SRF 330	SRF 321	9A x SRF 336	27A x SRF 327
	SRF 334	104A	14A x SRF 336	104A x SRF 337		SRF 327	9A	27A x SRF 327	9A x SRF 331
	CSV 15	SRF 331	104A x SRF 331	27A x SRF 317		9A	SPV 2113	27A x SPV 1616	27A x SPV 1616
	SRF 327	14A	104A x SPV 2113	104A x SPV 2113		SRF 336	SRF 330	14A x SRF 323	14A x SRF 321
Crude protein (%)	104A	SRF 330	104A x SRF 332	104A x SRF 331					
	SRF 321	9A	104A x SRF 331	27A x SRF 327					
	27A	SRF 332	9A x SRF 331	14A x SRF 336					
	9A	SRF 334	104A x SRF 330	104A x SRF 332					
	SRF 332	SRF 321	104A x SRF 321	14A x SPV 1616					

Table 6: Best high yielding hybrids with heterosis (%) over better parent and standard check (GFS 5), gca effects of their parents, sca effects and component traits showing standard heterosis based on pooled analysis in forage sorghum

Hybrids	Mean green fodder yield per plant (g)	Heterosis (%) over #		GCA effects		SCA effects	Significant standard heterosis for component traits in desired direction ##
		BP	SC	Female	Male		
27A x SRF 317	545.42	32.09	39.79	5.13*	44.59**	77.57**	PH, BRIX, HCN
14A x SRF 332	541.25	62.33	38.76	10.04**	49.75**	63.34**	PH, NLPP, LW, HCN
104A x SPV 2113	529.75	23.51	35.77	-5.13*	67.69**	49.07**	DF, PH, LW, DFY, BRIX, HCN
9A x SPV 2113	526.00	22.63	34.81	-10.04**	67.69**	50.23**	DF, LW, DFY, HCN
14A x SRF 335	504.33	82.40	29.26	10.04**	-8.08*	84.25**	NLPP, DFY, HCN
9A x SRF 331	499.50	57.32	28.02	-10.04**	5.44	85.98**	DFY, HCN
104A x SRF 328	490.42	38.37	25.69	-5.13*	18.42**	59.01**	DF, PH, LW, BRIX, HCN
14A x SRF 323	488.50	15.39	25.20	10.04**	27.34**	33.00**	PH, HCN
27A x SRF 323	481.83	13.82	23.49	5.13*	27.34**	31.24**	DF, PH, DFY, HCN
14A x SRF 330	480.83	91.38	23.24	10.04**	0.94	51.73**	PH, LW, DFY, HCN
14A x SPV 2113	474.25	10.57	21.55	10.04**	67.69**	-21.60**	DF, HCN
27A x SRF 334	472.33	96.87	21.06	5.13*	-2.25	51.32**	PH, HCN
104A x SPV 1616	472.08	32.30	20.99	-5.13*	-67.50**	25.69**	DF, PH, LW, BRIX, HCN
27A x SRF 327	471.75	54.67	20.91	5.13*	8.13*	40.37**	DF, PH, LW, BRIX, HCN
9A x SRF 328	470.42	32.73	20.57	-10.04**	18.42**	43.91**	DFY, HCN
GFS 5	390.17	-	-	-	-	-	-
*, **	Significant at 5 and 1 per cent level of significance, respectively.						
# BP = Better parent and SC = Standard check;				## PH = Plant height; DF = Days to flowering;			
NLPP = Number of leaves per plant;				LW = Leaf width;			
SDHP = Shoot fly dead heart percentage;				DFY = Dry fodder yield per plant;			
BRIX = Brix per cent;				HCN = HCN content.			

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