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COMBINING ABILITY AND HETEROSIS STUDIES IN FORAGE SORGHUM (*SORGHUM BICOLOR* (L.) MOENCH) ACROSS ENVIRONMENTS

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ABSTRACT

Combining ability analysis through a line x tester set for 9 forage characters in four environments and on pooled basis revealed the importance of both additive and nonadditive gene actions. However, the ratio of σ^2gca/σ^2 sca showed greater importance of nonadditive gene action. The parental genotypes 2077A, 36A and M-31-2A among females and Vidisha, IS 4776, IS 644, Rio, IS 3287 and IS 685 among males showed the highest gca effects, whereas the crosses 2077A x Vidisha, M-31-2A x IS 3353, 2219A x IS 4776 M-31-2A x Rio, 2219 A x IS 3287, and CK 60A x IS 4776 among hybrids exhibited the highest and significant sca effects for yield and its components. While gca was stable for fodder yield and number of yield components, sca was highly unstable for all the characters across the environments. Highly significant but varying degrees of heterosis was observed for the characters under study.

Key words: *Sorghum bicolor*, combining ability, heterosis.

Sorghum is the most important fodder crop in the northern and central parts of India. For developing high yielding varieties/hybrids through hybridization, the choice of the right type of parents is of paramount importance, hence the importance of testing parents for their combining ability. Further, for the system of breeding to be employed, the knowledge of gene action is of immense value which varies depending on the genetic variation as well as genetic divergence in the material. The information on these aspects is limited in forage sorghum. Accordingly, the present investigation aims to estimate combining ability and the magnitude and nature of heterosis for nine forage characters in sorghum.

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MATERIALS AND METHODS

The experimental material for the present investigation consisted of a line x tester set of 6 cytoplasmic genetic male sterile lines and 18 diverse pollinators, and their 108 F_1 hybrids. The parents were selected from the germplasm collection of forage sorghum maintained under the Forage Research Project at the Gujarat Agricultural University, Anand Campus, Anand. The experiment was laid out with these 108 hybrids and their parents in randomized block design with three replications in four environments created by sowing the experimental materials on two dates at two locations, viz., Anand (21 July and 20 August) and Sardar Krishinagar (30 July and 25 August). The parents were grown in a separate contiguous block. Each F_1 and parent had single row of 3 m length, 30 cm spacing between rows, and 10 cm between plants. Five competitive plants were used to record data on various quantitative characters. The character means were used for statistical analysis. The combining ability analysis was done according to [1]. Heterosis was estimated over midparent (MP) and better parent (BP). All characters were analyzed separately for each environment as well as pooled data.

RESULTS AND DISCUSSION

The analysis of variance for combining ability (Table 1) revealed that mean squares due to females, males and females x males were highly significant for all the characters, indicating wide genetic diversity among the genotypes for the various characters studied

Table 1. Analysis of variance (mean squares) and variance estimates for combining ability of

Source	d.f.	Green fodder yield	Dry fodder yield	Days to flowering	Plant height
Environments (env.)	3	1340903.0**	74324.4**	02370.4**	711868.0*
Rep. x environment	8	18963.8**	1113.1**	11.7**	4949.9**
Females	5	63808.8**	3840.9**	1643.4**	4499.6**
Males	17	25865.5**	1798.2**	488.4**	7700.7**
Females x males	85	7366.1**	513.7**	113.4**	1075.3**
Females x env.	15	6285.3*	297.2	58.4**	752.3
Males x env.	51	3810.9	317.3	62.2**	679.4
Females x males x env.	255	3626.5**	275.2**	23.2**	537.9**
Pooled Error	856	1067.9	54.6	3.7	245.3
σ^2gca		250.4**	15.8**	6.4**	33.7**
σ^2sca		311.6**	19.9**	7.5**	44.8**
σ^2gca x env.		39.1	0.9	1.0**	4.9
σ^2sca x env.		852.9	73.5**	6.6**	97.5**

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

and marked differences in combining ability due to males (Table 1). It was observed that the male parents showed greater variability for green fodder and dry matter yield, plant height, stem weight and leaf: stem ratio, whereas the females exhibited greater variability than the male with respect to flowering, stem diameter, number of internodes and leaf area per plant.

The estimates of variances due to combining ability revealed that σ^2 gca was highly significant for all the characters except stem diameter and leaf:stem ratio. This indicates that both additive and nonadditive gene actions were involved in the expression of these characters. However, the ratio of σ^2gca/σ^2 sca revealed the preponderance of nonadditive gene action for all the characters except for leaf : stem ratio, where additive gene action was more important. Both additive and nonadditive gene actions are reported to be responsible for the inheritance of forage yield and its components in sorghum [2–4]. Several workers have indicated in the past that additive genetic variance existed in substantial amount in sorghum populations alongwith nonadditive gene action for green fodder and its components [5–8]. Though, the present investigation also supports the earlier reports on the genetic control of yield and its components, here the nonadditive gene action was more important as compared to additive gene action.

The results on gca effects (Table 2) indicated that the parent 2077A for green and dry fodder yield, plant height, stem diameter, number of internodes, stem weight and leaf area per plant; 36A for green and dry fodder yield, stem diameter, number of internodes, stem

forage yield and its components in sorghum pooled over environments

Stem diameter	No. of internodes	Stem weight	Leaf : stem ratio	Leaf area per plant
1.15**	370.71**	959487.7**	0.063**	283343000**
0.12**	1.19**	13749.3**	0.002**	4354250**
0.08*	88.04**	39418.8**	0.022**	53214200**
0.05	28.10**	20037.2**	0.01**	16364235**
0.03**	5.48**	5288.1**	0.002	3459364**
0.04**	2.75**	4915.1*	0.003*	1875666**
0.03**	2.49**	2765.5	0.002	1430039**
0.02	1.05**	2729.5**	0.002**	663055**
0.01	0.35	771.9	0.001	298975
0.0001	0.355**	162.0**	0.00009	210694.8**
0.0015**	0.369**	213.2**	0.00001	233025.8**
0.0031*	0.044**	30.8	0.00002	27494.4**
0.0006	0.233**	652.5**	0.00048**	121359.8**

Table 2. Estimates of gca effects of lines and testers for forage yield and its components in sorghum pooled over environments

Parent	Green fodder yield	Dry fodder yield	Days to flowering	Plant height	Stem diameter	Number of internodes	Stem weight	Leaf:stem ratio	Leaf area per plant
Lines (females)									
CK 60 A	–15.4**	–3.19**	–2.80**	–0.10	–0.011	–0.65**	–11.01**	–0.010**	–536.7**
2077 A	27.3**	4.10**	2.30**	5.10**	0.021**	0.73**	23.28**	–0.002	454.3**
36 A	6.8**	3.96**	2.55**	–2.59**	0.024**	0.33**	3.46*	0.012**	437.9**
3660 A	2.8	–0.83*	–0.91**	1.56	–0.004	–0.07*	–1.53	–0.005**	–201.5**
2219 A	–20.1**	–6.34**	–3.48**	–7.53**	–0.002	–0.84**	–15.29**	–0.009**	–573.6**
M-31-2 A	3.8	2.31**	2.34**	3.64**	–0.03**	0.51**	1.09	0.013**	419.4**
SE (gi)	1.8	0.42	0.11	0.88	0.007	0.03	1.56	0.001	30.7
CD 5%	3.6	0.81	0.21	1.72	0.013	0.06	3.06	0.003	60.2
SE (gi-gj)	3.1	0.71	0.19	1.50	0.012	0.06	2.67	0.002	52.6
CD 5%	6.1	1.39	0.37	2.94	0.023	0.12	5.23	0.004	103.1
Testers (males)									
C 10-2	–11.2**	6.27	2.91**	11.29**	0.027*	0.78**	–11.29**	0.013**	476.8**
S 1049	–19.1**	1.09	–1.42**	17.20**	0.045**	–0.24**	–16.30**	0.002	1.3
Vidisha	32.7**	5.23**	5.21**	11.05**	0.040**	1.19**	25.01**	0.014**	851.7**
Rio	11.0**	0.47	–0.63**	–11.09**	0.019	0.03	9.40**	–0.001	394.7**
PC 6	1.0	4.17**	2.09**	3.79**	–0.011	0.40**	–0.91	0.008**	435.8**
IS 606	–22.9**	–6.78**	2.32**	–13.34**	–0.033**	–0.73**	–21.95**	0.015**	371.6**
IS 612	–3.1	–1.95	1.61**	–9.82**	–0.021	–0.03	–5.53	0.019**	102.5
IS 632	–15.9**	–5.70**	1.02**	–13.10**	–0.040**	–0.31**	–13.13**	–0.003	–405.2**
IS 643	–26.6**	–2.13	–3.04**	10.02**	0.017	–0.55**	–23.06**	0.002	–384.9**
IS 644	19.2**	3.88**	–0.03	8.53**	0.002	0.14**	21.39**	–0.026**	94.6
IS 662	–16.9**	–6.56**	–3.07**	–8.44**	–0.016	–0.95**	–11.53**	–0.017**	–670.9**
IS 685	7.9*	–1.67	2.84**	–11.30**	0.004	0.38**	6.26*	0.006*	309.8**
IS 3301	–17.5**	–9.08**	–5.32**	0.11	–0.032*	–1.14**	–14.33**	–0.005*	–995.4**
IS 3223	16.1**	2.25	–0.28	12.20**	0.039**	–0.17**	15.37**	–0.014**	–83.4*
IS 3353	–0.6	–4.07**	–1.42**	–4.75**	–0.025*	–0.29**	0.99	0.002	–389.8**
IS 3254	–3.9	2.33	0.53**	7.44**	0.024	0.08	–2.59	–0.006*	–42.2
IS 3287	10.6**	4.38**	1.07**	3.46*	0.001	0.70**	8.82**	0.002	372.7**
IS 4776	39.0**	7.94**	2.25**	8.84**	0.023	0.71**	35.35**	–0.010**	509.4**
SE (gi)	3.4	0.77	0.20	1.62	0.013	0.06	2.88	0.003	56.7
CD 5%	6.6	1.50	0.39	3.18	0.025	0.12	5.64	0.005	111.0
SE (gi-gj)	5.4	1.23	0.32	2.61	0.200	0.10	4.63	0.004	91.1
CD 5%	10.7	2.41	0.63	5.12	0.039	0.20	9.07	0.008	178.6

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

weight, leaf : stem ratio, and leaf area/plant showed significant and desirable gca effects. On the contrary CK 60A, 3660A, and 2219A were good general combiners for earliness. Among the male parents, IS 4776, Vidisha, IS 644, IS 3223, Rio and IS 3287 were good combiners for green and dry fodder yield (except Rio) and for many yield components. IS 3301, IS 606, IS 643, IS 662 and IS 3353 showed significant and negative gca effects for days to flowering. Thus, it can be concluded that these lines had relatively higher number of favourable alleles for fodder yield and its components. Earlier, the varieties Rio and Vidisha [9] and IS 4776 [10] were reported to be very good parents for yield improvement, whereas the latter genotype also showed the highest adaptability [10].

The results further revealed that the parents showing high mean performance also showed high general combining ability for fodder yield and its components. Thus, the per se performance itself can give an indication of gca of the parents involved in the crosses, as was also reported earlier [11].

It was observed that on pooled basis a number of hybrid combinations, viz., 2077A x Rio, 2219A x IS 3353, 2219A x IS 4776, M-31-2A x Rio, 2219A x IS 3287, and CK 60A x IS 4776, gave significantly high sca effects for fodder (green as well as dry) yield, and also for several yield components (Table 3). It is evident that the crosses involving either both or at least one high gca parent produced hybrids with high sca effects. The cross 2077A x Vidisha was

Table 3. Estimates of sca effects of ten best crosses for green fodder yield and its components in sorghum pooled over environments

Cross	Green fodder	Dry matter yield	Days to flowering	Plant height	Stem diameter	No. of internodes	Stem weight	Leaf: stem ratio	Leaf area per plant
2077 A x Vidisha	53.1**	11.03**	0.62	-5.89	0.08**	0.41**	43.2**	0.010	865.5**
M-31-2A x IS 3353	50.1**	14.07**	1.04	18.39**	0.09**	0.49**	44.0**	-0.011	879.9**
2219 A x IS 4776)	44.2**	10.90**	-0.82*	7.97*	0.06*	0.06	38.6**	-0.012	432.7**
M-31-2A x Rio	42.0**	8.58**	0.66	16.53**	0.05	0.38**	35.2**	-0.004	506.1**
2219 A x IS 3287	41.8**	10.99**	1.54**	19.30**	0.10**	0.66**	36.7**	-0.012*	792.0**
CK-60 A x IS 4776	37.4**	6.08**	1.51**	2.16	0.05	0.14	29.1**	0.018**	449.0**
3660 A x IS 612	35.1**	10.31**	3.42**	-5.57	-0.02	0.70**	26.8**	0.011	683.0**
3660 A x IS 3223	35.0**	6.30**	0.72	12.71**	0.01	0.35**	31.2**	-0.005	564.7**
CK 60 A x PC 6	33.4**	13.0**	8.24**	7.50*	0.03	1.70**	29.4**	-0.007	1139.3**
3660 A x IS 662	33.0**	0.31	1.10**	-3.85	-0.01	0.32*	28.8**	-0.002	-160.9
SE (Sij)	7.6	1.71	0.45	3.63	0.03	0.14	6.4	0.006	126.7
CD, 5%	14.8	3.35	0.78	7.11	0.06	0.27	12.6	0.012	248.3

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

Table 4. Range of MP and BP heterosis for nine forage characters in different environments and on pooled basis in forage sorghum

Character		Anand		Sardar Krishinagar		Pooled
		21 July	20 August	30 July	25 August	
Green fodder yield	MP	64.5** – 248.9**	46.2 – 294.7**	–29.3 – 183.7**	–21.0 – 146.3**	16.8 – 168.8**
		(–27.2) (128.0)	(25.8) (155.4)	(–21.6) (159.7)	(–14.6) (127.2)	(9.4) (149.0)
	BP	–146.9** – 216.7**	–29.7 – 265.7**	–37.0 – 139.7**	–57.3 – 139.3**	–15.8 – 164.1**
		(–45.9) (116.9)	(–11.7) (248.3)	(–25.8) (87.8)	(–28.4) (114.2)	(–7.8) (139.2)
Drymatter yield	MP	–21.2** – 68.3**	6.9 – 69.7**	–5.5 – 49.8**	–1.0 – 39.7**	3.5 – 41.1**
		(–36.9) (232.2)	(19.1) (179.9)	(–16.2) (195.4)	(–3.1) (132.2)	(7.8) (143.4)
	BP	–40.4** – 67.4**	–21.9** – 65.3**	–11.0* – 37.3**	–8.3 – 32.7**	–2.8 – 38.7**
		(–52.8) (218.7)	(–23.7) (199.6)	(–28.2) (96.2)	(–18.2) (110.6)	(–5.1) (124.1)
Days to flowering	MP	15.0** – –17.8**	9.5** – –16.7**	14.3** – –14.0**	7.2** – –13.5**	12.1** – –13.50**
		(26.5) (–24.8)	(17.2) (–23.1)	(26.7) (–22.1)	(10.8) (–17.9)	(21.6) (–18.9)
	BP	22.0** – –12.0	12.7** – –15.3**	16.7** – –9.7**	14.0** – –10.7**	14.3** – –12.58**
		(44.3) (–16.90)	(23.2) (–22.0)	(32.5) (–17.3)	(23.6) (–14.7)	(26.5) (–17.8)
Plant height	MP	22.63** – 149.9**	43.1** – 165.4**	–2.27 – 96.3**	8.3 – 119.1**	41.8** – 119.1**
		(9.8) (94.7)	(23.0) (138.2)	(–1.40) (85.6)	(7.9) (136.0)	(23.1) (88.8)
	BP	–13.7 – 106.9**	0.20 – 119.9**	–18.2 – 66.7**	–21.2 – 97.1**	0.17 – 80.38**
		(–5.5) (60.5)	(0.08) (72.6)	(–9.91) (45.6)	(–15.8) (88.7)	(0.08) (48.7)
Stem diameter	MP	–0.13 – 0.41**	–0.14 – 0.52**	–0.35** – 0.14	–0.29** – 0.26**	–0.16** – 0.29**
		(–11.3) (52.6)	(–11.5) (69.8)	(–28.4) (14.0)	(–23.4) (24.1)	(–13.7) (32.8)
	BP	–0.34** – 0.35**	–0.16 – 0.48**	–0.52** – 0.09	–0.49** – 0.25**	–0.29** – 0.24**
		(–26.8) (38.4)	(–13.2) (60.5)	(–36.7) (8.54)	(–33.6) (23.3)	(–22.4) (26.1)
No. of internodes	MP	–3.60** – 3.93**	–3.13** – 2.70**	–1.53** – 3.95**	–3.30** – 1.70**	–2.1** – 2.8**
		(–27.7) (41.1)	(27.3) (25.4)	(–15.1) (47.9)	(–28.1) (20.5)	(–18.0) (30.8)
	BP	–3.93** – 2.27**	–3.86** – 1.93**	–3.07** – 3.60**	–3.87** – 1.33	–3.1** – 2.28**
		(–28.9) (23.6)	(–26.4) (16.9)	(–26.3) (41.9)	(–29.7) (14.1)	(–24.1) (23.4)
Stem weight	MP	–41.8* – 220.4**	50.7 – 271.0**	–21.8 – 172.8**	–14.7 – 132.8**	33.4** – 154.0**
		(–22.3) (155.3)	(31.6) (199.3)	(–20.6) (202.1)	(–12.8) (153.6)	(32.6) (118.6)
	BP	–111.0** – 188.0**	–6.7 – 223.8**	–24.3 – 136.0**	–50.3** – 125.0	0.67 – 146.5**
		(–43.2) (175.2)	(–3.4) (254.8)	(–22.5) (111.2)	(–29.3) (111.9)	(0.42) (162.9)
Leaf : stem ratio	MP	–0.215** – 0.002	–0.30** – –0.09**	–0.22** – 0.05*	–0.24** – 0.11**	–0.20** – –0.06**
		(–53.6) (0.86)	(–62.9) (–28.8)	(–58.8) (21.1)	(60.8) (42.1)	(–50.6) (–19.9)
	BP	–0.328** – –0.058**	–0.45** – –0.16**	–0.31** – 0.04	–0.38** – 0.10**	–0.31** – –0.13**
		(–71.3) (–19.3)	(–74.3) (–36.9)	(–66.8) (17.0)	(–71.4) (33.4)	(–69.8) (–35.6)
Leaf area per plant	MP	–2119.7** – 4177.9	–1059.6* – 3237**	–954** – 3032**	–1627 – 2210	–979** – 2582**
		(–42.7) (152.4)	(–20.2) (104.9)	(–36.3) (194.6)	(–43.5) (86.4)	(–25.4) (110.1)
	BP	–3541.5** – 3379.9**	–1731** – 2285**	–1174** – 2257**	–2189 – 1618	–1458* – 2386.4**
		(–54.9) (140.1)	(–26.5) (76.4)	(–41.2) (133.7)	(–60.5) (51.4)	(–38.4) (93.9)

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

Note. Figures in parentheses indicate heterosis percentage.

between high x high combiners and the heterosis observed in this cross may be due to dominant x dominant gene interaction [12, 13]. The hybrids 2219A x IS 4776, 2219A x IS 3287, and CK 60A x IS 4776 resulted from crosses between high x low combiners and the heterosis in these cases seems to result from dominant x recessive type gene interaction. These results indicate that combining ability can be considered as a reliable criterion for the prediction of yield potential of a cross. This is in agreement with earlier reports [11–14].

A perusal of the data (Table 1) further revealed that the females showed less influence of environment on dry matter yield and plant height but more on other characters, whereas the males were less affected by the environment for green as well as dry fodder yield, plant height, stem weight and leaf : stem ratio, and more for days to flowering, stem diameter, number of internodes and leaf area per plant across the environments. Nonsignificant σ^2 gca x environment interactions for green and dry fodder yield, plant height, stem weight and leaf : stem ratio indicated less influence of environment on gca (additive genetic variance), whereas highly significant σ^2 sca x environment interactions for all characters except for stem diameter indicated that sca (nonadditive genetic variance) was highly influenced by environment. However, the ratio of σ^2 gca x environment/σ^2 sca x environment indicated that the additive genetic variance was less influenced by environment than nonadditive genetic variance for all the characters except for stem diameter where nonadditive genetic variance was less influenced by the environmental flactuations. Greater stability of gca effects in sorghum is already reported [5, 15].

An examination of the nature and extent of heterosis (Table 4) revealed that the hybrids varied in the magnitude of heterosis for various characters in different environments. The magnitude of heterosis, in general, was higher in the crop raised at Anand than at Sardar Krishinagar. The heterosis was highest for green fodder yield and the lowest for leaf : stem ratio in individual environments and also on pooled basis. High heterosis for fodder yield has been reported by several workers [4, 9, 15, 16]. High heterosis for green forage yield resulted into high heterosis for dry matter yield. These findings were in conformity with those of [17, 18]. In fact, the two characters represent the same phenomenon.

A majority of crosses showed highly significant negative heterosis for days to flowering. Heterosis in sorghum expressed by earlier blooming has also been reported earlier [4, 15, 16, 18].

The data (Table 4) suggest very high degree of heterosis for leaf area per plant in individual environments as well as on pooled basis. This means that the hybrids were more leafy, a character positively correlated with protein content [19, 20], digestibility [21], and green and dry fodder yield and stability [22].

On pooled basis, the crosses M-31-2A x IS 3353, 2077A x Vidisha, and 2077A x PC 6 showed very high heterosis for green and dry fodder yield and several yield components.

The preponderance of nonadditive gene action observed in this investigation for green and dry fodder yield, and the realization of high degree of heterosis suggest that exploitation of commercial heterosis would be the best method for utilization of such gene action. But to exploit both types of gene action, additive and nonadditive, lines showing good general combining ability, viz., IS 4776, Vidisha, IS 644, IS 685, Rio and IS 3287 for forage yield, and IS 3301 and IS 606 for earliness and leaf : stem ratio, may be intermated to develop a base population with new recombinants using genetic male sterility which could be improved upon by following an appropriate method of recurrent selection. The elite population, thus could be used as a source material for developing superior hybrid combinations experimental varieties, or may be further recombined for second cycle of selection to develop a still superior population. The crosses M-31-2A x IS 3353, 2077A x PC 6 and 2077A x Vidisha, which showed very high level of heterosis, and high sca effects can be exploited further in future breeding programme to develop high yielding genotypes in forage sorghum.

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