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Combining Ability Effects of Parents in Sweet Sorghum (*Sorghum bicolor*) for Analytical Characters at Different Growth Stages

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Abstract

Five A lines and ten sweet sorghum genotypes were used to develop 50 hybrids and studied sugar recovery and other related characters in summer and *rabi* seasons. Estimates of GCA effects revealed that MS 2077A and 296A had highest GCA for volume of juice per plant, reducing sugar and other desirable characters and among 10 male parents, only one was consistent over the seasons. Among the hybrids developed, five were better for total sugar in summer and five other hybrids were good in *rabi* season. One hybrid was better in both the seasons.

Key words : Combining ability, Sweet sorghum, Analytical characters, Growth stages, Sugar recovery.

Sorghum (*Sorghum bicolor* L.) ranking fourth in area globally, is the staple food in Asia and Africa besides the fodder use. In nature, sorghum occurs in several forms, of which sweet sorghum is one. It is characterized by sweet and juicy stalk with high sugar content, tall plants yielding high quality grain suitable for human consumption and nourishing fodder. The grain yield of sweet sorghum is comparable with that of grain sorghum (1) and useful as fiber for pressed wood papers (2). Sweet sorghum can be considered as sugarcane of temperate zone as it is a short duration crop of 80—140 days (3), suitable for staggered sowing : requires less water and fertilizer and has wider adaptability. The quality of sugar or jaggery prepared from the juice of sweet sorghum is equally good as that of sugarcane (4). This is widely grown for syrup, forage and silage in USA and other countries. It is also useful for energy production, principally ethanol production. Sweet sorghum stalk is sweet and juicy and currently used for alcohol production. Kaposci and Lazanyi (5) produced 1,372 liters of alcohol per hectare from a Hungarian variety ZK-122. Larger genetic variation observed in sweet sorghum for plant height (6) and stalk yield (7). However Bapat and Choudhari (8) reported increase in sugar percent from flowering to harvesting stage. Ayala and Parez (9) extracted the best quality juice at maturity. The stalk yield varied with genotypes : varieties like Keller, MN 1500 and Ramad (41—44 tons/ha) gave higher yield over other varieties (10) ; whereas varieties like Rio, Roma, Rm-57-1 recorded higher brix of 9.33° to 13.00° than other varieties (11). Ferraris and Stewart (3) reported 5.12—13.5% sucrose, 5.12 to 13.5° brix and 1.03 to 4.05% reducing sugar in different cultivars. Choudhari (1) confirmed variability among cultivars for brix, juice yield and green stem yield and opined that juice yield is determined by environmental conditions than by genotypes. Combining ability of parents determines the development of character at growth and maturity stage of hybrids. Higher GCA and SCA influences yield attributing characters like ear head length. Both additive and non-additive gene action played major role in the expression of ear length (12) while Chandrashekarappa (13) opined that additive gene action was predominant. However, dominance (non-additive) type of gene action was noticed by Chinna and Phul (14) and Patel and Desai (15). Several workers observed higher level of heterosis for ear length. Similarly additive gene action greatly influenced ear weight and test weight. Both additive and non-additive significance observed for both the characters (14). For juice recovery, Clark (16) reported significant GCA effects revealing additive gene ac-

Table 1. Estimate of general combining ability affects of parents for seven analytical characters in sweet sorghum. S_1 — Summer, S_2—*Rabi.* * and **—Significant at 5 and 1% respectively.

	Parents	TSS at bootleaf stage		TSS at grain filling stage		TSS at maturity		Volume of juice/pl	
		S_1	S_2	S_1	S_2	S_1	S_2	S_1	S_2
	Female								
1	2077A	– 2.10**	0.08	– 2.66**	– 2.68**	– 3.98**	– 1.18**	48.05**	31.30**
2	296A	– 0.54**	0.15**	– 0.01	0.32**	– 0.47**	– 0.45**	4.17**	11.56**
3	SB 101A	– 0.14	– 0.12*	– 0.22	– 1.29**	0.34**	0.85**	–2.50**	– 12.54**
4	SB 2415A	0.53**	– 0.11**	2.57**	2.03**	3.79**	1.01**	– 19.76**	– 13.85**
5	SB 2413A	2.26**	0.01	0.32**	1.63**	0.33**	0.23**	– 29.96**	– 16.47**
	Males								
1	SSV 53	– 0.62**	0.24**	– 0.34**	0.08	– 0.78**	0.65**	– 3.93**	2.31**
2	SSV 74	0.03	– 0.34**	– 1.54**	– 0.06	– 0.68**	– 0.79**	15.05**	5.36**
3	SSV 84	– 0.05	– 0.12**	0.83**	0.92**	– 0.34	0.84**	0.23	3.03**
4	SSV 96	0.57**	– 0.24**	0.48**	– 0.79**	– 0.62**	1.19**	7.11**	– 3.62**
5	SSV 108	– 0.05	– 0.16**	1.30**	– 0.07	– 0.38**	0.22	– 5.77**	2.81**
6	SSV 2525	0.39**	– 0.30**	0.16	– 1.40**	0.3	– 0.71**	– 6.91**	– 6.56**
7	SSV 12611	– 0.40*	0.06	– 1.99**	– 0.1	– 0.16	– 0.13	11.43**	4.85**
8	SDS 2656	– 0.66**	0.33**	– 0.50**	– 0.07	0.12	– 1.36**	0.34	– 3.12**
9	HES 4	0.47**	0.66**	1.04**	2.32**	1.06**	1.09**	–18.39**	– 1.61**
10	Rio	2.10**	– 0.04	0.58**	– 0.83**	1.48**	1.36**	0.86	– 3.44**
	CD 0.05	0.21	0.08	0.24	0.16	0.24	0.17	1.01	0.99
	SE	0.11	0.04	0.12	0.08	0.12	0.09	0.52	0.51

Table 1. Continued.

	Parents	Reducing sugar		Total sugar		Non-reducing sugar	
		S_1	S_2	S_1	S_2	S_1	S_2
Female							
1	2077A	0.34**	0.19**	1.84**	1.81**	1.52**	1.63**
2	296A	0.16**	– 0.15**	1.43**	1.45**	1.28**	1.63*
3	SB 101A	– 0.10**	– 0.54**	– 0.52**	– 0.88**	– 0.40**	– 0.35**
4	SB 2415A	– 0.07**	0.30**	– 1.17**	– 0.85**	– 1.11**	– 1.20**
5	SB 2413A	– 0.33*	0.19**	– 1.59**	– 1.51**	– 1.29**	– 1.71**
Males							
1	SSV 53	– 0.05	0.11*	0.31**	0.13	0.35**	0.02
2	SSV 74	0.40**	0.21**	1.91**	1.15**	1.51**	0.87**
3	SSV 84	0.23**	0.24**	0.52**	0.69**	0.29**	0.54**
4	SSV 96	– 0.17**	– 0.14**	– 1.42**	– 0.22	– 1.32**	0.02
5	SSV 108	– 0.26**	0.12**	– 1.34**	– 0.66**	– 1.06**	– 0.79**
6	SSV 2525	– 0.11**	– 0.36**	– 0.26**	– 2.54**	– 0.14	– 2.19**
7	SSV 12611	0.14**	0.19**	0.58**	1.30**	0.45**	1.11**
8	SDS 2656	0.09**	– 0.30**	– 0.81**	– 0.65**	– 0.89**	– 0.43**
9	HES 4	– 0.21**	– 0.03**	– 0.01	0.40**	0.21*	0.43**
10	Rio	– 0.07	– 0.05**	0.52**	0.39**	0.59**	0.43**
	CD 0.05	0.04	0.011	0.14	0.2	0.14	0.19
	SE	0.03	0.006	0.07	0.1	0.07	0.097

tion. Cheng et al. (17) observed higher GCA than SCA. Significant influence of SCA for sugar yield

Table 2. Estimate of specific combining ability affects of crosses for seven analytical characters in sweet sorghum. S_1—Summer, S_2—*Rabi*. *—Significant at 5%, **—Significant at 1%.

	Crosses	TSS at boot leaf stage		TSS at grain filling stage		TSS at maturity		Volume of juice/pl.	
		S_1	S_2	S_1	S_2	S_1	S_2	S_1	S_2
1	2077A×SSV 53	0.21	– 0.32**	2.03**	2.34**	–1.64**	1.39**	– 8.01	1.88
2	2077A×SSV 74	1.19**	– 0.61**	0.79*	– 0.85**	– 0.48**	0.90**	–25.90**	–4.24**
3	2077A×SSV 84	– 1.20**	0.54**	–0.24	– 2.02**	0.02	3.27**	–7.97**	2.00
4	2077A×SSV 96	– 0.58	– 0.34**	0.64	– 0.42	1.93**	0.50	69.38**	6.42
5	2077A×SSV 108	– 0.22	– 0.39**	–2.11**	0.10	1.02**	0.16	–11.47**	–5.78**
6	2077A×SSV 2525	– 0.60	– 0.11	–0.90**	0.69**	– 2.45**	–1.32**	1.83	–0.34
7	2077A×SSV 12611	– 0.51	0.42**	0.58	0.19	2.47**	0.08	11.49**	0.27
8	2077A×SDS 2656	1.92**	– 0.44**	–0.68	0.40	1.19**	2.03**	22.75*	5.38**
9	2077A×HES 4	– 0.81*	1.42**	0.15	0.44	–1.51**	– 4.18**	–14.85**	–3.33**
10	2077A×Rio	0.58	– 0.18	–0.26	– 0.88**	– 0.57	1.25**	–37.24**	–2.26
11	296A ×SSV 53	0.91**	– 0.42**	–2.09**	– 2.12**	0.12	0.36	3.24*	–2.51
12	296A ×SSV 74	0.09	– 1.15**	–1.20**	0.92**	– 0.49	2.30**	–14.91**	–3.93*
13	296A ×SSV 84	0.61	– 0.16	1.20**	– 2.66**	– 1.09**	–2.59**	–8.32**	–8.99**
14	296A ×SSV 96	0.83*	– 0.01	–0.74	0.62*	– 0.52	–1.79**	–14.13**	–0.61
15	296A ×SSV 108	–1.72**	0.24	2.04**	2.33**	1.04**	–0.24	18.08**	2.16
16	296A ×SSV 2525	0.84*	– 0.65**	1.44**	–1.98**	2.80**	–3.18**	10.22**	6.10**
17	296A ×SSV 12611	–2.04**	– 0.92**	0.99**	2.66**	– 0.08	3.18**	2.21	1.98
18	296A ×SDS 2656	–1.88**	2.12**	–1.56**	–0.60*	– 2.16**	1.71**	0.47	4.92**
19	296A ×HES 4	1.23**	1.19**	–0.003	–0.02	0.44	0.59*	4.37**	0.38
20	296A ×Rio	1.12**	– 0.25	–0.08	0.86**	– 0.08	–0.31	–1.22	0.48
21	SB101A×SSV 53	– 0.82*	1.04**	–2.45**	–0.32	0.31	–1.21**	4.07*	–0.41
22	SB101A×SSV 74	0.66	0.62**	1.08**	–1.11**	– 0.43	–2.27**	40.08**	3.74*
23	SB 101A×SSV 84	– 0.12	0.00	– 0.75*	0.18	– 0.07	0.34	17.58**	8.01**
24	SB 101A×SSV 96	– 0.04	– 0.28*	– 0.70	1.92**	– 1.09**	–1.26**	–21.14**	–1.21
25	SB 101A×SSV 108	0.62	0.24	– 0.25	0.67*	– 2.67**	2.32**	–8.59**	5.09**
26	SB 101A×SSV 2525	0.21	0.28*	2.45**	0.40	3.33**	0.05	–20.55**	–1.27
27	SB 101A×SSV 12611	0.23	0.21	1.33**	– 2.20**	0.11	–1.46**	–9.46**	–0.05
28	SB 101A×SDS 2656	1.09**	– 0.85**	0.15	2.27**	0.77*	1.50**	–15.20**	–6.71**
29	SB 101A×HES 4	– 0.57	– 1.32**	0.47	–3.58**	0.50	1.18**	–10.47**	–3.52*
30	SB 101A×Rio	–1.28**	0.05	–1.33**	1.76**	– 0.76	0.82**	23.68**	–3.69*
31	SB 2415A×SSV 53	– 0.22	0.01	–0.04	–1.40**	– 1.41**	1.46**	1.00	5.37**
32	SB 2415A×SSV 74	– 2.48**	0.51**	–0.24	–0.59*	0.75	– 0.53	0.35	0.85
33	SB 2415A×SSV 84	0.37	– 0.10	2.22**	1.60**	1.28**	0.47	–0.83	2.15
34	SB 2415A×SSV 96	0.46	0.35**	0.41	–1.39**	– 0.88*	1.14**	–18.87**	–4.03*
35	SB 2415A×SSV 108	0.18	– 0.34**	–1.08**	–1.75**	1.08**	–1.04**	2.67	4.03*
36	SB 2415A×SSV 2525	0.10	0.38**	–0.34	1.31**	– 3.06**	1.52**	–17.02**	–5.86**
37	SB 2415A×SSV 12611	1.22**	– 0.06	–1.32**	0.68*	– 0.87*	–2.62**	8.64**	– 4.46**
38	SB 2415A×SDS 2656	0.15	– 0.36**	0.52	–0.68*	1.88**	– 0.89**	0.73	0.29
39	SB 2415A×HES 4	1.72**	– 0.66**	– 0.15	1.17**	– 0.05	0.45	12.46**	1.72
40	SB 2415A×Rio	–1.52**	0.28*	– 0.29	1.05**	1.26**	0.05	10.87**	–0.08
41	SB 2413A×SSV 53	– 0.09	– 0.29*	2.54**	1.49**	2.62**	–1.99**	–0.30	–4.34**
42	SB 2413A×SSV 74	0.52	0.63**	– 0.43	1.63**	0.65	–0.39	0.38	3.57*
43	SB 2413A×SSV 84	0.34	– 0.29*	– 2.42**	2.89**	– 0.15	–1.48**	–0.46	–3.16
44	SB 2413A×SSV 96	– 0.67	0.27*	0.39	–0.73**	0.55	1.42**	–15.24**	–0.58
45	SB 2413A×SSV 108	1.14**	0.25*	1.40**	–1.35**	– 0.49	–1.19**	–0.69	–5.51**

Table 2. Continued.

	Crosses	TSS at boot leaf stage S_1	TSS at boot leaf stage S_2	TSS at grain filling stage S_1	TSS at grain filling stage S_2	TSS at maturity S_1	TSS at maturity S_2	Volume of juice / pl. S_1	Volume of juice / pl. S_2
46	SB 2413A×SSV 2525	– 0.56	0.09	–2.66**	–0.43	– 0.63	2.93**	25.52**	1.36
47	SB 2413A×SSV 12611	1.09**	0.35**	–1.58**	– 1.33**	–1.64**	0.83**	–12.89**	2.24
48	SB 2413A×SDS 2656	– 1.28**	– 0.47**	1.57**	– 1.39**	– 1.69**	0.28	–8.74**	–3.88**
49	SB 2413A×HES 4	– 1.56**	– 0.64**	–0.77*	1.99**	0.61	1.97**	8.50**	4.74**
50	SB 2413A×Rio	1.08**	0.09	1.96**	–2.79**	0.15	–1.80**	3.91*	5.54**
	CD 5%	0.67	0.25	0.74	0.51	0.76	0.53	3.18	3.11
	CD 1%	0.86	0.33	0.97	0.68	1.00	0.69	4.20	4.11
	SE	0.34	0.13	0.38	0.26	0.39	0.27	1.62	1.59

Table 2. Continued.

	Crosses	Reducing sugar S_1	Reducing sugar S_2	Total sugar S_1	Total sugar S_2	Non-reducing sugar S_1	Non-reducing sugar S_2
1	2077A×SSV 53	– 0.21**	– 0.05**	– 1.74**	2.72**	– 1.51**	2.81**
2	2077A×SSV 74	– 0.89**	– 0.27**	– 1.14**	2.14**	– 3.26**	2.12*
3	2077A×SSV 84	– 0.35**	0.40**	– 1.79**	0.96**	– 1.44**	0.95**
4	2077A×SSV 96	0.43**	0.18**	2.74**	– 0.90**	2.37**	– 1.20**
5	2077A×SSV 108	– 0.40**	– 0.09**	– 2.47**	– 2.54**	– 2.08**	– 2.46**
6	2077A×SSV 2525	0.12	– 0.09**	0.98**	– 1.90**	0.85**	– 1.83**
7	2077A×SSV 12611	0.06	– 0.08**	1.27**	1.65**	1.20**	1.72**
8	2077A×SDS 2656	0.53**	0.16**	3.12**	0.81**	2.59**	0.70*
9	2077A×HES 4	0.85**	– 0.08**	3.64**	– 3.15**	2.77**	– 3.08**
10	2077A×Rio	– 0.15*	– 0.07**	– 1.62**	0.21	– 1.48**	0.26
11	296A × SSV 53	0.20**	– 0.11**	1.37**	– 0.37	1.17**	–0.32
12	296A × SSV 74	– 0.09	– 0.47**	– 1.17**	– 1.45**	– 1.09**	– 0.96**
13	296A × SSV 84	– 0.44**	– 0.42**	– 2.41**	– 2.24**	– 1.97**	– 1.97**
14	296A × SSV 96	– 0.12	0.09**	0.01	2.65**	0.19	2.97**
15	296A × SSV 108	0.46**	0.21**	2.67	3.40**	2.20**	3.15**
16	296A × SSV 2525	0.39**	0.26**	2.98**	– 0.89**	2.59**	– 1.20**
17	296A × SSV 12611	0.02	– 0.04	– 1.78**	– 1.51**	–1.81**	– 1.52**
18	296A × SDS 2656	0.24**	0.25**	– 0.70**	0.55	–0.95**	0.32
19	296A × HES 4	– 0.19**	0.14**	1.00**	0.44	1.18**	0.25
20	296A × Rio	– 0.47**	0.09**	– 1.97**	– 0.58	–1.50**	– 0.71*
21	SB101A×SSV 53	0.01	– 0.08**	0.37	0.67*	0.36	0.74*
22	SB101A×SSV 74	0.25**	0.21**	1.68**	– 3.56**	1.42**	– 3.68**
23	SB101A×SSV 84	0.62**	0.20**	1.59**	4.06**	0.97**	3.77**
24	SB101A×SSV 96	– 0.20**	– 0.07**	– 1.33**	– 0.09	–1.06**	– 0.13
25	SB101A×SSV 108	0.11	0.24**	1.38**	– 0.41	1.21**	– 0.64*
26	SB101A×SSV 2525	– 0.45**	0.09**	– 2.55**	1.19**	– 2.11**	1.10**
27	SB101A×SSV 12611	– 0.51**	0.00	– 2.69**	1.62**	– 2.19**	1.63**
28	SB101A×SDS 2656	0.07	– 0.15**	1.93**	– 1.53**	1.85**	– 1.31**
29	SB101A×HES 4	– 0.14*	– 0.14**	– 1.24**	– 0.88**	– 1.10**	– 0.72*
30	SB101A×Rio	0.24**	– 0.30**	0.90**	– 1.08**	0.65**	– 0.77*
31	SB2415A×SSV 53	– 0.10	0.44**	– 0.73**	– 1.11**	– 0.70**	– 1.52**
32	SB2415A×SSV 74	1.03**	0.27**	3.79**	0.78*	2.77**	0.62*
33	SB2415A×SSV 84	0.30**	– 0.12**	2.70**	– 1.78**	2.42**	–1.71**
34	SB2415A×SSV 96	0.01	– 0.09**	– 1.87**	0.06	–1.93**	0.08
35	SB2415A×SSV 108	– 0.16*	– 0.16**	0.24	– 0.20	0.40	– 0.01
36	SB2415A×SSV 2525	– 0.68**	0.11**	– 5.10**	1.99**	– 4.40**	1.93**
37	SB2415A×SSV 12611	0.21**	– 0.23**	1.70**	– 2.16**	1.50**	– 1.89**

Table 2. Continued.

	Crosses	Reducing sugar S_1	Reducing sugar S_2	Total sugar S_1	Total sugar S_2	Non-reducing sugar S_1	Non-reducing sugar S_2
38	SB2415A×SDS 2656	–0.22**	0.07**	–1.15**	0.83*	– 0.92**	0.53*
39	SB2415A×HES 4	– 0.25**	– 0.15**	– 1.13**	0.78*	– 0.87**	0.97**
40	SB2415A×Rio	– 0.15*	– 0.13**	1.55**	0.82*	1.72**	0.99**
41	SB2413A×SSV 53	0.10	– 0.20**	0.74**	– 1.91**	0.67**	– 1.71**
42	SB2413A×SSV 74	– 0.31**	0.27**	– 0.17	2.09**	0.17	1.90**
43	SB2413A×SSV 84	– 0.13*	– 0.05**	– 0.08	– 1.00**	0.02	– 1.05**
44	SB2413A×SSV 96	– 0.12	– 0.11**	0.45*	– 1.72**	0.43	– 1.71**
45	SB2413A×SSV 108	– 0.02	– 0.19**	– 1.77**	– 0.25	–1.72**	– 0.04**
46	SB2413A×SSV 2525	0.62**	– 0.37**	3.69**	– 0.39	3.07**	0.01
47	SB2413A×SSV 12611	0.22**	0.35**	1.49**	– 0.40	1.30**	0.06
48	SB2413A×SDS 2656	–0.62**	– 0.33**	– 3.20**	– 0.66**	–2.56**	– 0.25
49	SB2413A×HES 4	– 0.27**	0.23**	– 2.27**	2.81**	–1.98**	2.58**
50	SB2413A×Rio	0.53**	0.41**	1.13**	0.63	0.60**	0.23*
	CD 5%	0.12	0.04	0.42	0.64	0.43	0.59
	CD 1%	0.16	0.05	0.56	0.84	0.57	0.78
	SE	0.06	0.02	0.24	0.33	0.22	0.30

was observed by Antonov (18), role of additive gene action for sugar content is reported by Wu et al. (19).

Methods

The study consisted of 65 entries including five male sterile lines (three of A_1 cytoplasm and two of A_2 cytoplasm) and 10 sweet sorghum varieties used as male parents. These were grown in the crossing block and staggered twice and developed 50 hybrids. These 65 entries were sown in three replications in rando-mized complete block design and followed recommended package.

Observations were recorded for growth and yield parameters. For TSS, brix values were recorded with the help of a refractometer (in brix^0), TSS values were determined at boot leaf stage, grain-filling stage and at maturity. Volume of juice was measured and analyzed for reducing, non-reducing and total sugar for parents and hybrids. Reducing and non-reducing sugar were estimated using Nelson-Somogy's method and computed the total sugar. GCA and SCA of different combinations were worked out based on procedure developed by Kempthorne (20).

Results and Discussion

GCA Effect

TSS at Boot Leaf Stage. Significant positive GCA effects were noticed in female parents—SB 2415 A and SB 2413A during summer season, but in 296A during *rabi* season. The two lines differed with negative GCA effect during summer season viz. 2077A and 296A while SB 101A and SB 2415A showed negative GCA effect in *rabi* season. Among male parents, only HES 4 had positive significant effect in both *rabi* and summer seasons (Table 1).

The lines which differed significantly in *rabi* season included SSV 53, SSV 96 and Rio while SSV 53 and SDS 2656 showed negative GCA effect in *rabi* season. Highly significant negative effects in summer were recorded in SSV 53, SSV 12611 and SDS 2656 while in *rabi* season, negative effect were observed in SSV 74, SSV 84, SSV 96, SSV 108 and SSV 2525.

TSS at Grain Filling Stage. Among five female parents, 296A, SB 2415A and SB 2413A had significant positive GCA effects and 2077A and SB 101A had negative effects. Among male parents SSV 84 and HES 4 had positive and significant GCA effect in both the seasons. SSV 96, SSV 108 and Rio had negative GCA effect in *rabi* season while SSV 53, SSV 74, SSV 1264 and SDS 2656 showed negative effect during summer season.

TSS at Maturity. In both *rabi* and summer seasons SB 101A and SB 2415A showed significantly positive for GCA effects while SB 2413A showed it in summer season. On the contrary, female parents 2077A and 296A showed negative effects in both the

Table 3. Estimate of SCA effect of different crosses. xx—positive highly significant ; x—positively significant ; —xx—negative highly significant ; —x—negatively significant.

	Summer						*Rabi*					
Crosses	TSS at boot leaf stage	TSS at grain filling stage	TSS at maturity	Total sugar	Reducing sugar	Non-reducing sugar	TSS at boot leaf stage	TSS at grain filling stage	TSS at maturity	Total sugar	Reducing sugar	Non-reducing sugar
2077A×SSV 53		xx	–xx	–xx	–xx	– xx	–x	xx	xx	xx	–xx	xx
2077A×SSV 74	xx	x	–xx	–xx	– xx	– xx	–xx	– xx	xx	xx	–xx	xx
2077A×SSV 84	– xx			–xx	– xx	– xx	xx	– xx	xx	xx	xx	xx
2077A×SSV 96			xx	xx	xx	xx	–xx			– xx	xx	–xx
2077A×SSV 108		– xx	xx				–xx					
2077A×SSV 2525		– x	– xx	xx		xx		xx	–xx	– xx	–xx	–xx
2077A×SSV 12611			xx	xx		xx	xx			xx	–xx	xx
2077A×SDS 2656	xx		xx	xx	xx	xx	–xx		xx	xx	xx	xx
2077A×HES 4			– xx	xx	xx	xx	xx		–x	– xx	–xx	–xx
2077A×Rio				–xx	– x	– xx			xx		– xx	
296A ×SSV 53	xx	–xx		xx	xx	xx	–x	– xx			– xx	
296A ×SSV 96	x							x	–xx	xx	xx	xx
296A ×SSV 108	– xx	xx	xx		xx	xx		xx		xx	xx	xx
296A ×SSV 2525	x	xx	xx	xx	xx	xx	–xx	–xx	–xx	– xx	xx	–xx
296A ×74		– xx		–xx		– xx	–xx	xx	xx	– xx	–xx	–xx
296A ×84		xx	–xx	–xx	–xx	– xx		– xx	–xx	– xx	– xx	–xx
296A ×SDS 2656	– xx	– xx	– xx	–xx	xx	– xx	xx	– x	xx		xx	
296A ×HES 4	xx			xx	– xx	xx	xx			xx		
296A ×Rio	xx			–xx	– xx	– xx		xx		xx		– x
SB101A×SSV 53	– x	– xx					xx		– xx	x	–xx	x
SB101A×SSV 74		xx		xx	xx	xx	xx	– xx	–xx	– xx	xx	–xx
SB101A×SSV 84		– x		xx	xx	xx				xx	xx	xx
SB101A×SSV 96			– xx	–xx	– xx	– xx	–x	xx	– xx		– xx	
SB101A×SSV 2525		xx	xx	–xx	– xx	– xx	x			xx	xx	xx
SB101A×SSV 12611		xx		–xx	– xx	– xx		– xx	– xx	xx		xx
SB101A×SDS 2656	xx		x	xx		xx	– xx	xx	xx	– xx	– x	– xx
SB101A×HES 4				–xx	– x	– xx	– xx	– xx	xx	– xx	– xx	– x
SB101A×Rio	– xx	– xx		xx	xx	xx		xx	xx	– xx	– xx	– x
SB2415A×SSV 74	– xx			xx	xx	xx	xx	– x		x	xx	x
SB2415A×SSV 84		xx	xx	xx	xx	xx		xx		–xx	–xx	– xx
SB2415A×SSV 96			–x	–xx		– xx	xx	– xx	xx		– xx	
SB2415A×SSV 2525			–xx	–xx	– xx	– xx	xx	xx	xx	xx	xx	xx
SB2415A×SSV 12611	xx	– xx	– x	xx	xx	xx		x	– xx	– xx	– xx	– xx
SB2415A×HES 4	xx			–xx	– xx	– xx	–xx	xx		x	– xx	xx
SB2415A×Rio	– xx		xx	xx	– x	xx	x	xx		x	– xx	xx
SB2413A×SSV 53		xx	xx	xx	xx		– x	xx	– xx	– xx	– xx	– xx
SB2413A×SSV 84		– xx		x	– x		– x	xx	– xx	– xx	– xx	– xx
SB2413A×SSV 96							x	– xx	xx	– xx	– xx	– xx
SB2413A×SSV 108	xx	xx		–xx	– xx		x	– xx	– xx		– xx	– xx
SB2413A×SSV 12611	xx	–	xx	–xx	xx	xx	xx	xx	– xx	xx	–	xx
SB2413A×SDS 2656	– xx	xx	– xx	–xx	– xx	– xx	– xx	– xx		– x	– xx	
SB2413A×HES 4	– xx	– xx		–xx	– xx	– xx	– xx	xx	xx	xx	xx	xx
SB2413A×Rio	xx	xx		xx	xx	xx		– xx	– xx		xx	

seasons. In male parents, HES 4 and Rio showed positive GCA in both the seasons while SSV 74 and SSV 96 showed negative effect in both the seasons. SSV 53 and SSV 84 showed positive effects in *rabi* while SSV 53 and SSV 108 showed negative effects in summer season.

Volume of Juice per Plant. Among female parents, 2077A and 296A indicated highly significant

positive GCA effect whereas the other three exhibited significant negative effects. Among male parents, SSV 74 and SSV 12611 showed positive GCA effects in both the seasons while in summer, SSV 96 showed positive and SSV 53, SSV 84 and SSV 108 showed positive GCA effects during *rabi* season. It showed negative effects in both the seasons for SSV 2525 and HES 4.

Reducing Sugar. NS 2077A showed positive GCA effect in both the seasons while 296A showed it in summer and SB 2415A, SB 2413A in *rabi* season. On the contrary, SB 101A showed negative effects during both the seasons. Among male parents, SSV 74, SSV 84 and SSV 12611 showed positive GCA during both the seasons while SSV 53 and SSV 108 showed positive during *rabi* season. It showed negative in both the seasons for SSV 96, SSV 2525 and HES 4. The others showed negative GCA effects in either of the seasons.

Total Sugar. The results revealed that 2077A and 296A had highly significant positive GCA effect for total sugar while SB 101A, SB 2415A and SB 2413A had significant negative GCA effect for total sugar. Of the 10 male parents, SSV 74, SSV 84, SSV 12611 and Rio indicated positive GCA effect in both the seasons while SSV 53 showed it during summer and HES 4 during the *rabi* season. SSV 108, SSV 2525 and SDS 2656 had negative effects in both the seasons whereas SSV 96 expressed negative GCA effect during the summer season.

Non-Reducing Sugar. A similar trend was observed for total sugar, but among male parents, in addition to SSV 74, SSV 84, SSV 12611 and Rio, HES 4 also showed significant and positive GCA effect in both the seasons.

Specific Combining Ability Effects for Analytical Characters

Total Soluble Salts at Boot Leaf Stage. Twenty-four crosses of the total 50 had significant SCA effects of which 13 were positively significant and 11 crossed showed negative effect. The highest value of SCA effect for TSS (1.72) was observed in cross SB 2415A × HES 4, whereas the lowest (–2.48) was shown by SB 2415A × SSV 74 in summer season (Table 2).

During *rabi* season, cross combination of 296A × SDS 2656 had highest (2.12) among 16 positively significant crosses whereas 296A× SSV 74 had the least SCA effect (–1.15) among 19 crosses.

Total Soluble Solids at Grain Filling Stage. In summer season, 29 crosses had significant SCA effect for this trait. Among 14 positively significant crosses, the cross SB 2413A×SSV 53 had maximum SCA effect (2.54) while the lowest observed in cross SB 2413A×SSV 2525 (–2.66) among 14 negatively significant crosses. During *rabi* season, 20 positively and 20 negatively significant crosses were observed among 40 significantly differing crosses. The cross SB 2413A×SSV 84 had maximum (2.89) and SB 101A× HES 4 had minimum SCA effect.

Total Soluble Solid at Maturity. During the summer season, 24 crosses and 3 crosses showed highly significant and significant SCA effect for this trait, respectively. Of these, 13 crosses had the effects greater than zero and 14 had smaller than zero. The highest value noticed in the cross SB 101A× SSV2525 (3.33) while the least effect (–3.06) was observed in cross SB 2415A× SSV2525. During *rabi* season, cross combination of 2077A×SSV 84 has shown highest SCA effect (3.27) among 19 positively significant crosses whereas among 17 negatively significant crosses, 2077A×HES 84 expressed least SCA effect of –4.18.

Total Sugar. The result during two seasons revealed that 23 cross combinations during summer and 18 crosses during *rabi* season showed positive significant SCA effects. The cross combination of SB 2415A×SSV 74 had the highest (3.79) and SB 2415A× SSV 2525 had least (–5.10) SCA effect during summer while SB101A× SSV 84 had the highest (4.06) ; SB 101A×SSV 74 had the least (–3.56) SCA effect during *rabi* season.

Non-Reducing Sugar. In summer out of 44 crosses, 22 had positive and 22 had negative significant SCA effects. The cross SB 2413A× SSV 2525 had the highest (3.07) SCA effect while SB 2415A× SSV 2525 had the least (–4.40) SCA effect. Similarly during the *rabi* season, out of 38 crosses, 17 had positive and 21 had negative significant SCA effects. SB 101A when crossed with SSV 84 showed the highest (3.77) effect and when crossed with SSV 74 showed the least (–3.68) SCA effect.

Average Performance Over Season

The results revealed that in summer and *rabi* seasons, the average performance was significantly different for some combinations whereas it was similar for some crosses and in the remaining crosses, no significant effects were observed.

Positive SCA Effects in Both Seasons

The following cross-combinations showed significant positive SCA effects for different parameters over the seasons. MS 2077A×SDS 2656 showed highly significant positive effect for total sugars, non-reducing sugar, reducing sugar and TSS at maturity while it was positive for TSS at boot leaf stage in summer and negatively significant in *rabi* season. MS 296A×SSV 108 cross was positive for total sugars, reducing and non-reducing sugar and TSS at grain filling stage whereas cross combination of MS 296A×HES 4 showed highly positive significant SCA effect for total sugar and TSS at boot leaf stage. SB 101A×SSV 84 showed highly significant positive effect for total sugar, reducing sugar and non-reducing sugar.

Cross combination of 2415A×SSV 74 showed highly significantly positive effect for total sugar, reducing sugar and non-reducing sugar, it was positive for TSS at boot leaf stage in *rabi* while it showed negative effect during summer season. Similarly 2077A×SSV 12611 cross revealed highly significant positive effect for total sugar and non-reducing sugar in both the seasons ; positive effect was found for TSS at maturity in summer season while in *rabi* season, it was positive for TSS at boot leaf stage.

Highly positively significant effect was found for SCA for non-reducing sugar in cross 2415 A× Rio ; positive effect for total sugar and TSS at maturing in summer while it showed significantly positive effect for total sugar in *rabi* season.

Positive Effect in Summer and Negative in Rabi Season for SCA

The following cross combinations showed varied response in *rabi* and summer season. In cross combination of 2077A×SSV 53, positive high significant SCA effect was observed for total sugar, reducing sugar, non-reducing sugar, TSS at maturity and TSS in grain filling stage while the cross had negative effect for total sugar, reducing and non-reducing sugar and TSS at maturity in the summer season. In cross MS 2077A×SSV 74, highly significant SCA effect was found in *rabi* season for total sugar, non-reducing sugar and TSS at maturity whereas highly negative significant SCA effect was found for total sugar, reducing sugar, non-reducing sugar, TSS at maturity and TSS at boot leaf stage in the summer season. In cross MS 2077A×SSV 84, the effect was highly significant for reducing sugar, non-reducing sugar, total sugar and TSS at boot leaf stage in *rabi* season while it was negative and highly significant for total, reducing and non-reducing sugar, TSS at boot leaf stage in the summer season. MS 2077A×SSV 96 cross showed highly significant positive SCA effect for total sugar, reducing and non-reducing sugar in summer, while it was negative for total sugar and non-reducing sugar but positive for reducing sugar in the *rabi* season.

In MS 2077A× SSV 2525 cross, positive highly significant effect was observed for total sugar and non-reducing sugar in the summer season while negative effect was observed for TSS at maturity, and it was negative for total sugar, non-reducing sugar and TSS at maturity in the *rabi* season.

MS 2077A × HES 4 showed highly significant and positive for total sugar, reducing sugar and non-reducing sugar in the summer whereas it showed highly negative effect for total sugar, reducing and non-reducing sugar content in the *rabi* season.

In 296A×SSV 2525 cross, highly significant positive effect was observed for total sugar, non-reducing sugar, TSS at boot leaf stage, grain filling state and at maturity in the summer season while showed negative and highly significant for all these characters in the *rabi* season.

SB 101A×SSV 74 cross revealed highly positive significant effect for total sugar, reducing and non-reducing sugar, TSS at grain filling stage in the summer season, while it was negative for total sugar, non-reducing sugar, RSS at grain filling stage and at maturity stage in the *rabi* season.

Similar differential response in summer and *rabi* seasons was also observed for crosses SB 101A×SSV 2525, SB 101A× SDS 2556, SB 101A×Rio, MS 2415A

× SSV 84, MS 2415A× SSV 2525, MS 2413A×SSV 53 and MS 2413A×HES 4 and their reaction is shown in Table 3. In some crosses, negative highly significant effects were observed in both the seasons. The crosses MS 296A×SSV 74 and MS 101A×HES 4, they showed negative effect for total sugar and non-reducing sugar in both the seasons while MS 296A × SSV 84 showed negatively significant effect for total sugar, reducing sugar and non-reducing sugar, TSS at maturity in both the seasons.

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