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Combining Ability Studies for Quality Traits in Sweet Sorghum (*Sorghum bicolor* (L.) Moench)

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Combining ability analysis helps in the evaluation of inbreds in terms of their genetic value and in the selection of suitable parents for hybridization. It also helps in the identification of superior cross combinations. In the present study, the general combining ability of the 12 parents and specific combining ability of 35 crosses were estimated through combining ability analysis for yield, yield components and juice quality characters in sweet sorghum using a line x tester mating design. The estimated components of *gca* and *sca* variances showed preponderance of non-additive gene action for all the characters studied. This showed the possibilities of improvement of these traits through heterosis breeding. Based on *gca* effects the lines BJ 3A, CK 60A and AKMS 22A and the testers RSSV 9, SSV 84 and ASV 9401 were good combiners for most of the characters. These parents can be used in pedigree breeding programme for incorporation of desired traits. The hybrid combinations AKMS 22A x RSSV 9, BJ 3A x VMS 98001, BJ 3A x RSSV 9, AKMS14A x RSSV 9 and CK 60 A x VMS 98001 were recorded as the best specific combiners. These hybrids could be exploited for heterosis breeding programme.

Key words: sweet sorghum, combining ability, non-additive gene action

Sorghum is normally grown for grain as well as fodder in most parts of the country. Sorghum with high stem sugar has emerged as a leading crop for biomass utilization among energy crops due to high yield potential. Fresh weight biomass yields in excess of 60t ha^{-1} and ethanol yields in excess of 5000 litres ha^{-1} are possible from the use of improved cultivars (Monk *et al.,* 1984). Development of sorghum for energy utilization will require more effort but should be rapid; hence knowledge on the genetics of desirable characteristics is essential. Precise information on the genetics of most of the characters related to stem sugar in sorghum is lacking. The present investigation was therefore taken up, to study the nature of gene action governing the inheritance of agronomic and quality attributes and to identify useful parents and hybrids for further exploitation to develop varieties and hybrids for total biomass, grain and ethanol yield.

Materials and Methods

The experimental material consisted of 35 hybrid combinations obtained from crossing five male sterile lines *viz.,* TNAU MS 1A, BJ 3A, AKMS 14A, AKMS 22A and CK 60 A with seven sweet stalk genotypes used as testers *viz.,* ASSV 9401, ASV 9404, ASV 9408, RSSV 9, GSSV 153, VMS 98001 and SSV 84 respectively. The observations recorded were plant height, days to 50 per cent flowering, stem thickness, grain yield, total biomass yield, fresh cane yield, juice yield, juice extractability in percentage, reducing sugars in percentage, non-reducing sugars in percentage, total sugars, brix and ethanol yield. The parental materials were raised in rows of 4m length, with a spacing of 45cm x 15 cm between rows and plants respectively during summer, 2005. Each of the five lines were crossed with each of the seven testers in line x tester fashion to produce thirty-five cross combinations. The hybrids along with their parents were raised in a randomized block design with two replications during *kharif,* 2005. The recommended packages of practices were followed uniformly throughout the crop period. Biometrical observations on six metric traits were recorded on five randomly selected plants and the mean values were subjected to statistical analysis. Observations on seven juice quality attributes were recoded by crushing ten randomly selected canes from the parents and hybrids. Recorded data of each of twelve traits were then subjected to appropriate statistical analysis. The general and specific combining ability of the parents and hybrids were worked out as per the method outlined by Kempthorne (1957).

Results and Discussion

The analysis of variance revealed that the variance due to lines was significant for grain yield. This indicates that the grain yield contributes much for genetic diversity among the lines. The variance

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due to testers was significant for plant height, days to 50 per cent flowering, fresh cane yield, juice yield, reducing sugars, non-reducing sugars, total sugars, brix and ethanol yield. The testers exhibited greater variation for most of the characters than that of the lines. This is indicative of the larger contribution of testers to greater *gca* effects than that of lines for these characters. The variance among the hybrids was highly significant for all the characters, which indicated the presence of considerable amount of heterosis in the hybrids for all the characters. The variance due to lines x testers interaction was highly significant for all the characters. The SCA variance was greater in magnitude than GCA variance for all the characters studied; indicating the predominance on non-additive gene action for all characters (Table 1). This showed the possibilities of improvement of these traits through heterosis breeding.

Table 1. Analysis of variance (mean squares) for different characters in sweet sorghum

source	d.f	Plant Height	Days to 50% flowering	Stem thick ness	Grain yield	Total biomass yield	Fresh cane yield	Juice yield	Juice extract ability %	Reducing sugars	Non reducing sugars	Total sugars	Brix	Ethanol yield
Hybrids	34	3251.9**	52.68**	0.10**	81.28**	29889.12**	9495.3565**	1951.94**	212.02**	3.1986**	9.8034**	15.66**	16.733**	6.854**
Lines	4	1465.5	34.48	0.245	336.47*	6509.9	11864.726	2756.88	130.63	2.68	13.43	14.82	13.35	8.1646
Testers	6	2348**	165.56**	0.023	42.870	55182.46	26101.7155**	5095.28*	104.09	6.212*	17.81**	37.43**	39.54*	15.2819*
Lines x testers	24	1275.7**	27.50**	0.101*	48.34**	27462.32**	4948.87**	1031.96**	252.57**	2.531**	7.198**	10.36**	11.59**	4.5286**
Error	34	11.793	5.63	0.04	3.96	39.20	78.32	63.21	18.93	0.5666	0.7598	0.767	1.141	0.0351
ó²gca/ ó²sca	0.092	0.068	0.003	0.0435	0.005	0.055	0.056	0.020	0.024	0.032	0.028	0.024	0.030	

** significant at 1 per cent level
* significant at 5 per cent level

The success of any crop breeding proramme depends on the choice of parents based on the *per se* performance (Anita and Stephen Dorairaj, 1990). The selected genotypes can be used either for the exploitation of heterosis or for recombination breeding. Parents with significant *per se* performance are expected to yield desirable recombination in the segregating generations. In the present study, for plant height, the *gca* estimate showed that the line BJ 3A and the testers SSV 84 and RSSV 9 had significant positive *gca* effects and these can be utilized in pedigree breeding programme for increased plant height. Out of the thirty five hybrids BJ 3A x GSSV 153, TNAU MS 1A x VMS 98001 and CK 60A x SSV 84 recoded highly significant and positive *sca* effects. The cross CK 60A x SSV 84 obtained from poor x good general combiners, showed high *per se* performance and this hybrid may be considered to be the best for this trait. The present study is in accordance with findings of earlier workers Umakanth *et al.* (2002) and Kukadia *et al.* (1983).

The early and medium duration groups are the most productive group of materials in sorghum, as they may tend to escape drought incidence and earhead pests and diseases. In the present study significant negative effects of *gca* for days to 50 per cent flowering in the line CK 60A and the tester ASV 9401, indicated them as good general combining parents for this trait as they are transmitting genes for earliness (Table 2). The hybrid BJ 3A x ASV 9401 recorded the lowest *per se* performance, and lower *sca* effect though involving one good combiner (ASV 9401). The present study is in accordance with the findings of Veeabadhiran *et al.* (1994) and Shah and Joshi (1996) who observed additive gene action in their studies.

Table 2. Estimates of general combining ability (*gca*) effects for yield, yield components and juice quality characters in sweet sorghum

source of variation	Plant Height	Stem thick ness	Days to 50% flowering	Grain yield	Total biomass yield	Fresh cane yield	Juice yield	Juice extract ability %	Reducing sugars	Non reducing sugars	Total sugars	Brix	Ethanol yield
TNAUMS1A	-3.61**	0.14*	1.39*	7.48*	3.27ns	36.66**	10.66**	-0.72	0.20	0.27	0.47*	1.17**	0.25**
BJ 3A	13.91**	0.12*	1.96**	-233**	25.36**	23.07**	17.23**	4.96**	0.51*	0.71**	1.22**	0.90**	0.58**
AKMS 14A	5.07**	-0.17**	-0.61	1.96**	-14.00**	-22.48**	-11.03**	-2.84*	0.09	-1.67**	-1.58**	-0.87**	-1.34**
AKMS 22A	-1.84	-0.07	-1.33*	-1.86**	13.96**	-6.08*	-0.89	-1.96	-0.14	0.01	-0.13	-0.31	0.29**
CK 60A	-13.54**	-0.03	-1.40*	-5.24**	-28.53**	-31.17**	-15.97**	0.56	-0.66**	0.68**	0.02	-0.89**	0.23**
ASV 9401	-5.57**	0.00	-4.04**	2.55**	30.98**	3.05	-7.26**	-5.58**	-0.62*	-0.70*	-1.33**	-1.37**	-0.86**
ASV 9404	-10.50**	-0.05	-1.24	-0.50	-71.11**	-40.06**	-8.93**	3.11*	-1.17**	-0.89**	-2.07**	-2.35**	-1.09**
ASV 9408	-22.24**	-0.05	-1.34	1.77**	-42.54**	-20.27**	-13.47**	-3.01*	-0.31	-0.83**	-1.14**	-1.46**	-0.83**
RSSV 9	49.05**	0.07	-2.54**	-2.25**	141.07**	104.75**	49.44**	1.98	0.79**	2.28**	3.07**	2.92**	2.04**
GSSV 153	-27.82**	-0.04	-1.74*	-0.23ns	-50.77**	-43.06**	-16.99**	0.08	0.72**	-1.11**	-0.39	0.02	-0.43**
VMS 98001	-32.97**	0.05	3.16**	1.54*	-41.79**	-22.20**	-3.10	2.89*	-0.23	-0.23	-0.45	-0.13	-0.28**
SSV 84	50.06**	0.01	7.76**	-2.89**	34.00**	17.79**	0.31	0.52	0.82**	1.49**	2.32**	2.37**	1.45**

** significant at 1 per cent level
* significant at 5 per cent level

Stem thickness is an important trait since better extraction of juice is obtained from the thick and juicy stems. Among the lines TNAU MS 1A and BJ 3A had significant *gca* effects and moderate *per se* performance. In sweet sorghum cultivars grain yield is as much important as that of the juice quality traits as the cereal crop is going to sustain the food and fuel requirements. The present study indicated that *sca* variance was higher than *gca* variance for grain yield. The TNAU MS 1A, AKMS 14A among the lines and ASV 9401, ASV 9408 among the testers possessed high *gca* effects. The hybrid between the two good general combiners TNAU MS 1A x ASV 9408 showed high *per se* performance and moderate *sca* effects. Hence, these parents could be utilized in exploiting hybrid vigour in F_1. The hybrid TNAU MS 1A x ASV 9408 indicated that all the three criteria for selection can be satisfied in one hybrid. The presence of considerable non-additive gene action for grain yield in the present study suggested that once high yielding improved lines are isolated, further yield improvement could be achieved by a hybrid programme and subsequent improvement through transferring favourable genes by reciprocal recurrent selection as suggested by Doggett and Eberhart (1968). With regard to total biomass yield, the *gca* effects were significant for the lines BJ 3A and AKMS 22A and the testers RSSV 9 and SSV 84. The hybrid AKMS 22A x RSSV 9 obtained from good x good combiner showed significant positive *sca* effects for this trait. This indicates that testing of parental lines for *gca* can be supplemented by thorough evaluation of individual hybrid combinations for *sca* as suggested by Kirby and Atkins (1968).

Table 3. Estimates of specific combining ability effects based on mean performance of best crosses in sweet sorghum

Characters	Hybrids with high sca effects and per se performance	mean	sca effect	gca status of parents	
Plant height (cm)	CK 60 A x SSV 84	273.20	29.71**	Low	High
Days to 50% flowering	TNAU MS1A x SSV 84	60.50	- 8.69**	High	High
Stem thickness(cm)	CK 60 A x VMS 98001	2.15	0.37*	Low	Low
	BJ 3 A x ASV 9408	2.18	0.34*	High	Low
	BJ 3 A x ASV 9404	2.17	0.33*	High	Low
Grain yield(g)	TNAU MA IA x SSV 84	26.41	7.66*	High	Low
	TNAU MA IA x ASV 9408	29.60	6.19**	High	High
Total biomass yield(g)	AKMS 22A x SSV 84	647.90	206.94**	High	High
	AKMS 22A x RSSV 9	681.50	133.47**	High	High
Fresh cane yield(g)	AKMS 22A x SSV 84	260.95	107.55**	Low	High
	BJ 3 A x RSSV 9	356.30	86.79**	High	High
Juice yield(g)	BJ 3 A x RSSV 9	140.75	25.97**	High	High
Juice extractability					
Percentage (%)	CK 60 A x VMS 98001	62.57	16.58**	Low	High
	BJ 3 A x SSV 84	59.68	11.65**	High	High
Reducing sugars (%)	BJ 3 A x ASV 9401	6.10	1.44**	High	Low
Non- reducing sugars (%)	AKMS 22A x RSSV 9	9.95	2.39**	Low	High
	CK 60 A x SSV 84	9.74	2.29**	High	High
Total sugars (%)	CK 60 A x SSV 84	15.14	2.76**	Low	High
Brix (%)	BJ 3A x VMS 98001	15.65	3.46**	High	Low
	AKMS 14A x SSV 84	15.69	2.78**	Low	High
Ethanol yield (g)	CK 60 A x SSV 84	8.87	2.38**	High	High

** significant at 1 per cent level
* significant at 5 per cent level

In the present study, the main objective is to obtain in a single genotype of high grain yield for consumption and greater output of stalk juice that can be utilized for extraction of sugars and for synthesis of ethanol. The lines TNAU MS 1A and BJ 3A and the tester RSSV 9 were good general combiners as they have contributed the maximum number of favourable genes for these traits. However, among the hybrids involving these parents, BJ 3A x RSSV 9 alone showed high *sca* effects. The parents AKMS 22A and ASV 9401 though showed high *per se* performance, the hybrid obtained from these two parents had negative *sca* effects and these parents could be used in hybridization programme and selection could be postponed to later generation.

The quantum of juice yield is important, since it directly reflects on the yield of sugar and ethanol. The *gca* estimate of the lines BJ 3A and TNAU MS 1A and the tester RSSV 9 showed that they were good general combiners. The hybrid BJ 3A x RSSV 9 obtained from these good general combiners exhibited high *sca* effects and high *per se* performance. The juice extractability percentage is the important character for which the good general combiners were BJ 3A and ASV 9404 among the lines and testers respectively. The hybrid BJ 3A x ASV 9404 exhibited low *sca* effect for this trait, though both the parents of the crosses were good general combiners. The *per se* performance was found to be high in TNAU MS IA and CK 60A among the lines and VMS 98001 and RSSV 9 among the testers. Analysis of components of variance indicated that variance due to specific combining ability was predominant for this trait and so there was preponderance of non-additive gene action.

For reducing sugars, the *gca* estimate showed that BJ 3A among the lines and SSV 84 among the testers has significant *gca* effect. Among the hybrids BJ 3A x ASV 9401 showed highly significant positive *sca* effect and *per se* performance. The character for non-reducing sugars, the *gca* estimate showed that the lines BJ 3A and CK 60A and the testers RSSV 9 and SSV 84 were significant for *gca* effects. The hybrid combination CK 60A x SSV 84 showed better *sca* effect and *per se* performance. For total sugars, brix and ethanol yield RSSV 9, SSV 84, BJ 3A and CK 60A as the good combiners (Table 3).

In the present study among the lines BJ 3A, CK 60A and TNAU MS 1A and among the testers RSSV 9, SSV 84 and ASV 9401 were good general combiners for most of the characters. The line TNAU MS 1A and BJ 3A showed significant *gca* effects for most of the juice quality characters *viz.,* juice yield, total sugars, brix and ethanol yield while the *per se* performance of CK 60A was significant for all the grain yield and juice quality characters. Among the testers RSSV 9 and SSV 84 were the good general combiners for the characters *viz., plant* height, total biomass yield, fresh cane yield, non-reducing sugars, total sugars, brix and ethanol yield while ASV 9401 was found to be good in *per se* performance for all the juice quality characters. These genotypes could be utilized in the breeding programme to develop sweet sorghum varieties for ethanol production.

The hybrid combinations AKMS 22A x RSSV 9 and BJ 3A x VMS 98001 showed significant *per se* performance and *sca* effects for most of the sweet sorghum characters studied. Hybrids BJ 3A x RSSV 9 and AKMS 14A x RSSV 9 besides showing significant *per se* performance and *sca* effects for plant height, fresh cane yield, juice yield and ethanol yield also showed significant *per se* performance for days to 50 per cent flowering, stem thickness, total biomass yield, non-reducing sugars, total sugars and brix percentage. The hybrid combination CK 60 A x VMS 98001 recorded the high *sca* effect with high *per se* performance for stem thickness and extractable juice yield. These hybrid combinations could be exploited in heterosis breeding. Another hybrid TNAU MS 1A x ASV 9408 showed significant *sca* effect for plant height, grain yield, total biomass yield, fresh cane yield, reducing sugars, total sugars, brix and ethanol yield can also be exploited to develop high yielding sweet sorghum hybrids.

However, a number of parental lines possessed high *gca* effects for one or more traits, which may be difficult to bring together all the desirable genes into a single genotype, due to non-additive gene action. Hence, *inter se* crossing of desirable F_1s in all possible combinations may be undertaken and selection should be postponed to later generations for extracting superior lines.

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