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Research Article

Combining ability and heterosis on millable stalk and sugar concentration for bioethanol production across environments in sweet sorghum (*Sorghum bicolor* (L.) Moench.)

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Abstract
Combining ability studies involving five females, six males and 30 hybrids respectively at three semi-arid locations by following a line x tester mating design. Five top ranking hybrids selected for the present investigation revealed the presence of significant differences due to liens, testers and lines x testers x environment effects for all traits suggesting the environmental influence on tester and the interactions. The estimates of variance components exhibited presence of additive gene action for total soluble solids and non-additive for fresh stalk yield, juice yield, bio ethanol yield and grain yield. Among female NSS 1016 A was highly efficient and productive line for all characters, best general combiner for these traits. Female NSS 8 A for grain yield and PMS 71 A for fresh stalk yield, total soluble solids and grain yield indicate that the best general combiner for these traits. Tester SSV-74 was potential male parent with high significant GCA effect for all traits and RSSV-138-1 was best general combiner for fresh stalk yield, juice yield and bio ethanol yield. The top ranking five hybrids viz., NSS 1016 A x RSSV-138-1 for fresh stalk yield and total soluble solids, Juice yield and bio ethanol yield, NSS 8 A x RSSV-138-1 for juice yield, Ethanol yield and fresh stalk yield. PMS-71 x RSSV-138-1 for total soluble solids, NSS 1016 A x UK-81 for bio ethanol yield and total soluble solids, NSS 1016 A x SSV-74 for grain yield after testing across many locations, these hybrids recommended for commercial exploitation for bio-ethanol production of the semi-arid target environments in India.

Key words:
Sweet sorghum, combining ability, Heterosis, Millable stalk, Bio ethanol.

Introduction

In recent years, a new round of enthusiasm in biomass (millable stalk) and bio-energy has been initiated with the recognition that the global crude oil reserve is finite and its depletion is occurring much more seriously than previously predicted. In addition, the environmental deterioration resulting from the over consumption of petroleum-derived products, especially the transportation fuels, is threatening the sustainability of human society. Ethanol is an alternative fuel energy resources, has been a subject of great interest since the oil crisis of the 1970s. Therefore, a strong need exists for efficient ethanol production with low cost in row material and the production process. As for material, one of the prime sources being investigated for ethanol is sweet sorghum. Sweet sorghum [*Sorghum bicolor* (L.) Meonch] is a high yielding sugar crop that has many characteristics, such as wide adoptability and tolerance to abiotic stresses, such as drought, water lodging, salinity and alkalinity. Meanwhile, sweet sorghum stalk contain quite a few quantities of soluble (glucose, fructose and sucrose) and insoluble (cellulose and hemicelluloses) carbohydrate. Besides, the stalk of sweet sorghum can be synthetically used as raw materials for ethanol and some by-product with high addition values, such as forage, paper making and laminate floor, which can cut the cost of ethanol production from sweet sorghum. Therefore, many crops currently being investigated for energy and industries, sweet sorghum is one of the most promising energy crop, particularly for ethanol production. (Feishen and Ronghon Liu, 2009).

Hybrid vigour and its commercial exploitation have paid rich dividends in *kharif* sorghum leading to quantum jump in sorghum production. However, the progress in sweet sorghum is limited and there is a need for critical studies on combining ability and heterosis involving diverse sources of genotypes. The exploitation of heterosis by developing the hybrids is one of the quickest and simpler to improve productivity for grain as well as stem biomass (millable stalk) yield with special reference to combining ability

The information on the nature and magnitude of gene action is important in understanding the genetic potential of a population and decide the breeding procedure to be adopted in a given population

(Prabhakar *et al.*, 2013). Line x Tester analysis is a precise method for obtaining such information when a large number of parents are to be tested. Till date only one sweet sorghum hybrid CSH 22 SS has been released (in the year 2005) for general cultivation in India and current yield level of new hybrids are unable to surpass this hybrid. This necessitates the identification of new hybrids and parents with good combining ability for different trait of interest. Keeping these things in view, the present study involved a line x tester analysis in sweet sorghum to develop suitable new sweet sorghum hybrids and its parents.

Material and Methods

Five maintainer lines of sweet sorghum viz., PMS 71 A, ICSA 675 A, NSS 23 A, NSS 8 A and NSS 1016 A were crossed with 6 testers viz., SSV 74, SSV 84, CSV 19 SS, RSSV 138-1, RS 647 and UK 81. The parents were crossed in a line x tester mating design during *Rabi* 2011-12. All the 30 crosses along with parents and check CSH 22 SS were grown in *kharif* 2012 in a randomized block design with three replications over three locations in three different state of India with semi-arid environment *viz.*, at Field Experimentation Centre of Department of Genetics and Plant Breeding, SHIATS, Allahabad, (U.P.). Centre on Rabi Sorghum (DSR), Solapur, (M.S.) and Directorate of Sorghum Research Rajendranagar, Hyderabad, (A.P.). Each plot consisted of 2 rows of 3 meter length with a spacing of 60 x 15 cm. Observations were recorded for all 5 quantitative characters viz., fresh stalk (millable) yield (t ha^{-1}), juice yield (lt ha^{-1}), total sugar solids (%), bio-ethanol yield (lt ha^{-1}) and grain yield (kg ha^{-1}) on 5 randomly selected plants from each plot, male fertile line (B) used for grain yield data purpose instead of corresponding female line. Statistical analysis of variance for combining ability was carried out using mean value across environments by Kempthorne (1957). The F_1 hybrids performance was calculated as the estimate of heterosis over better parents (heterobeltiosis) and the test of significance was done.

Results and Discussion

Combined analysis of variance for combining ability was carried out using mean value across environment Kempthorne (1957) to test the significance of differences among the genotypes including crosses and parents Snedecor and Cocharan (1967), Panse and Sukhatme (1964). The combined analysis of variance for five characters measured over three environments in present investigation revealed the significant differences among replication, environments, lines, testers, crosses, environments x testers and environment x lines x tester effects were observed for all the characters studie. The testers contributed a major share of variance with highly positive significant for all the characters. Testers were more variable than lines in a line x tester study across locations and years in forage sorghum (Mohammed and Mohamed 2009), Indhubala *et al.* (2010) and Umakanth *et al*. (2012) in sweet sorghum similar to the present investigation.

The importance of the source of variation is indicated by the relative magnitude of variance component. The variance component estimates of *sca* were greater than that of *gca* for fresh stalk yield, juice yield, bioethanol yield and grain yield (Table 1) indicating the non-additive control of genetic variation in these traits. On the contrary, the *gca* variance was higher than the *sca* variance for total soluble solids indicating the presence of additive gene action. This implies that improvement for these traits can be achieved through both selection and hybridization.

The interaction effect of *sca* variance with that of environment was significant for all of the characters studied. The predominant role of non-additive gene action for plant height, stem girth, total soluble solids, millable sweet stalk yield and juice yield was observed in a study on heterosis and combining ability for juice yield and related characteristics in sweet sorghum Shankarpandian *et al*. (1994) indicating the importance of heterosis breeding for improving these traits.

Estimate of *gca* effects and *per se* performance for different traits, *viz*., fresh stalk yield, juice yield, total sugar solids, bioethonal yield and grain yield for the eleven parents used in this study are presented in Table 2. The identification of new hybrids and parents with good combining ability for different traits of interest was one of the important objective of the present study.

Female NSS 1016 A was the most promising productive and excelled general combiner for all traits with higher positive significant GCA effects. The female NSS 8 A was the good general combiner for grain yield with positive and significant *gca*, while female NSS 23 A were exhibited negative significant for all the traits. Female PMS 71 A were shown positive significant for grain yield, fresh stalk yield and total soluble solids indicate that the best general combiner for these straits and negative significant for juice yield and bio ethanol yield. Female ICS 675 A showed significant with negative direction for grain yield and negative insignificant for fresh stalk yield and total sugar solids with positive insignificant for juice yield and bio-ethanol yield indicate that the line was poor combiner for these traits.

Among the male parents the tester SSV 74 was the excelled positive significant *gca* indicate that the best general combiner for all traits followed by tester RSSV 138-1 for fresh stalk yield, juice yield and bio-ethanol yield indicate that the genotype was best general combiner for most of the important traits related to biofuel production. The tester RS 647 showed highly significant with negative direction for all traits. The tester UK 81 and SSV 84 recorded positive significant *gca* for total sugar solids. Tester CSV 19 SS showed positive with insignificant *gca* for juice yield total sugar solids and bio-ethanol yield with high significant *gca* for grain yield. Among the male parent SSV 74 and CSV 19 SS exhibited high *gca* value recorded for grain yield character. However, the grain yield is a secondary source of sweet sorghum and priority for biofuel production Reddy *et al.* (2004), Umkanath *et al.* (2012). Among female parent NSS 1016 A which was the most promising and elite line for all traits and PMS 71 was efficient and productive for fresh stalk yield and grain yield and NSS 8 A was most promising line for grain yield. Tester SSV 74 and RSSV 138-1 was the best combiner for fresh stalk yield and ethanol yield, while, RSSV 138-1was poor combiner for total sugar solids. UK 81 and SSV 84 were the best general combiners for total sugar solids. The *gca* effect of parents indicate that the parent showing high mean performance sowed high general combining ability for fresh stalk yield, juice yield, bioethanol yield and grain yield, similar trend was reported by Umakanth *et al.* (2012). Thus, suggests that in addition to *gca* effect, *per se* performance could also be considered as a criterion to select the parents in future breeding programme Prabhakar *et al*. (2013).

The mean performance, heterosis and specific combining ability effect of top ranking five hybrids, with GCA effects of their parents for different biometrical characters, studied presented in Tables 3-7. Mid parent heterosis and better parent heterosis for important in sugar related traits, *e.g.* Fresh stalk yield juice yield, total sugar solids (%) and bio-ethanol yield were studied, similar findings earlier suggested by Umakanth *et al.* (2012).

Heterosis breeding could be exploited for increasing the fresh stalk yield juice yield, bioethanol yield and grain yield owing to the importance of non-additive gene action in determining this character, the other important trait, i.e. total sugar solids ranged from 16–17(%) in the hybrids and was controlled by additive gene action and further gains for this trait can be achieved through selection, similar findings were conformity with Tsuchihashi and Goto (2004) and Woods (2000).

The hybrids NSS 1016 A and RSSV-138-1, which was the top fresh yielder showed highly significant positive *sca* effect and heterosis were trait in per *se* performance. It also excelled in total soluble solids and juice yield. The hybrids ICSA 675 x SSV 74 and NSS 23 A x SSV-74 recorded positive significant heterosis and *sca* effect with high *per se* performance along with the one parent had negative significant and other had positive significant *gca* effect. Hybrid ICSA 675 x RSS-138-1 cross which showed positive significant heterosis with low negative insignificant *sca* effect, one parent had negative insignificant and other had positive significant with higher *per se* performance.

The hybrids NSS 8 A x RSSV-138-1 and NSS 1016 A x RSSV-138-1, which were top juice yielders, exhibited positive insignificant heterosis and positive significant heterobeltiosis of mid parent with highest value of *sca* effect and both parents had positive *gca* effect were trend in *per se* performance, hybrids ICSA 675 x SSV 74 and ICSA 675 x CSV 19 SS which were exhibited positive significant heterosis with SCA effect and both parents had positive significant and positive insignificant *gcs* effect. However, NSS 1016 A x RSSV-138-1, which was the top fresh stalk yield and juice yield was similar to total soluble solids and bio-ethanol yield with both parents had positive significant and another had positive insignificant *gca* effects, hybrid NSS 1016 A x SSV 74 was demarcated considerable negative insignificant *sca* effects with high positive significant *gca* effect of both parents

A perusal of Table-5, the hybrid PMS 71 x RSSV-138-1 which showed high significant and positive heterosis, one parent had positive significant and other had negative insignificant *gca* effect with highest *sca* effect and *per se* performance were recorded for total soluble solids. Similar to NSS 1016 A x RSSV-138-1, ICSV 675 x SSV 84 were showed positive heterosis with positive insignificant SCA effects one parent had negative and other with positive *gca* effect. While, hybrid PMS 71 A x UK-81 were exhibit positive insignificant heterosis and *sca* effects with both parents had positive significant *gca* effect, hybrid PMS 71 A x SSV 84 showed positive heterosis and negative insignificant *sca* effects with both parents had positive *gca* effects.

The hybrid 1016 A x UK 81 which was recorded highest positive significant heterosis and SCA effect with both the parents had positive significant *gca* effect along with higher *per se* performance and it also excelled to total soluble solids, similar to NSS 1016 A x RSSV-138-1 and ICSA 675 x SSV 74 were exhibited positive significant heterosis and *sca* effect with both parents had positive significant and another had positive insignificant *gca* effect. Hybrid NSS 1016 A x SSV 74 were showed positive significant heterosis and negative insignificant *sca* effect with both parents had positive *gca* effect.

A perusal of Table7, the hybrid NSS 1016 A x SSV-74 which was the top grain yielder demonstrated higher *per se* performance along with positive significant heterosis and *sca* effect, both the parents had highly significant *gca* effects and it also good in bio-ethanol yield and juice yield, similar to hybrids NSS 8 A x UK-81, NSS 23 A x SSV 74 and PMS 71 A x UK-81 were exhibited positive significant heterosis with highest *sca* effects, one parent had negative and other had positive *gca* effect. It was noticed that the hybrid NSS 8 A x CSV 19 SS were performance higher positive significant heterosis with low negative insignificant *sca* effect. While both parents had higher positive significant *gca* effect. It was notice that the crosses were involved in different trait in present study, which showed the positive significant *sca* effects had one parent with negative and other parent with positive *gca* effect. However, both the parent had positive *gca* effect for the different traits crosses under such situation if additive genetic system is present in good combiner and complementary one in another acting in the same direction to maximize the expression of desirable attributes, then such crosses are expected to throw transgressive segregation in future generation. The finding suggested that it is very important to consider the heterosis, *gca* effect of the parents involved *per se* performance of the crosses while selecting the best cross combination. Thus, the combination of poor x high or high x poor combiners could result in to the hybrids with high performance depending on the *per se* performance of the parents concerned, the present findings conformity with earlier reported by Prabhakar *et al*. (2013).

It is evident that most of the hybrids promising for various traits were observed to be constituted from hybrids with both or one parents exhibiting significant *gca* effect and produced hybrids with higher *sca* effect, the significance of both *gca* and *sca* effects suggesting both additive and non-additive gene effect Itai Makanda *et al.* (2009), similar to the present findings, earlier suggested by Umakanth *et al.* (2012), parental selection for crop improvement programme cannot be based on *sca* effects alone, but in association with hybrids means and *gca* effects of the parents involved, suggested by Marilia *et al.* (2001). It is prudent to consider only those hybrids between parents with positive and significant *gca* effects because genetic gain is realized in the presence of sufficient additive variance. The interaction effect of *sca* variance with that of environment was significant for all the characters. This implies that the environment significantly influenced expression of non-additive gene effect. The observation of significant environment influence on *sca* effects is consistent with reports that genotypes x environment interaction is important in sorghum Panse and Sukhatme (1964); Chapman *et al*. (2000); Yu and Tuinstra (2001). Therefore, it is necessary to conduct with location testing for *gca* and *sca* to select the best parents and potential hybrids Itai *et al.* (2010).

It was observed that on a pooled basis and the *per se* performance of different traits parent and hybrids. The parents *viz*., NSS 1016 A among female group for fresh stalk yield, juice yield, bioethanol yield, total soluble solids and grain yield were identified as promising and productive lines which were shown positive and significant heterosis and *sca* effect with both the parents had a positive and significant *gca* effect. Female NSS 8 A for grain yield were showing positive significant of *gca*, female PMS 71 A for fresh stalk yield, total soluble solids and grain yield showing positive significant *gca* effect of the parents among male parents RSSV-138-1 which was promising and potential parent for fresh stalk yield, juice yield and bioethanol yield shown highly positive significant heterosis and *sca* effect with both had positive *gca* effect of the parents, followed by tester SSV-74 for fresh stalk yield, juice yield, total soluble solids, bio-ethanol yield and grain yield with positive significant *gca* effect. Tester SSV-84 and UK-81 were best general combiners for total soluble solids and tester CSV 19 SS was best general combiner for grain yield. All these parents can be used in sweet sorghum cultivar development programme to address bioethanol production from juice without compromising on grain yield and offer solution to the ongoing food vs fuel debate. The study also demonstrated the significance of both additive and non-additive type of gene actions for important traits.

It is observed that female line NSS 1016 A for all traits, PMS 71 A for fresh stalk yield, total soluble solids and grain yield and NSS 8 A for grain yield. Tester SSV 74 were excelled general combiners for all traits and RSSV 138-1 for fresh stalk yield, juice yield and bio-ethanol yield were involved in the crosses having positive *sca* and *gca* effects with high heterosis performance. These crosses can be directly used in the breeding programme for improvement of bioethanol related traits.

Most of the hybrids, which recordd significantly positive heterosis also recorded higher positive and significant *sca* effects with both of the parents had significant positive *gca* effect. Further the study identified the hybrids NSS 1016 A x rSSV-138-1, NSS 8 A x RSSV-138-1, PMS-71 x RSS-138-1, NSS 1016 A x UK-81 and NSS 1016 A x SSV-74 with significantly higher *sca* effects for sweet sorghum productivity traits. These hybrids would be recommended for further testing across many locations in the semi-arid target production environment for fuel production, food for human consumption and fodder for animal alternately welfare for the dry land farmers. Investigation is completely agreement with Umakanth *et al*. (2012).

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Table 1. Pooled Analysis of variance for combing ability in line x testers for characters in sweet sorghum over tree locations

Source of variation	d.f.	Fresh stalk yield (t ha^{-1})	Juice yield (lt ha^{-1})	Total soluble solids (%)	Bio-ethanol yield (lt ha^{-1})	Grain yield (kg ha^{-1})
Replication	2	63.21***	36927410.00***	17.91***	710374.80***	242645.20*
Environment	2	327.33***	102789100.00***	28.72***	1165064.00***	1412893.00***
Crosses	29	779.01***	190346000.00***	5.40***	1420.313.00***	13382470.00***
Lines (parents)	4	88.87***	8784575.00***	13.80***	93651.31***	9666553.20***
Testers (parents)	5	670.11***	444702800.00***	23.02***	2596357.00***	4406546.00***
Lines x testers effects	20	436.52***	126848800.00***	3.57***	962637.90***	8670448.00***
Env. x line x testers	40	197.83***	15819120.00***	2.77***	109201.00***	130352.10***
Estimation of variance components						
Line x env. (parent)	8	22.49***	1995695.00	5.71***	9271.12	379328.70***
Tester x env. (parent)	10	111.35***	4721551.00	0.92	30097.39	127675.50*
σ^2 environment	–	0.68	435704.22	0.191*	6249.94	6527.02
σ^2 gca	–	19.11	3636862.94	0.098	25996.20	287936.56*
σ^2 sca		26.52*	12336628.34***	0.088	94826.32***	948899.52***
σ^2 gca x env.		1.38	1011464.40*	0.073	8700.61	14536.86*
σ^2 sca x env.		64.11***	3955999.77***	0.701***	26934.54***	23943.10***

*,**,*** Significant at $P \leq 0.05$, 0.01 and 0.001, respectively

Table 2. General combining ability effects and *per se* performance of lines and testers for characters in sweet sorghum

	Fresh stalk yield (tha^{-1})		Juice yield (lt ha^{-1})		Total soluble solids (%)		Bioethanol yield (t ha^{-1})		Grain yield (kg ha^{-1})	
	gca	*per se*	gca	*per se*	gca	*per se*	gca	*per se*	gca	*per se*
PMS-71 A	0.68*	14.29	–2498.68***	6538.27	0.63***	15.22	–160.65***	530.88	303.91***	1460.518
ICSA-675	–0.55	10.08	270.89	4342.96	–0.20	11.88	1.75	276.44	–425.25***	1892.04
NSS-23 A	–1.64***	11.52	–1411.85***	6123.08	–0.58***	13.88	–171.08***	460.00	–722.50***	1922.64
NSS-8 A	–1.43***	7.32	445.92	4433.70	0.07	14.22	26.86	332.11	650.22***	1210.62
NSS-1016 A	2.95***	15.92	3193.71***	5132.56	0.22*	13.22	308.12***	364.22	193.61***	1919.28
S.E. (gi)	0.31		270.49		0.04		22.93		32.92	
S.E. (gi-gj)	0.45		382.54		0.06		32.43		46.55	
Testers										
SSV-74	3.58***	35.30	2383.61***	17713.58	0.05**	16.00	203.65***	1511.11	910.84***	2181.42
SSV-84	–3.34***	22.58	–2264.87***	8632.46	0.37*	14.77	–161.11***	682.55	–5.25	1581.51
CSV-19 SS	–0.30	30.66	196.21	15597.40	0.14	16.55	26.99	1376.11	711.89***	1553.66
RSSV-138-1	13.30***	40.14	4089.67***	25322.53	–0.09	13.44	302.63***	1816.22	–1367.32***	807.33
RS-647	–7.64***	19.50	–4013.92***	8719.13	–0.78***	12.55	-387.63***	571.00	–240.84***	1888.72
UK-81	–5.59***	20.06	–390.70	7223.45	0.30*	16.00	15.45	622.00	–9.32	2903.80
S.E. (gi)	0.34		296.31		0.04		25.12		36.06	
S.E. (gi-gj)	0.49		419.05		0.6		35.52		51.00	

*,**,*** Significant at $P \leq 0.05$, 0.01 and 0.001, respectively

Table 3. *Per se* performance, heterosis and specific combining ability effects of top ranking 5 hybrids with general combining ability effect of their parents for fresh stalk yield (t ha^{-1}) in sweet sorghum

Hybrids	*per se*	Heterosis (%)		;ca effects	gca of parent	
		MP	BP		P_1	P_2
S 1016 x RSSV-138-1	71.26	158.35**	77.53**	14.82***	2.95***	13.30***
S 8 A x RSSV-138-1	55.66	134.51**	38.51**	3.61**	–1.43**	13.30***
SA 675 x RSSV-138-1	52.75	110.05**	31.42**	–0.17	–0.55	13.30***
SA 675 x SSV-74	50.05	120.53**	41.77**	6.83***	–0.55	3.58***
S-23 A x SSV-74	47.01	100.82**	33.18**	4.89***	–1.64***	3.58***

Table 4. *Per se* performance, heterosis and specific combining ability effects of top ranking 5 hybrids with general combining ability effect of their parents for juice yield (lt ha^{-1}) in sweet sorghum

Hybrids	*per se*	Heterosis (%)		effects	gca of parent	
		MP	BP		P_1	P_2
S 8 A x RSSV-138-1	121.11	29**		75.65***	5.92	39.67***
S 1016 A x RSSV-138-1	528.58	21**	6	35.33*	93.71***	39.67***
SA 675 A x SSV-74	535.06	2.47**	51**	70.69***	0.89	33.61***
S 1016 A x SSV-74	765.25	54**	87**	21.94	93.71***	33.61***
SA 675 x CSV 19 SS	058.64	1.22**	01**	31.68**	0.89	5.21

Table 5. *Per se* performance, heterosis and specific combining ability effects of top ranking 5 hybrids with general combining ability effect of their parents for total soluble solids (%) in sweet sorghum

Hybrids	*per se*	Heterosis (%)		:a effects	gca of parent	
		MP	BP		P_1	P_2
IS 71 A x RSSV-138-1	17.00	18.6**	11.08**	0.85*	0.63***	–0.09
S 1016 A x UK-81	16.56	13.31**	3.47	0.41	0.22*	0.30*
IS 71 A x SSV-84	16.44	9.63**	8.03**	–0.16	0.63***	0.37*
SA 675 x SSV 84	16.22	21.67**	9.77**	0.44	–0.20	0.37*
S 1016 A x RSSV-138-1	16.00	20.00**	19.01*	0.26	0.22*	–0.09

*,**,*** Significant at $P \leq 0.05$, 0.01 and 0.001, respectively
MP = Mid parent; BP = Better parent

Table 6. . *Per se* performance, heterosis and specific combining ability effects of top ranking 5 hybrids with general combining ability effect of their parents for bio-ethanol yield (lt ha^{-1}) in sweet sorghum

Hybrids	*per se*	Heterosis (%)		sca effects	gca of parent	
		MP	BP		P_1	P_2
S 1016 A x UK-81	2404.33	387.58**	286.55**	661.18***	0.22*	0.30*
S 8 A x RSSV-138-1	2248.33	106.23**	23.79**	218.01**	0.22*	302.63***
S 8 A x RSSV-138-1	2137.44	98.99**	17.69	383.38***	26.86	302.63***
SA 675 x SSV-74	1991.67	122.84**	31.80**	361.69***	1.75	203.65***
S 1016 A x SSV-74	1868.56	99.28**	23.65**	–62.78	0.22*	203.65***

Table 7. . *Per se* performance, heterosis and specific combining ability effects of top ranking 5 hybrids with general combining ability effect of their parents for grain yield (kg ha^{-1}) in sweet sorghum

Hybrids	*per se*	Heterosis (%)		;ca effects	gca of parent	
		MP	BP		P_1	P_2
S 1016 A x SSV-74	4520.36	120.47**	107.22**	271.41*	193.61***	910.84***
S 8 A x CSV-19 SS	4476.47	220.4**	182.66**	–30.13	650.22***	711.89***
S 8 A x UK-81	4378.05	112.81**	50.77**	592.68***	650.22***	–9.32
S 23 A x SSV-74	4247.56	106.99**	94.71**	014.73***	–722.50***	910.84***
IS 71 A x UK-81	4236.86	94.16**	45.91**	797.79***	303.91***	–9.32

*,**,*** Significant at $P \leq 0.05$, 0.01 and 0.001, respectively
MP = Mid parent; BP = Better parent