Evaluation of Sweet Sorghum Hybrids for Juce yield, Ethanol yield and its attributing traits

Abstract:

An investigation was carried out to assess the extent of heterosis for juice yield and its attributing traits in 45 new hybrids of sweet sorghum developed by crossing 3 male sterile lines with 15 restorer in L x T mating design and were sown in randomized block design (RBD) with three replications during *Kharif* 2018 at Botany Farm, Post Graduate Institute, M.P.K.V., Rahuri. The significant average heterosis, heterobeltiosis and standard heterosis recorded for total biomass, juice yield and its contributing characters in fourty five crosses. The cross CMS-1409 x RSSV-512 showed the highest significant average heterosis (224.84%) and heterobeltiosis (286.36%) for juice yield. The extent of standard heterosis observed for juice yield over the check, CSH-22SS was upto 59.15 per cent. The highest significant standard heterosis was recorded by the cross CMS-1409 x RSSV-512 (59.15%), followed by cross ICMS-479 x RSSV-355 (43.58%) and CMS-1409 x RSSV-355 (24.30%). Based on *per se* performance and heterotic performance for yield and its principal components in the F_1 hybrids the cross combinations *viz*; CMS-1409 x RSSV-512, ICMS-479 x RSSV-355 and CMS-1409 x RSSV-499 CMS-1409 x RSSV-498 and CMS-1409 x RSSV-355 were appeared to be promising.

Key Words : Sweet Sorghum, Juce, Ethanol, Hetrosis

Introduction

Sweet sorghum [*Sorghum bicolor* (L.) Moench] is a very special purpose sorghum with a sugar-rich stalk, almost similar to sugarcane. Besides having fast growth, major sugar accumulation, and biomass production capacity. sweet sorghum has wider adaptability (Reddy and Sanjana, 2003). Given that water availability is poised to become a major issue to agricultural production in coming years (Rayan and Spencer, 2001), cultivation of sugarcane becomes difficult. Sweet sorghum would be a good crop option in lieu of sugarcane in such situations. Sweet sorghum required less irrigation and rainfall and purchased less inputs compared to sugarcane. The sugar content in the juice extracted from sweet sorghum ranges from 16-23 per cent Brix. It has a great capacity for jaggery, syrup and most importantly biofuel l production (Ratnavathi *et al*., 2004). The silage after extraction of juice from sweet sorghum can be used for co-generation of power. Major goal of any crop improvement programme to maximizing production of that particular crop. Sweet sorghum (*Sorghum bicolor* L.) is an emerging most important biofuel crop, it is a special purpose sorghum with a sugar-rich stalk, almost like sugarcane. It produces food (grain) and fuel (ethanol from stem sap) and the stalks contain 10-15 % sugars (Monti *et al*., 2007). It is a unique crop with multiple advantages as food, feed, fodder, fuel, and fiber. Hence, it is popularly known as a smart crop (Chandel and Paroda, 2000). Sweet sorghum is solving the food-versus-fuel issue. Major constraints for sweet sorghum are lack of high and quality juice yielding genotypes adapted to biotic and abiotic stresses. Since future breeding efforts will be largely focus on high juice yielding with stable hybrids in sweet sorghum. Heterosis has positive relationship with specific combining ability (SCA) variance. Heterosis has been fully exploited by developing several high yielding grain sorghum hybrids (CSH-1 to CSh-25). However, heterosis for juice yield and its contributing traits has not been exploited, as sweet sorghum breeding is still in its infancy. Hence, the present investigation was carried out to assess the extent of heterosis of newly developed hybrids of sweet sorghum for juice yield and its contributing traits in 45 hybrids with their 18 parents and one check (CSH-22).

Material and Methods

The present investigation was conducted at Botany Farm, Post Graduate Institute, M.P.K.V., Rahuri, during the period *Kharif* **-** 2018. The experimental material consisting of 64 genotypes (45 hybrids, 15 restorer lines, 3 maintainer (B) lines and one check) were laid out in randomized block design (RBD) with three replications. Each entry was sown in two rows of 4 m length in each replication. The inter and intra-row spacing was 60 cm and 15 cm, respectively. The F_1's, lines, testers and check were separately randomized within the replications. Half of the recommended dose of nitrogen along with the entire dose of phosphorus and potassium were applied at the time of sowing. The remaining 50 per cent of the nitrogen was top dressed at 35 days after sowing. The crop stand and the crop growth were satisfactory. All the recommended practices were followed for raising successful crop. Observations were recorded on randomly selected 5 competitive plants in each replication in respective 1**0** characters *viz*., days to 50 % flowering, days to physiological maturity, node/plant, stem girth /diameter cm, plant height (cm), cane weight (t/ha), juice yield (l/ha), total biomass yield (t/ha), brix (%), ethanol yield (l/ha). The mean values of these five plants were computed for each entry for all characters and were subjected to analysis of variance following the methods of Panse and Sukhatme (1967).

Result and Discussion

The mean performance of hybrids for different traits studied were compared with the corresponding mid parent (MP), better parent (BP) and standard check hybrids (CSH-22SS) and the differences expressed as per cent heterosis for juice yield, ethanol yield and its components traits. In sweet sorghum, positive heterosis was desirable for all the characters studied except days to 50% flowering, days to maturity and reducing sugar where negative heterosis is desirable. Character wise results of average heterosis (H_1) heterobeltiosis (H_2) and standard heterosis (H_3) observed in the 45 crosses is given in table 1.

Exploitation of heterosis is a quick and convenient way of combining desirable combinations. It is important in sweet sorghum, as it may be an indicative of producing transgressive segregants for many quantitative characters in advanced generation.

Among the thirteen characters studied, majority of the characters exhibited mid-parents as well as better parent heterosis along with standard heterosis in desirable direction in most of the hybrids, indicating the predominant role inter-allelic interactions and over dominance in the expression of heterosis in regard of all these attribute. Hybrids exhibited positive and significant heterosis for juice yield and its attributing traits. The magnitude of heterosis for juice yield and its contributing traits suggested enough diversity among the parental lines and restorers. Low and negative heterosis can be attributed to the presence of large epistasis gene effects or to incomplete dominant gene effects. These results are in conformity with the earlier findings of Meshram *et al*., (2005), Rajashekhar (2007), Pfeiffer *et al*., (2010), Sidramappa *et al*., (2012).

The significant average heterosis, heterobeltiosis and standard heterosis has been observed for juice yield and it's contributing characters in number of crosses. The cross CMS-1409 x RSSV-512 showed the highest significant average heterosis (224.84%) and heterobetiosis (286.36%) for juice yield. The extent of standard heterosis observed for juice yield over the check CSH-22 was upto 59.15 per cent. The highest significant standard heterosis was recorded by the cross CMS-1409 x RSSV-512 (59.15 %) and followed by ICMS-479 x RSSV-355 and CMS-1409 x RSSV-499. For Ethanol yield, the cross CMS-1409 x RSSV-512 (80.30%) has recorded the highest significant standard heterosis over the check CSH-22 and followed by CMS-1409 x RSSV-355(50.24%) and ICMS-479 x RSSV-355 (43.61%).

From the present investigation majority of crosses exhibited significant better parents heterosis for all the characters studied indicating the preponderance of non-additive gene action in the genetic control of these traits in sweet sorghum. This is an accordance with the results reported by Ganesh *et al*., (1996), Senthil and Khan (1997), Chaudhari *et al*., (2004), Rajashekhar *et al*., (2007), Sandeep *et al*., (2009), Sudhir Kumar *et al*.(2011) and Sidramappa *et al*., (2012). Most of the hybrids exhibited significant standard heterosis for most of the characters over the check CSH-22, whereas only 6 hybrids for juice yield and 7 hybrids for ethanol yield expressed significant standard heterosis. Similar findings were reported by Meshram *et al*., (2005), Sandeep *et al*., (2009), Rajashekhar (2007), Vinaykumar (2009), Sudhir Kumar *et al*., (2011) and Sidramappa *et al*., (2012).

On the basis of mean juice yield and ethanol yield performance and heterosis per cent, five crosses were identified as promising crosses (Table 2). The cross CMS- 1409 x RSSV-512 recorded highest juice yield (15067 l/ha), highest standard heterosis (59.15%). The second cross ICMS-479 x RSSV-355 has recorded second highest mean juice yield (13592 l/ha), standard heterosis (43.58%). The cross CMS-1409 x RSSV-355 showed high mean juice yield (11767 l/ha) with high standard heterosis (24.30%), as one of the parents in their cross combinations having high juice yielding. Hence, these parents can be further utilized in developing new superior hybrids for full exploitation of economically important traits in sweet sorghum. The fourth cross CMS-1409 x RSSV-498 has given the mean juice yield (11274 l/ha) with standard heterosis (10.30%) and fifth cross CMS-1409 x RSSV-499 exhibit the mean juice yield (10441 l/ha), standard heterosis (10.30%).

Thus these five crosses *viz*., CMS-1409 x RSSV-512, ICMS-479 x RSSV-355, CMS-1409 x RSSV-355, CMS-1409 x RSSV-498 and CMS-1409 x RSSV-499 identified as promising crosses for juice yield, ethanol yield and its attributing traits and these crosses should be further tested in preliminary or multilocation hybrid trials for further commercial exploitation.

Conclusions:

The significant average heterosis, heterobeltiosis and standard heterosis has been observed for juce yield and its contributing characters in most of the crosses. The cross CMS-1409 x RSSV-512 showed highest significant average heterosis (224.84%) and heterobetiosis (286.36%) for juice yield. The extent of standard heterosis observed for juice yield over the check CSH-22 was upto 59.15 per cent. The highest significant standard heterosis was recorded by the cross CMS-1409 x RSSV-512 (59.15%) followed by cross ICMS-479 x RSSV-355 (43.58%) and CMS-1409 x RSSV-355 (24.30%). CMS-1409 x

RSSV-498 (10.30%) and CMS-1409 x RSSV-499 (10.30%)

Thus these five crosses *viz*., CMS-1409 x RSSV-512, ICMS-479 x RSSV-355, CMS-1409 x RSSV-355, CMS-1409 x RSSV-498 and CMS-1409 x RSSV-499 identified as promising crosses for juice yield, ethanol yield and its attributing traits and these crosses should be further tested in preliminary or multilocation hybrid trials for further commercial exploitation.

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Table 1: Heterosis (%) over mid-parent (MP), better-parent (BP) and standard check (CSH-22SS) for different characters in sweet sorghum

Sr. No	Crosses	Days to 50% Flowering			Days to Maturity		
		1			2		
		MP(H_1)	BP(H_2)	Check(H_3)	MP(H_1)	BP(H_2)	Check(H_3)
1	CMS-185 x RSSV- 454	2.97 *	6.12 **	-22.68 **	2.12 *	5.87 **	-11.95 **
2	CMS-185 x RSSV- 498	-11.71 **	-5.77 **	-27.14 **	-7.15 **	-6.01 **	-16.10 **
3	CMS-185 x RSSV- 499	-3.92 **	-2	-27.14 **	-3.50 **	-1.15	-15.85 **
4	CMS-185 x RSSV- 500	1.98	5.10 **	-23.42 **	0.99	5.01 **	-13.17 **
5	CMS-185 x RSSV- 502	-5.16 **	-3.02	-28.25 **	-4.07 **	-1.44	-16.59 **
6	CMS-185 x RSSV- 503	-10.45 **	-5.29 **	-26.77 **	-6.06 **	-4.64 **	-14.88 **
7	CMS-185 x RSSV- 483	-9.31 **	-8.65 **	-29.37 **	-6.61 **	-5.83 **	-17.32 **
8	CMS-185 x RSSV- 453	-9.42 **	-2.88	-24.91 **	-5.73 **	-3.28 **	-13.66 **
9	CMS-185 x RSSV- 417	-10.43 **	-0.96	-23.42 **	-8.21 **	-3.83 **	-14.15 **
10	CMS-185 x RSSV- 512	3.80 **	18.27 **	-8.55 **	-5.82 **	-0.55	-11.22 **
11	CMS-185 x RSSV- 350	-8.44 **	4.33 **	-19.33 **	-6.74 **	-1.64	-12.20 **
12	CMS-185 x RSSV- 397	-0.71	0.48	-22.30 **	-2.88 **	-2.48 *	-13.66 **
13	CMS-185 x RSSV- 430	-9.81 **	-7.21 **	-28.25 **	-4.76 **	-4.37 **	-14.63 **
14	CMS-185 x RSSV-386	-13.57 **	-8.17 **	-29.00 **	-7.32 **	-6.56 **	-16.59 **
15	CMS-185 x RSSV- 355	-12.97 **	-4.81 **	-26.39 **	-9.26 **	-6.28 **	-16.34 **
16	ICMS-479 x RSSV- 454	8.96 **	11.73 **	-18.59 **	4.69 **	7.92 **	-10.24 **
17	ICMS-479 x RSSV-498	-12.22 **	-5.83 **	-27.88 **	-2.04 *	-0.28	-11.95 **
18	ICMS-479 x RSSV- 499	1.48	3	-23.42 **	0.98	2.87 **	-12.44 **
19	ICMS-479 x RSSV- 500	-1.99	0.51	-26.77 **	-0.71	2.65 *	-15.12 **
20	ICMS-479 x RSSV- 502	-4.20 **	-2.51	-27.88 **	-4.65 **	-2.59 *	-17.56 **
21	ICMS-479 x RSSV- 503	-9.13 **	-3.40 *	-26.02 **	-4.19 **	-2.21 *	-13.66 **
22	ICMS-479 x RSSV- 483	1.2	2.43	-21.56 **	1.39	1.67	-10.73 **
23	ICMS-479 x RSSV- 453	-3.15 *	4.37 **	-20.07 **	-1.47	1.66	-10.24 **
24	ICMS-479 x RSSV- 417	-7.86 **	2.43	-21.56 **	-6.42 **	-1.38	-12.93 **
25	ICMS-479 x RSSV- 512	7.20 **	22.82 **	-5.95 **	0.13	6.35 **	-6.10 **
26	ICMS-479 x RSSV- 350	8.47 **	24.27 **	-4.83 **	3.13 **	9.39 **	-3.41 **
27	ICMS-479 x RSSV- 397	5.97 **	7.77 **	-17.47 **	0.97	1.1	-10.73 **
28	ICMS-479 x RSSV- 430	1.41	4.85 **	-19.70 **	-1.78 *	-0.83	-12.44 **
29	ICMS-479 x RSSV-386	-6.36 **	0.00	-23.42 **	-3.00 **	-1.66	-13.17 **
30	ICMS-479 x RSSV- 355	-12.14 **	-3.40 *	-26.02 **	-7.45 **	-3.87 **	-15.12 **
31	CMS-1409 x RSSV- 454	18.09 **	19.90 **	-12.64 **	11.05 **	12.02 **	-6.83 **
32	CMS-1409 x RSSV-498	6.39 **	15.35 **	-13.38 **	6.37 **	10.66 **	-6.34 **
33	CMS-1409 x RSSV- 499	1.99	2.50	-23.79 **	4.31 **	4.61 **	-11.46 **
34	CMS-1409 x RSSV- 500	9.55 **	11.22 **	-18.96 **	7.87 **	9.14 **	-9.76 **
35	CMS-1409 x RSSV- 502	4.24 **	5.03 **	-22.30 **	6.34 **	6.34 **	-10.00 **
36	CMS-1409 x RSSV- 503	-1.38	5.94 **	-20.45 **	1.38	5.76 **	-10.49 **
37	CMS-1409 x RSSV- 483	16.22 **	18.81 **	-10.78 **	8.63 **	10.66 **	-6.34 **
38	CMS-1409 x RSSV- 453	2.73 *	11.88 **	-15.99 **	2.19 *	7.78 **	-8.78 **
39	CMS-1409 x RSSV- 417	-3.08 *	8.91 **	-18.22 **	-2.67 **	4.90 **	-11.22 **
40	CMS-1409 x RSSV- 512	-9.83 **	4.46 **	-21.56 **	-3.98 **	4.32 **	-11.71 **
41	CMS-1409 x RSSV- 350	3.85 **	20.30 **	-9.67 **	7.57 **	16.71 **	-1.22

42	CMS-1409 x RSSV- 397	4.58 **	7.43 **	-19.33 **	8.73 **	11.24 **	-5.85 **
43	CMS-1409 x RSSV- 430	9.48 **	14.36 **	-14.13 **	5.31 **	8.65 **	-8.05 **
44	CMS-1409 x RSSV-386	9.63 **	18.32 **	-11.15 **	7.93 **	11.82 **	-5.37 **
45	CMS-1409 x RSSV- 355	-4.23 **	6.44 **	-20.07 **	1.22	7.49 **	-9.02 **
	SE(D)±	0.916	1.052	1.058	1.023	1.181	1.181
	CD 5%	1.820	2.102	2.102	2.033	2.347	2.347
	CD 1%	2.412	2.785	2.785	2.693	3.110	3.110

Note : * Significant at 5% level of significance , ** Significant at 1% level of significance

Cont.…Table 1: Heterosis (%) over mid-parent (MP), better-parent (BP) and standard check (CSH-22SS) for different characters in sweet sorghum

Sr. No	**Crosses**	**No of nodes/plant**			**Plant Height (cm)**		
		3			**4**		
		MP(H_1)	**BP(H_2)**	**Check(H_3)**	**MP(H_1)**	**BP(H_2)**	**Check(H_3)**
1	CMS-185 x RSSV- 454	27.59 **	37.04 **	-5.13	59.65 **	110.19 **	0.07
2	CMS-185 x RSSV- 498	33.33 **	48.15 **	2.56	62.58 **	110.63 **	0.28
3	CMS-185 x RSSV- 499	20.63 **	40.74 **	-2.56	29.44 **	59.68 **	-23.98 **
4	CMS-185 x RSSV- 500	5.88	33.33 **	-7.69	27.48 **	96.51 **	-6.44 **
5	CMS-185 x RSSV- 502	-6.25	11.11	-23.08 **	28.67 **	95.63 **	-6.86 **
6	CMS-185 x RSSV- 503	-3.03	18.52	-17.95 *	43.42 **	87.05 **	-10.95 **
7	CMS-185 x RSSV- 483	6.06	29.63 **	-10.26	24.03 **	88.94 **	-10.05 **
8	CMS-185 x RSSV- 453	6.06	29.63 **	-10.26	26.84 **	88.50 **	-10.26 **
9	CMS-185 x RSSV- 417	15.15 *	40.74 **	-2.56	33.46 **	104.66 **	-2.56 **
10	CMS-185 x RSSV- 512	16.42 *	44.44 **	0.00	38.44 **	111.79 **	0.83
11	CMS-185 x RSSV- 350	26.15 **	51.85 **	5.13	36.14 **	109.17 **	-0.42
12	CMS-185 x RSSV- 397	12.12	37.04 **	-5.13	18.28 **	80.35 **	-14.14 **
13	CMS-185 x RSSV- 430	3.03	25.93 *	-12.82	-5.72 **	45.27 **	-30.84 **
14	CMS-185 x RSSV-386	21.21 **	48.15 **	2.56	25.65 **	89.67 **	-9.70 **
15	CMS-185 x RSSV- 355	25.00 **	48.15 **	2.56	36.16 **	110.48 **	0.21
16	ICMS-479 x RSSV- 454	45.45 **	66.67 **	2.56	64.95 **	129.37 **	0.14
17	ICMS-479 x RSSV-498	40.35 **	66.67 **	2.56	38.60 **	89.52 **	-17.26 **
18	ICMS-479 x RSSV- 499	23.33 **	54.17 **	-5.13	31.14 **	70.48 **	-25.57 **
19	ICMS-479 x RSSV- 500	13.85	54.17 **	-5.13	15.87 **	89.52 **	-17.26 **
20	ICMS-479 x RSSV- 502	24.59 **	58.33 **	-2.56	12.80 **	81.90 **	-20.58 **
21	ICMS-479 x RSSV- 503	14.29	50.00 **	-7.69	16.89 **	60.95 **	-29.73 **
22	ICMS-479 x RSSV- 483	14.29	50.00 **	-7.69	7.66 **	73.97 **	-24.05**
23	ICMS-479 x RSSV- 453	20.63 **	58.33 **	-2.56	39.24 **	119.37 **	-4.23**
24	ICMS-479 x RSSV- 417	17.46 *	54.17 **	-5.13	25.85 **	104.76 **	-10.60**
25	ICMS-479 x RSSV- 512	28.13 **	70.83 **	5.13	39.85 **	126.98 **	-0.90
26	ICMS-479 x RSSV- 350	29.03 **	66.67 **	2.56	40.02 **	128.25 **	-0.35
27	ICMS-479 x RSSV- 397	14.29	50.00 **	-7.69	28.16 **	107.30 **	-9.49 **
28	ICMS-479 x RSSV- 430	20.63 **	58.33 **	-2.56	20.68 **	97.30 **	-13.86 **
29	ICMS-479 x RSSV-386	20.63 **	58.33 **	-2.56	30.69 **	109.21 **	-8.66 **
30	ICSA-479 x RSSV- 355	34.43 **	70.83 **	5.13	41.85 **	132.70 **	1.59 *
31	CMS-1409 x RSSV- 454	46.43 **	64.00 **	5.13	71.75 **	152.86 **	1.11
32	CMS-1409 x RSSV-498	41.38 **	64.00 **	5.13	77.96 **	157.54 **	2.98 **
33	CMS-1409 x RSSV- 499	21.31 **	48.00 **	-5.13	83.47 **	151.99 **	0.76
34	CMS-1409 x RSSV- 500	12.12	48.00 **	-5.13	34.26 **	133.62 **	-6.58 **
35	CMS-1409 x RSSV- 502	16.13 *	44.00 **	-7.69	45.93 **	150.26 **	0.07
36	CMS-1409 x RSSV- 503	15.63 *	48.00 **	-5.13	74.55 **	154.42 **	1.73 *
37	CMS-1409 x RSSV- 483	25.00 **	60.00 **	2.56	50.68 **	158.93 **	3.53 **
38	CMS-1409 x RSSV- 453	25.00 **	60.00 **	2.56	47.00 **	146.10 **	-1.59 *
39	CMS-1409 x RSSV- 417	18.75 *	52.00 **	-2.56	31.20 **	127.04 **	-9.22 **
40	CMS-1409 x RSSV- 512	23.08 **	60.00 **	2.56	51.91 **	162.22 **	4.85 **

41	CMS-1409 x RSSV- 350	33.33 **	68.00 **	7.69	50.12 **	160.31 **	4.09 **
42	CMS-1409 x RSSV- 397	28.13 **	64.00 **	5.13	49.52 **	157.19 **	2.84 **
43	CMS-1409 x RSSV- 430	25.00 **	60.00 **	2.56	45.89 **	153.73 **	1.46
44	CMS-1409 x RSSV-386	25.00 **	60.00 **	2.56	46.95 **	150.09 **	0.00
45	CMS-1409 x RSSV- 355	25.81 **	56.00 **	0.00	45.78 **	154.42 **	1.73 *
	SE(D)±	0.776	0.896	0.896	3.194	3.688	3.688
	CD 5%	1.543	1.782	1.782	6.348	7.330	7.330
	CD 1%	2.044	2.361	2.361	8.410	9.711	9.711

Note : * Significant at 5% level of significance , ** Significant at 1% level of significance

Cont.…Table 1 Heterosis (%) over mid-parent (MP), better-parent (BP) and standard check (CSH-22SS) for different characters in sweet sorghum

Sr.No.	Crosses	Stem girth (cm)			Total Biomass Yield (t/ha)		
		5			6		
		MP(H_1)	BP(H_2)	Check(H_3)	MP(H_1)	BP(H_2)	Check(H_3)
1	CMS-185 x RSSV- 454	44.21	63.87	2.03	46.12 **	52.27 **	3.13
2	CMS-185 x RSSV- 498	49.36	62.94	1.45	49.10 **	53.05 **	3.66
3	CMS-185 x RSSV- 499	-7.10	0.70	-37.30	-4.03	15.04 *	-22.08 **
4	CMS-185 x RSSV- 500	-0.82	27.27	-20.75	17.39 **	31.28 **	-11.09 *
5	CMS-185 x RSSV- 502	-22.32	-11.19	-44.70	37.83 **	38.46 **	-7.07
6	CMS-185 x RSSV- 503	-6.40	5.59	-34.25	13.95 **	23.09 **	-16.64 **
7	CMS-185 x RSSV- 483	-39.42 *	29.84	-19.16	8.76	17.22 **	-20.61 **
8	CMS-185 x RSSV- 453	-7.31	0.47	-37.45	-18.36 **	-4.71	-35.46 **
9	CMS-185 x RSSV- 417	25.70	62.47	1.16	13.96 **	25.70 **	-14.87 **
10	CMS-185 x RSSV- 512	31.66	64.80	2.61	82.32 **	96.21 **	32.89 **
11	CMS-185 x RSSV- 350	27.66	62.47	1.16	44.14 **	52.74 **	3.45
12	CMS-185 x RSSV- 397	-4.18	6.76	-33.53	28.50 **	36.65 **	-17.87 **
13	CMS-185 x RSSV- 430	-31.51	-15.38	-47.31 *	2.77	19.49 **	-19.07 **
14	CMS-185 x RSSV-386	2.19	19.58	-25.54	16.32 **	27.95 **	-13.34 **
15	CMS-185 x RSSV- 355	32.06	61.31	0.44	36.88 **	49.91 **	1.53
16	ICMS-479 x RSSV- 454	39.98	59.48	-1.16	62.47 **	96.91 **	1.53
17	ICMS-479 x RSSV-498	12.21	22.72	-23.95	2.04	21.58 *	-37.31 **
18	ICMS-479 x RSSV- 499	-12.28	-4.68	-40.93	10.35	56.45 **	-19.33 **
19	ICMS-479 x RSSV- 500	-26.66	-5.62	-41.51	-20.02 **	4.94	-45.89 **
20	ICMS-479 x RSSV- 502	17.88	35.13	-16.26	-14.30 *	-1.38	-49.15 **
21	ICMS-479 x RSSV- 503	-23.81	-13.82	-46.59	-19.49 **	1.60	-47.61 **
22	ICMS-479 x RSSV- 483	-48.18 **	11.48	-30.91	-23.14 **	-3.24	-50.11 **
23	ICMS-479 x RSSV- 453	48.92	61.83	0.29	16.09 **	59.78 **	-17.61 **
24	ICMS-479 x RSSV- 417	4.25	35.13	-16.26	5.90	36.83 **	-29.44 **
25	ICMS-479 x RSSV- 512	29.85	63.00	1.02	51.00 **	89.78 **	-2.15
26	ICMS-479 x RSSV- 350	32.48	69.09	4.79	-1.22	22.00 *	-37.09 **
27	ICMS-479 x RSSV- 397	35.43	51.29	-6.24	66.78 **	80.59 **	-6.88
28	ICMS-479 x RSSV- 430	-1.13	22.48	-24.09	-13.14 *	19.03 *	-38.62 **
29	ICMS-479 x RSSV-386	11.58	30.91	-18.87	19.74 **	54.22 **	-20.48 **
30	ICMS-479 x RSSV- 355	56.21 *	91.33 *	18.58	55.39 **	99.19 **	2.71
31	CMS-1409 x RSSV- 454	45.78	69.25	1.45	60.57 **	80.27 **	6.28
32	CMS-1409 x RSSV-498	71.74 *	91.28 *	14.66	98.73 **	119.57 **	29.45 **
33	CMS-1409 x RSSV- 499	60.61	77.72	6.53	76.02 **	129.30 **	35.19 **
34	CMS-1409 x RSSV- 500	18.53	55.69	-6.68	31.58 **	59.24 **	-6.11
35	CMS-1409 x RSSV- 502	46.94	71.67	2.90	70.27 **	82.05 **	7.33
36	CMS-1409 x RSSV- 503	47.69	70.22	2.03	49.86 **	74.81 **	3.06
37	CMS-1409 x RSSV- 483	-22.00	72.15	3.19	52.16 **	77.08 **	4.40
38	CMS-1409 x RSSV- 453	45.95	61.50	-3.19	21.63 **	54.05 **	-9.18 *
39	CMS-1409 x RSSV- 417	-10.70	18.16	-29.17	21.45 **	44.86 **	-14.59 **

40	CMS-1409 x RSSV- 512	32.33	69.49	1.60	102.09 **	134.80 **	38.43 **
41	CMS-1409 x RSSV- 350	29.74	69.01	1.31	69.40 **	93.62 **	14.15 **
42	CMS-1409 x RSSV- 397	47.87	68.28	0.87	84.05 **	85.83 **	9.56 *
43	CMS-1409 x RSSV- 430	37.74	74.09	4.35	48.19 **	86.90 **	10.19 *
44	CMS-1409 x RSSV-386	40.69	68.28	0.87	52.87 **	81.80 **	7.18
45	CMS-1409 x RSSV- 355	39.34	74.09	4.35	102.19 **	139.35 **	41.11 **
	SE(D)±	0.468	0.541	0.541	2.228	2.573	2.573
	CD 5%	0.931	1.075	1.075	4.129	5.114	5.114
	CD 1%	1.233	1.424	1.424	5.867	6.775	6.775

Note : * Significant at 5% level of significance , ** Significant at 1% level of significance

Cont.…Table 1: Heterosis (%) over mid-parent (MP), better-parent (BP) and standard check (CSH-22SS) for different characters in sweet sorghum

Sr. No	Crosses	Cane Weight (t/ha)			Juice Yield (l/ha)		
		7			8		
		MP(H_1)	BP(H_2)	Check(H_3)	MP(H_1)	BP(H_2)	Check(H_3)
1	CMS-185 x RSSV- 454	54.90 **	73.07 **	1.15	89.35 **	231.44 **	10.92
2	CMS-185 x RSSV- 498	83.06 **	90.63 **	2.90	65.48 **	153.25 **	2.84
3	CMS-185 x RSSV- 499	16.17 **	30.59 **	-23.67 **	-1.03	97.24 **	-44.72 **
4	CMS-185 x RSSV- 500	31.00 **	50.73 **	-11.90 **	45.99 **	142.92 **	-12.68
5	CMS-185 x RSSV- 502	30.75 **	41.23 **	-17.46 **	-50.95 **	-8.41	-71.97 **
6	CMS-185 x RSSV- 503	6.78	24.93 **	-26.98 **	18.46	146.93 **	-34.79 **
7	CMS-185 x RSSV- 483	-21.10 **	-3.41	-43.55 **	-21.30	12.64	-49.39 **
8	CMS-185 x RSSV- 453	0.41	0.65	-41.17 **	-15.96	33.19	-48.63 **
9	CMS-185 x RSSV- 417	20.40 **	23.46 **	-31.34 **	16.40	103.05 **	-31.72 **
10	CMS-185 x RSSV- 512	81.53 **	108.96 **	22.13 **	80.84 **	174.12 **	12.92
11	CMS-185 x RSSV- 350	51.15 **	74.31 **	1.87	74.97 **	206.38 **	2.48
12	CMS-185 x RSSV- 397	14.33 **	17.46 **	-31.35 **	-29.73 **	-24.63 *	-44.93 **
13	CMS-185 x RSSV- 430	-17.74 **	1.71	-40.56 **	-39.14 **	-29.31 *	-55.29 **
14	CMS-185 x RSSV-386	3.29	14.64 *	-33.00 **	-22.25 *	-13.37	-40.98 **
15	CMS-185 x RSSV- 355	72.26 **	78.60 **	-2.78	58.23 **	133.65 **	0.11
16	ICMS-479 x RSSV- 454	65.61 **	115.39 **	-2.94	132.42 **	199.03 **	0.07
17	ICMS-479 x RSSV-498	17.46 **	29.08 **	-41.83 **	15.64	32.78	-46.08 **
18	ICMS-479 x RSSV- 499	-23.49 **	0.19	-54.85 **	-36.91 *	-9.20	-74.55 **
19	ICMS-479 x RSSV- 500	5.73	42.07 **	-35.98 **	53.25 **	88.85 **	-32.11 **
20	ICMS-479 x RSSV- 502	-16.50 **	4.58	-52.87 **	29.50	76.15 **	-46.10 **
21	ICMS-479 x RSSV- 503	-34.44 **	-10.25	-59.56 **	-17.54	23.43	-67.40 **
22	ICMS-479 x RSSV- 483	-34.01 **	-5.02	-57.20 **	7.78	17.03	-47.42 **
23	ICMS-479 x RSSV- 453	33.78 **	54.07 **	-30.57 **	71.82 **	103.18 **	-21.63 **
24	ICMS-479 x RSSV- 417	22.98 **	37.37 **	-38.10 **	100.47 **	157.17 **	-13.52
25	ICMS-479 x RSSV- 512	43.45 **	92.87 **	-13.09 **	94.63 **	121.69 **	-8.68
26	ICMS-479 x RSSV- 350	-6.20	26.36 **	-43.06 **	63.50 **	110.43 **	-29.62 **
27	ICMS-479 x RSSV- 397	23.09 **	45.74 **	-34.33 **	10.92	32.42 *	-30.28 **
28	ICMS-479 x RSSV- 430	-4.48	38.99 **	-37.37 **	12.05	23.33	-35.07 **
29	ICMS-479 x RSSV-386	13.75 **	46.85 **	-33.83 **	-22.60	-11.22	-53.26 **
30	ICMS-479 x RSSV- 355	112.01 **	134.06 **	5.48	200.72 **	235.12 **	43.58 **
31	CMS-1409 x RSSV- 454	56.48 **	77.57 **	0.92	134.21 **	215.86 **	5.70
32	CMS-1409 x RSSV-498	165.48 **	172.50 **	47.09 **	144.52 **	193.25 **	19.09 *
33	CMS-1409 x RSSV- 499	120.48 **	151.77 **	43.09 **	160.06 **	293.52 **	10.30
34	CMS-1409 x RSSV- 500	-4.77	11.33	-36.73 **	64.40 **	112.07 **	-23.77 **
35	CMS-1409 x RSSV- 502	49.00 **	63.39 **	-7.14 *	130.36 **	228.95 **	0.67
36	CMS-1409 x RSSV- 503	49.17 **	77.35 **	0.79	142.40 **	281.87 **	0.85
37	CMS-1409 x RSSV- 483	44.72 **	80.14 **	2.38	98.51 **	124.72 **	0.97
38	CMS-1409 x RSSV- 453	47.04 **	49.49 **	-15.04 **	94.95 **	141.01 **	-7.04
39	CMS-1409 x RSSV- 417	38.00 **	39.52 **	-22.41 **	82.38 **	145.21 **	-17.54 *

40	CMS-1409 x RSSV- 512	119.63 **	156.88 **	45.99 **	224.84 **	286.36 **	59.15 **
41	CMS-1409 x RSSV- 350	63.27 **	91.31 **	8.73 *	128.65 **	208.45 **	3.17
42	CMS-1409 x RSSV- 397	78.19 **	85.73 **	5.56	56.70 **	79.14 **	1.74
43	CMS-1409 x RSSV- 430	46.61 **	84.33 **	4.76	68.56 **	78.13 **	1.17
44	CMS-1409 x RSSV-386	54.87 **	74.56 **	-0.79	56.43 **	72.04 **	-2.29
45	CMS-1409 x RSSV- 355	175.56 **	181.63 **	53.31 **	149.49 **	190.11 **	24.30 **
	SE(D)±	1.224	1.414	1.414	659.3	761.4	761.4
	CD 5%	2.433	2.810	2.810	1310.3	1513.1	1513.1
	CD 1%	3.224	3.722	3.722	1736.0	2004.6	2004.6

Note : * Significant at 5% level of significance , ** Significant at 1% level of significance

Cont.…Table 1: Heterosis (%) over mid-parent (MP), better-parent (BP) and standard check (CSH-22SS) for different characters in sweet sorghum

Sr. No	Crosses	Brix (%)			Ethanol Yield (l/ha)		
		9			10		
		MP(H_1)	MP(H_1)	BP(H_2)	Check(H_3)	BP(H_2)	Check(H_3)
1	CMS-185 x RSSV- 454	5.38	76.46 **	102.66 **	-17.35 *	6.52	-14.04 **
2	CMS-185 x RSSV- 498	7.53	92.09 **	123.04 **	-10.78	8.70	-12.28 **
3	CMS-185 x RSSV- 499	6.67	5.83	71.43 *	-59.52 **	9.09	-15.79 **
4	CMS-185 x RSSV- 500	4.44	88.30 **	151.91 **	-20.48 *	6.82	-17.54 **
5	CMS-185 x RSSV- 502	-7.84 *	-26.30	19.39	-71.81 **	2.17	-17.54 **
6	CMS-185 x RSSV- 503	-7.07	111.69 **	313.58 **	-24.76 **	0.00	-19.30 **
7	CMS-185 x RSSV- 483	8.51 *	37.77 *	88.89 **	-42.65 **	10.87 *	-10.53 **
8	CMS-185 x RSSV- 453	5.95	2.07	18.11	-52.47 **	6.52	-14.04 **
9	CMS-185 x RSSV- 417	6.38	74.25 **	111.91 **	-21.75 **	8.70	-12.28 **
10	CMS-185 x RSSV- 512	15.56 **	192.28 **	243.54 **	34.52 **	18.18 **	-8.77 *
11	CMS-185 x RSSV- 350	6.38	155.81 **	256.62 **	5.48	8.70	-12.28 **
12	CMS-185 x RSSV- 397	19.59 **	8.98	9.41	-42.59 **	26.09 **	1.75
13	CMS-185 x RSSV- 430	-2.91	-24.64	-23.26	-60.84 **	8.70	-12.28 **
14	CMS-185 x RSSV-386	10.87 **	-3.43	6.76	-53.37 **	10.87 *	-10.53 **
15	CMS-185 x RSSV- 355	-4.35	65.01 **	129.15 **	-31.81 **	-4.35	-22.81 **
16	ICMS-479 x RSSV- 454	15.22 **	124.29 **	142.37 **	-14.88	17.78 **	-7.02
17	ICMS-479 x RSSV-498	21.74 **	39.05 *	48.71 *	-47.77 **	24.44 **	-1.75
18	ICMS-479 x RSSV- 499	12.36 **	-20.82	-1.53	-76.75 **	13.64 **	-12.28 **
19	ICMS-479 x RSSV- 500	25.84 **	85.55 **	95.99 **	-38.13 **	27.27 **	-1.75
20	ICMS-479 x RSSV- 502	8.91 *	70.87 **	112.50 **	-49.82 **	22.22 **	-3.51
21	ICMS-479 x RSSV- 503	10.20 **	7.57	57.62	-71.33 **	20.00 **	-5.26
22	ICMS-479 x RSSV- 483	17.20 **	50.32 *	62.10 *	-50.78 **	21.11 **	-4.39
23	ICMS-479 x RSSV- 453	31.15 **	114.23 **	129.85 **	-19.28 *	33.33 **	5.26
24	ICMS-479 x RSSV- 417	7.53	107.19 **	112.52 **	-25.36 **	11.11 *	-12.28 **
25	ICMS-479 x RSSV- 512	32.58 **	119.95 **	132.59 **	-18.31 *	34.09 **	3.51
26	ICMS-479 x RSSV- 350	18.28 **	79.33 **	96.13 **	-41.99 **	22.22 **	-3.51
27	ICMS-479 x RSSV- 397	8.33 *	43.47 **	78.90 **	-37.17 **	15.56 **	-8.77 *
28	ICMS-479 x RSSV- 430	15.69 **	10.63	35.68	-52.35 **	31.11 **	3.51
29	ICMS-479 x RSSV-386	16.48 **	-8.10	3.09	-63.80 **	17.78 **	-7.02
30	ICMS-479 x RSSV- 355	23.08 **	342.71 **	382.59 **	43.61 **	24.44 **	-1.75
31	CMS-1409 x RSSV- 454	13.64 **	204.38 **	230.45 **	15.06	21.95 **	-12.28 **
32	CMS-1409 x RSSV-498	15.91 **	227.86 **	252.25 **	22.65 **	24.39 **	-10.53 **
33	CMS-1409 x RSSV- 499	10.59 *	262.06 **	347.96 **	5.78	14.63 **	-17.54 **
34	CMS-1409 x RSSV- 500	20.00 **	121.60 **	133.02 **	-26.45 **	24.39 **	-10.53 **
35	CMS-1409 x RSSV- 502	3.09	287.63 **	379.59 **	13.25	21.95 **	-12.28 **
36	CMS-1409 x RSSV- 503	-9.57 *	272.50 **	442.72 **	-1.27	3.66	-25.44 **
37	CMS-1409 x RSSV- 483	10.11 *	174.49 **	194.64 **	-10.54	19.51 **	-14.04 **
38	CMS-1409 x RSSV- 453	0.57	109.95 **	126.30 **	-21.20 **	7.32	-22.81 **
39	CMS-1409 x RSSV- 417	12.36 **	154.07 **	161.76 **	-8.86	21.95 **	-12.28 **

40	CMS-1409 x RSSV- 512	36.47 **	387.46 **	417.82 **	80.30 **	41.46 **	1.75
41	CMS-1409 x RSSV- 350	-7.87	239.57 **	269.65 **	9.34	0.00	-28.07 **
42	CMS-1409 x RSSV- 397	19.57 **	77.78 **	122.84 **	-22.41 **	34.15 **	-3.51
43	CMS-1409 x RSSV- 430	4.08	147.44 **	205.02 **	6.20	24.39 **	-10.53 **
44	CMS-1409 x RSSV-386	5.75	221.57 **	262.46 **	26.20 **	12.20 *	-19.30 **
45	CMS-1409 x RSSV- 355	19.54 **	365.30 **	404.86 **	50.24 **	26.83 **	-8.77 *
	SE(D)±	0.606	37.40	43.191	43.191	0.700	0.700
	CD 5%	1.205	74.33	85.832	85.832	1.391	1.391
	CD 1%	1.596	98.48	113.71	113.71	1.843	1.843

Crosses	**Mean Juice yield (lit/ha)**	**Heterosis (%) for juice yield**			**Significant H$_3$ for other characters**	**Mean Ethanol yield (lit/ha)**
		H$_1$	**H$_2$**	**H$_3$**		
CMS-1409 x RSSV-512	**15067**	224.84 **	286.36 **	59.15**	1,2,4,6,7,11,12	998
ICMS-479 x RSSV-355	**13592**	200.72 **	235.12 **	43.58**	1,2,4,7,11,12	795
CMS-1409 x RSSV-355	**11767**	149.49 **	190.11 **	24.30**	1,2,4,5,7,11,12	831
CMS-1409 x RSSV-498	**11274**	144.52 **	193.25 **	10.30**	1,2,4,6,7,12	679
CMS-1409 x RSSV-499	**10441**	160.06 **	293.95 **	10.30**	1,2,4,6.7,	585

Note : * Significant at 5% level of significance, ** Significant at 1% level of significance

Table 2: Mean juice and ethanol yield performance and heterosis effects in promising crosses

Note : * Significant at 5% level of significance, ** Significant at 1% level of significance

H_1 - Average heterosis

H_2 - Heterobeltiosis

H_3 - Standard heterosis over CSH-22

1) Days to 50% Flowering **2)** days to Maturity **3**) Nodes/plant **4**) Plant height **5)** Stem girth **6)** Total biomass yield **7)** Cane weight **8**) Juice yield **9)** Brix % **10**) Reducing sugar % **11)** Total sugar **12)** Ethanol yield.