Madras Agric. J., 100 (1-3): 1-8, March 2013
https://doi.org/10.29321/MAJ.10.001227

Heterosis Studies for Ethanol Yield and Its Related Traits in F$_1$ Hybrids of Sweet Sorghum [*Sorghum bicolor* (L.) Moench]

Ch. Rani*, A.V. Umakanth, Vemanna Iraddi and V.K. Tanmay
Department of Plant Breeding, Directorate of Sorghum Research,
Rajendranagar, Hyderabad - 500 030

Sweet sorghum [*Sorghum bicolor* (L.) Moench], a specific type of sorghum, has been considered a potentially valuable source for biofuel production because of its high energy convertion efficiency. Many characteristics such as green stalk yield, stalk sugar content, stalk juice extractability and grain yield have been proved as major contributors to its economic superiority. Although heterosis is well established in grain and forage sorghum [*Sorghum bicolor* (L.) Moench], reports of heterosis in sweet sorghum are limited to results from grain sorghum × sweet sorghum hybrids. Thirty hybrids, derived from a line × tester trial, were evaluated in *kharif* season during 2010 along with their parents and the checks. Heterosis over mid parent, better parent and standard checks *viz.,* CSH 22SS, PAC 52093 and NSSV 13 was studied for bioethanol yield and its component characters. Based on standard heterosis the hybrids *viz.,* NSS 1007A × CSV 19SS and RS 1220A × SSV 74 are found highly suitable for heterosis breeding as they exhibited significant positive standard heterosis for ethanol yield and its contributing traits.

Key words: Ethanol yield, heterosis, total soluble solids, total biomass and juice yield

Sweet sorghum (*Sorghum bicolor* L. Moench) or sweet stalk sorghum is a high potential field crop for food, feed and fuel. Its grain is used for food and feed, juice for alcohol production and stalks are used as silage or fodder. In recent years, the energy crisis and environmental pollution have become more serious. So, many countries look for green energy from biomass and sweet sorghum hybrid cultivars.

Growing sweet sorghum hybrid with high cane juice, sweetness and the total fermentable sugars is considered to be a highly efficient in producing ethanol. In USA, the sorghum production has tripled since the adoption of hybrid sorghum cultivars and exploitation of hybrid vigour in conjunction with intensive management practices. The heterosis or hybrid vigour is the expressions of the F$_1$ hybrid over its parents. Heterosis in sorghum was first observed in 1927, but commercial exploitation was not possible until the discovery of cytoplasmic genetic male sterility system by Stephens and Holland in 1954. The substantial magnitude of standard heterosis for all the traits related to ethanol production (plant height: up to 46.9%, stem girth: up to 5.3%, total soluble solids (%): up to 7.4%, millable stalk yield: up to 1.5% and extractable juice yield: up to 122.6%) further supports breeding for heterosis for genetic enhancement of sweet sorghum (Sankarapandian *et al.* 1994). However, for quantitative traits like total biomass, fresh stalk yield, juice yield and sugar yield the progress has been hindered due to lack of understanding in the inheritance and complex relationship among themselves. Most of the sweet sorghum varieties mature between 115 and 125 days during rainy season. Stalks can be harvested along with grain. The green cane yield varies from 30 to 50 tons ha^{-1}, and grain yield from 0.8 to 2.0 tons ha^{-1} with a brix value of 16 to 20%. Sweet sorghum varieties and hybrids bred at NRCS, India has potential to produce biomass up to 48 tons ha^{-1} and 1.5 to 2.9 tons ha^{-1} grain with brix value of 14 to 18%. The juicy stalks of sweet sorghum can be used for preparation of syrup, jaggery and fuel grade ethanol. Sweet sorghum has ability to yield 40-45 tons ha^{-1} millable cane and 1-1.5 tons ha-1 grain, and an average brix of 18.4%. The juice has a minimum of 12% sucrose and at least 15% total fermentable sugar (Ratnavathi, C. V. 2008.). Ethanol, the finished product of fermentation has high commercial value. It is a "clean burning fuel" with high octane rating and the existing automobile engines can be operated with petrol blended with 20% ethanol (80% petrol) without engine modifications.

At present, very few hybrids of sweet sorghum are released. In 2005, ICRISAT (India) recommended 8 pure lines sweet sorghum to public namely NTJ2, SPV422 (ICSV574), SPV1411, ICSR93034, ICSV93046, ICSV700, S35, and E36-1. In 2008, it was reported that two pure lines, SSV84 and CSV19 and one hybrid, CSH 22 (NSSH104) were used in the research on a potential energy crop for bio-fuel production in India. Hence, to choose

*Corresponding author email: rani.chapara@gmail.com

the high potential sweet sorghum for growing, the objective of this research was to estimate the extent and nature of heterosis among F_1 hybrids for ethanol yield and its related traits.

Material and Methods

Thirty F_1 hybrids were produced by crossing five lines with six testers in a L × T mating design during rabi 2009. These hybrids along with there parents were planted in a randomized complete block design (RCBD) in three replications during kharif at experimental farm, Rajendranagar, Hyderabad, Mahatma Phule Krishi Vidyapeeth, Rahuri and Centre for Plant Breeding and Genetics farm, Coimbatore. Each entry was sown in two rows of 4m length with a spacing of 60 cm between rows and 15 cm between plants. Five competitive plants were selected at random from each replication for recording the observations on brix per cent (using an Atago PAL-1 digital hand -held pocket refractometer with automatic temperature compensation ranging from 0 to 50°C at the hard dough stage).

At physiological maturity stage, total biomass were recorded on selected plants by weighing leaves, stems and panicles in kilograms while fresh stalk yield were recorded by removing panicles and leaves along with sheath and later converted to t ha^{-1}. Further, juice extraction was done on an electrically operated three-roller stalk crusher with a minimum of three passings of the selected stalk measured in kilograms and later converted into litres to get juice yield in L ha^{-1}. The total soluble solids and ethanol yield were calculated by using formula given by Corleto and Cazzato (1997), as reported by Reddy *et al*. (2005).

Total soluble solids (%) = 0.1516 + (Brix % × 0.8746)

Total sugar index (t ha^{-1}) = [Sugar (%) / 100] × [Juice yield (l ha^{-1}) / 1000]

Juice extraction per cent = [Juice weight (Kg) / Fresh stalk yield (Kg)] × 100

Ethanol yield (L ha^{-1}) = [Total sugar yield (t ha^{-1}) / 5.68] × 3.78 × 1000 × 0.8

Statistical Analysis

The analysis was done using INDOSTAT software. The error variances in the trials conducted in three locations were homogeneous, as revealed by Bartlett's test (Bartlett 1937), providing statistical validity to carry out combined ANOVA.

Estimation of Heterosis: Heterosis of F_1 over mid parent (MP) and better parent (BP) were calculated as per Turner (1953) and Hayes *et al.* (1955).

i. Mid Parental Heterosis / Relative Heterosis (RH)

Heterosis over mid parental value (H_{MP}) was estimated using the following formula.

Relative Heterosis (RH) % = $\frac{(\overline{F_1}-\overline{MP})}{\overline{MP}}\times 100$

F_1 : Mean of F_1

$\overline{MP}$: Mean of mid parent

ii. Heterobeltiosis (HB)

The superiority of F_1 over better parent was estimated as follows

Heterobeltiosis (HB) % = $\frac{(\overline{F_1}-\overline{BP})}{\overline{BP}}\times 100$

$\overline{BP}$: Mean of better parent

iii. Standard Heterosis

Standard Heterosis (SH) % = $\frac{(\overline{F_1}-\overline{SC})}{\overline{SC}}\times 100$

Where, $\overline{SC}$: Mean of standard check

iv. Test of Significance for Heterosis

Estimates of heterosis were tested for significance at error degrees of freedom as suggested by Turner (1953).

a. Mid-parent heterosis = $\frac{\overline{F_1}-\overline{MP}}{\sqrt{\frac{Me}{r}\times\frac{3}{2}}}$

Better parent heterosis = $\frac{\overline{F_1}-\overline{BP}}{\sqrt{\frac{M_e}{r}\times\frac{3}{2}}}$

c. Standard heterosis = $\frac{\overline{F_1}-\overline{SC}}{\sqrt{\frac{Me}{r}\times\frac{3}{2}}}$

Where, r : Number of replications

M_e : Error variance

Significance of 't' is tested by referring to 't' table at the appropriate error degrees of freedom.

Results and Discussion

The heterosis over mid parent for total soluble solids ranged from -5.50 (NSS 10A × RSSV 76) to 17.46% (NSS 1007A × CSV 19SS) and 19 hybrids exhibited significant positive heterosis over mid parent. The range of heterobeltiosis was from -10.23 (NSS 10A × CSV 19SS) to 12.09% (NSS 10A × RSSV 120) and eight hybrids expressed significant positive heterosis. The hybrids namely, NSS 10A × RSSV 120 (12.09%), NSS 10A × M 11 (8.69%) and NSS 8A × RSSV 76 (8.68%) occupied first three positions for better parental heterosis. Positive and significant superiority over commercial check CSH 22SS was exhibited by three cross combinations with a range from -10.89 (NSS 10A × RSSV 76) to 9.35% (RS 1220A × SSV 84). The range of standard heterosis over check PAC 52093 varied from -11.69% (NSS 10A × RSSV 76) to 8.36% (RS 1220A × SSV 84). Three hybrids exhibited significant positive heterosis over this check. Vinaykumar *et al*. (2011) pointed out similar result of significant positive heterobeltiosis and standard heterosis in sweet sorghum.The range of standard heterosis was from -2.63 (RS 1220A × SSV 84) to -20.65% (NSS 10A × RSSV 76) against check NSSV 13. None of the hybrids was superior to this check.The hybrids *viz.,* RS 1220A × SSV 84 (9.35% and 8.36%) expressed maximum positive standard heterosis followed by NSS 1007A × CSV 19SS (8.83% and 7.86%) and NSS 10A × RSSV 120 (6.61% and 5.65%) against checks CSH 22SS and PAC 52093 respectively (Table 1).

For total biomass the mid parental heterosis ranged from -22.98 (NSS 10A × RSSV 76) to 71.34% (NSS 1007A × M 11). Twenty-three hybrids performed significant positive heterosis. The other top hybrids

Table 1. Mean performance, Relative Heterosis (RH), Heterobeltiosis (HB) and Standard Heterosis (SH) for total soluble solids over three locations in sweet sorghum

S. No.	Hybrid	Total soluble solids (%)					
		Per se	MP Heterosis(%)	BP Heterosis(%)	STD Heterosis(%) CSH 22SS	PAC 52093	NSSV 13
1	NSS 8A × SSV 84	14.28	0.87	-5.92*	-3.29	-4.16	-13.88**
2	NSS8A×M11	14.43	6.53**	3.40	-2.27	-3.15	-12.98**
3	NSS 8A × CSV 19SS	15.39	7.40**	-0.85	4.21	3.28	-7.20**
4	NSS 8A × SSV 74	14.20	1.53	-4.32	-3.80	-4.66*	-14.34**
5	NSS 8A × RSSV 76	15.39	12.77**	8.68**	4.24	3.31	-7.17
6	NSS 8A × RSSV 120	14.85	9.30**	5.76*	0.59	-0.32	-10.43
7	NSS 10A × SSV 84	15.03	4.16*	-0.97	1.80	0.88	-9.35
8	NSS 10A × M 11	15.17	9.77**	8.69**	2.73	1.81	-8.52**
9	NSS 10A × CSV 19SS	13.93	-4.58*	-10.23**	-5.64*	-6.49**	-15.98**
10	NSS 10A × SSV 74	13.77	-3.47	-7.25**	-6.75**	-7.59**	-16.96**
11	NSS 10A × RSSV 76	13.16	-5.50*	-7.10**	-10.89**	-11.69**	-20.65**
12	NSS 10A × RSSV 120	15.74	13.55**	12.09**	6.61**	5.65*	-5.07*
13	NSS 1007A × SSV 84	15.17	12.30**	-0.04	2.75	1.83	-8.50**
14	NSS 1007A × M 11	14.67	13.72**	5.11*	-0.66	-1.55	-11.54**
15	NSS 1007A × CSV 19SS	16.07	17.46**	3.54	8.83**	7.86**	-3.09
16	NSS 1007A × SSV 74	15.37	15.21**	3.56	4.12	3.19	-7.28**
17	NSS 1007A × RSSV 76	15.22	17.06**	7.47**	3.08	2.16	-8.21**
18	NSS 1007A × RSSV 120	14.84	14.68**	5.70*	0.53	-0.38	-10.48**
19	NSS 1016A × SSV 84	14.46	6.02**	-4.74*	-2.07	-2.95	-12.80**
20	NSS 1016A × M 11	14.47	11.08**	3.69	-2.00	-2.88	-12.73**
21	NSS 1016A × CSV 19SS	14.37	4.07	-7.40**	-2.67	-3.55	-13.33**
22	NSS 1016A × SSV 74	14.13	4.86*	-4.84*	-4.33	-5.19*	-14.81**
23	NSS 1016A × RSSV 76	14.30	8.89**	0.96	-3.16	-4.03	-13.77**
24	NSS 1016A × RSSV 120	13.39	2.42	-4.67	-9.33**	-10.15**	-19.26**
25	RS 1220A × SSV 84	16.14	9.63**	6.37**	9.35**	8.36**	-2.63
26	RS 1220A × M 11	14.20	0.61	-0.52	-3.82	-4.68*	-14.35**
27	RS 1220A × CSV 19SS	14.18	-4.81*	-8.62**	-3.95	-4.81*	-14.47**
28	RS 1220A × SSV 74	15.39	5.67**	3.65	4.21	3.27	-7.21**
29	RS 1220A × RSSV 76	14.76	3.81	3.40	-0.02	-0.92	-10.97**
30	RS 1220A × RSSV 120	14.49	2.37	1.53	-1.83	-2.71	-12.58**
	S.Em±		0.30	0.35		0.35	
	CD at 5 %		0.60	0.69		0.69	
	CD at 1 %		0.79	0.91		0.91	

MP: Mid Parental heterosis; BP: Better Parental heterosis, STD heterosis: Standard heterosis * Significance at 5% level; ** Significance at 1% level

viz., RS 1220A × M 11 and NSS 1016A × SSV 84 exhibited significant positive mid parental heterosis of 62.36% and 62.23% respectively. The magnitude of heterosis over the better parent was in the range of -36.02 (NSS 10A × RSSV 76) to 45.67% (RS 1220A × M 11). Twelve hybrids showed significant positive heterobeltiosis. The top hybrids that marked performance in positive direction were *viz.,* RS 1220A × M 11, NSS 1007A × M 11 and RS 1220A × RSSV 76 with 45.67%, 35.19% and 29.22% heterosis, respectively. For standard heterosis over check CSH 22SS, the F_1 hybrids range varied from -49.99 (NSS 10A × RSSV 76) to 2.05% (RS 1220A × RSSV 120). The range of standard heterosis over check PAC 52093 was from -36.77 (NSS 10A × RSSV 76) to 29.01% (RS 1220A × RSSV 120). Eight hybrids recorded significant positive standard heterosis over the check PAC 52093. A range of -44.82 (NSS 10A × RSSV 76) to 12.58% (RS 1220A × RSSV 120) was observed for standard heterosis over the standard check NSSV 13. Four hybrids exhibited significant positive heterosis over this standard check. The hybrids namely, RS 1220A × RSSV 120 exhibited maximum standard heterosis in positive direction

Table 2. Mean performance, Relative Heterosis (RH), Heterobeltiosis (HB) and Standard Heterosis (SH) for total biomass over three locations in sweet sorghum

S. No.	Hybrid	Total biomass (t ha-1)					
		Per se	MP	BP	STD Heterosis(%)		
			Heterosis(%)	Heterosis(%)	CSH 22SS	PAC 52093	NSSV 13
1	NSS 8A × SSV 84	61	24.45**	-3.87	-24.30**	-4.31	-16.49**
2	NSS8A×M11	45	6.64	-9.74*	-44.10**	-29.33**	-38.33**
3	NSS 8A × CSV 19SS	72	39.84**	5.62	-11.26**	12.19**	-2.10
4	NSS 8A × SSV 74	73	57.78**	26.66**	-10.27**	13.44**	-1.00
5	NSS 8A × RSSV 76	68	38.83**	7.51*	-15.96**	6.25	-7.28*
6	NSS 8A × RSSV 120	58	17.12**	-10.11**	-27.92**	-8.88*	-20.48**
7	NSS 10A × SSV 84	55	3.08	-14.62**	-32.77**	-15.01**	-25.83**
8	NSS 10A × M 11	51	11.37**	2.17	-36.72**	-20.01**	-30.19**
9	NSS 10A × CSV 19SS	83	50.20**	21.31**	1.93	28.85**	12.45**
10	NSS 10A × SSV 74	67	34.61**	16.43**	-17.52**	4.27	-9.00**
11	NSS 10A × RSSV 76	41	-22.98**	-36.02**	-49.99**	-36.77**	-44.82**
12	NSS 10A × RSSV 120	51	-4.94	-21.83**	-37.31**	-20.76**	-30.84**
13	NSS 1007A × SSV 84	48	3.98	-24.38**	-40.45**	-24.72**	-34.31**
14	NSS 1007A × M 11	68	71.34**	35.19**	-16.28**	5.84	-7.63*
15	NSS 1007A × CSV 19SS	73	50.42**	7.25*	-9.88**	13.92**	-0.58
16	NSS 1007A × SSV 74	65	49.35**	12.41**	-20.37**	0.67	-12.15**
17	NSS 1007A × RSSV 76	49	5.53	-23.07**	-39.86**	-23.98**	-33.65**
18	NSS 1007A × RSSV 120	53	12.27**	-18.80**	-34.89**	-17.69**	-28.17**
19	NSS 1016A × SSV 84	80	62.23**	24.73**	-1.78	24.16**	8.35**
20	NSS 1016A × M 11	55	28.98**	8.58	-32.75**	-14.99**	-25.81**
21	NSS 1016A × CSV 19SS	51	-1.32	-25.79**	-37.65**	-21.18**	-31.21**
22	NSS 1016A × SSV 74	62	34.53**	7.47	-23.87**	-3.76	-16.01**
23	NSS 1016A × RSSV 76	66	35.28**	4.28	-18.48**	3.06	-10.06**
24	NSS 1016A × RSSV 120	60	21.00**	-7.56*	-25.87**	-6.29	-18.22**
25	RS 1220A × SSV 84	62	19.43**	-2.98	-23.60**	-3.42	-15.72**
26	RS 1220A × M 11	73	62.36**	45.67**	-9.78**	14.05**	-0.47
27	RS 1220A × CSV 19SS	64	17.68**	-6.71*	-21.61**	-0.91	-13.52**
28	RS 1220A × SSV 74	67	37.50**	16.49**	-17.48**	4.32	-8.96**
29	RS 1220A × RSSV 76	82	58.61**	29.22**	1.02	27.70**	11.44**
30	RS 1220A × RSSV 120	83	57.75**	27.26**	2.05	29.01**	12.58**
	S.Em±		1.96	2.26		2.26	
	CD at 5 %		3.90	4.45		4.45	
	CD at 1 %		5.09	5.87		5.87	

MP: Mid Parental heterosis; BP: Better Parental heterosis, STD heterosis: Standard heterosis * Significance at 5% level; ** Significance at 1% level

followed by NSS 10A × CSV 19SS and RS 1220A × RSSV 76 against the checks CSH 22SS and PAC 52093 (Table 2).

Among the sweet sorghum hybrids for fresh stalk yield the range was from -12.58 (NSS 10A × RSSV 76) to 46.25% (NSS 1016A × SSV 84) for mid parent heterosis for fresh stalk yield. Twenty- four out of 30 hybrids displayed significant positive mid parental heterosis. The better parent heterosis varied between -26.62 (NSS 10A × RSSV 76) and 28.81% (RS 1220A × SSV 74) and 8 hybrids showed significant positive better parental heterosis. These results are in conformity with the results of Vinaykumar *et al*. (2011). The range of standard heterosis speckled from -32.58 (NSS 10A × RSSV 76) to 10.78% (NSS 8A × CSV 19SS) over check CSH 22SS and only two hybrids (NSS 8A × CSV 19SS and RS 1220A × SSV 74) exhibited significant positive standard heterosis over this check. The range of heterosis over the standard check PAC 52093 was from -20.03 (NSS 10A × RSSV 76) to 31.40% (NSS 8A × CSV 19SS). Ten hybrids exhibited significant positive heterosis over check PAC 52093. The standard heterosis over the check NSSV 13 was varied from -27.20 (NSS 10A × RSSV 76) to 19.62% (NSS 8A × CSV 19SS). Seven hybrids showed significant positive standard heterosis over this check. The highest positive standard heterosis of 10.78%, 31.40% and 19.62% over check CSH 22SS, PAC 52093 and NSSV 13 respectively was exhibited by the hybrid NSS 8A × CSV 19SS (Table 3) . Similar results were earlier reported by Pothisoong and Jaisil (2011).

Table 3. Mean performance, Relative Heterosis (RH), Heterobeltiosis (HB) and Standard Heterosis (SH) for fresh stalk yield over three locations in sweet sorghum

S. No.	Hybrid	Fresh stalk yield (t ha-1)					
		Per se	MP	BP	STD Heterosis(%)		
			Heterosis(%)	Heterosis(%)	CSH 22SS	PAC 52093	NSSV 13
1	NSS 8A × SSV 84	44	29.62**	3.81	-8.69**	8.30*	-1.41
2	NSS8A×M11	40	26.71**	6.63	-17.39**	-2.01	-10.80**
3	NSS 8A × CSV 19SS	54	42.24**	7.72*	10.78**	31.40**	19.62**
4	NSS 8A × SSV 74	46	36.80**	11.17**	-5.9	11.62**	1.61
5	NSS 8A × RSSV 76	43	23.86**	-2.4	-10.32**	6.37	-3.17
6	NSS 8A × RSSV 120	39	0.93	-24.61**	-19.20**	-4.16	-12.76**
7	NSS 10A × SSV 84	41	11.92**	-4.36	-15.88**	-0.22	-9.17**
8	NSS 10A × M 11	41	21.03**	9.24*	-15.37**	0.38	-8.62*
9	NSS 10A × CSV 19SS	51	27.24**	2.21	5.12	24.68**	13.50**
10	NSS 10A × SSV 74	42	17.21**	1.79	-13.83**	2.2	-6.96*
11	NSS 10A × RSSV 76	33	-12.58**	-26.62**	-32.58**	-20.03**	-27.20**
12	NSS 10A × RSSV 120	43	5.21	-16.78**	-10.81**	5.8	-3.69
13	NSS 1007A × SSV 84	36	7.3	-16.07**	-26.18**	-12.44**	-20.29**
14	NSS 1007A × M 11	39	26.08**	3.43	-19.87**	-4.95	-13.48**
15	NSS 1007A × CSV 19SS	50	36.54**	1.23	4.11	23.48**	12.41**
16	NSS 1007A × SSV 74	42	29.24**	2.52	-13.21**	2.94	-6.29
17	NSS 1007A × RSSV 76	39	12.66**	-13.23**	-20.28**	-5.44	-13.92**
18	NSS 1007A × RSSV 120	42	10.50**	-19.16**	-13.35**	2.78	-6.44
19	NSS 1016A × SSV 84	49	46.25**	15.75**	1.81	20.76**	9.93**
20	NSS 1016A × M 11	42	33.82**	11.19**	-13.86**	2.18	-6.99*
21	NSS 1016A × CSV 19SS	43	14.68**	-14.08**	-11.63**	4.82	-4.58
22	NSS 1016A × SSV 74	41	24.79**	0.19	-15.19**	0.6	-8.42*
23	NSS 1016A × RSSV 76	40	14.62**	-10.71**	-17.96**	-2.69	-11.42**
24	NSS 1016A × RSSV 120	39	1.84	-24.72**	-19.32**	-4.3	-12.88**
25	RS 1220A × SSV 84	42	13.32**	-1.49	-13.35**	2.78	-6.44
26	RS 1220A × M 11	48	38.32**	27.15**	-1.49	16.84**	6.37
27	RS 1220A × CSV 19SS	43	5.7	-13.76**	-11.31**	5.2	-4.24
28	RS 1220A × SSV 74	53	45.75**	28.81**	9.04**	29.33**	17.74**
29	RS 1220A × RSSV 76	48	27.37**	8.71*	-0.11	18.48**	7.85*
30	RS 1220A × RSSV 120	49	16.98**	-6.06*	0.69	19.43**	8.72*
	S.Em±		1.36	1.57		1.57	
	CD at 5 %		2.68	3.09		3.09	
	CD at 1 %		3.53	4.08		4.08	

MP: Mid Parental heterosis; BP: Better Parental heterosis, STD heterosis: Standard heterosis * Significance at 5% level; ** Significance at 1% level

The relative heterosis for the trait juice yield ranged from -12.57 (NSS 10A × RSSV 76) to 82.04% (NSS 1016A × M 11). Twenty five out of 30 hybrids accounted positive mid parental heterosis. Heterobeltiosis varied from -29.98 (NSS 1007A × SSV 84) to 62.65% (RS 1220A × M 11) and seven hybrids had shown significant positive heterobeltiosis. Vinaykumar *et al.* (2011) have also observed significant positive heterobeltiosis. Heterosis exhibited by hybrids over standard check CSH 22SS ranged from -46.39 (NSS 10A × RSSV 76) to 6.92% (NSS 1007A × CSV 19SS) and none of the hybrids expressed significant positive heterosis. The range of standard heterosis over check PAC 52093 differed from -39.50 (NSS 10A × RSSV 76) to 20.67% (NSS 1007 × CSV 19SS) and two hybrids (NSS 1007A × CSV 19SS and RS 1220A × CSV 19SS) exhibited significant positive standard heterosis. The range of heterosis over the standard check NSSV 13 was -42.08 (NSS 10A × RSSV 76) to 15.53% (NSS 1007A × CSV 19SS) and two hybrids exhibited significant positive standard heterosis. The hybrid NSS 1007A × CSV 19SS revealed the highest significant positive standard heterosis of 20.67% and 15.53% over checks PAC 52093 and NSSV 13 respectively (Table 4). Positive standard heterosis over checks was also noted by Pothisoong and Jaisil (2011) and Vinaykumar *et al*. (2011).

Mid parental heterosis for juice extraction per cent was significantly highest in the affirmative direction (16.77%) in the hybrid NSS 1016A × M 11 while RS 1220A × RSSV 76 registered the lowest

Table 4. Mean performance, Relative Heterosis (RH), Heterobeltiosis (HB) and Standard Heterosis (SH) for juice yield over three locations in sweet sorghum

S. No.	Hybrid	Juice yield (l ha^{-1})					
		Per se	MP Heterosis(%)	BP Heterosis(%)	STD Heterosis(%) CSH 22SS	PAC 52093	NSSV 13
1	NSS 8A × SSV 84	10496	39.28**	-1.95	-16.49**	-5.75	-9.77
2	NSS8A×M11	9563	73.35**	43.45**	-23.91**	-14.12*	-17.78**
3	NSS 8A × CSV 19SS	12471	54.41**	5.81	-0.77	11.99	7.22
4	NSS 8A × SSV 74	11994	73.70**	27.02**	-4.57	7.70	3.11
5	NSS 8A × RSSV 76	8839	27.10**	-7.36	-29.67**	-20.62**	-24.01**
6	NSS 8A × RSSV 120	9800	19.68*	-18.40**	-22.02**	-11.99	-15.74*
7	NSS 10A × SSV 84	9428	13.77	-11.92	-24.98**	-15.34*	-18.95**
8	NSS 10A × M 11	8983	43.32**	34.75**	-28.52**	-19.33**	-22.77**
9	NSS 10A × CSV 19SS	12649	43.29**	7.32	0.65	13.59	8.75
10	NSS 10A × SSV 74	10495	37.09**	11.15	-16.49**	-5.75	-9.77
11	NSS 10A × RSSV 76	6737	-12.57	-29.40**	-46.39**	-39.50**	-42.08**
12	NSS 10A × RSSV 120	9757	9.14	-18.76**	-22.36**	-12.38	-16.12*
13	NSS 1007A × SSV 84	7495	4.92	-29.98**	-40.36**	-32.70**	-35.56**
14	NSS 1007A × M 11	7988	55.86**	19.81	-36.44**	-28.27**	-31.33**
15	NSS 1007A × CSV 19SS	13438	74.86**	14.01*	6.92	20.67**	15.53*
16	NSS 1007A × SSV 74	9457	45.21**	0.15	-24.75**	-15.07*	-18.69**
17	NSS 1007A × RSSV 76	8759	33.47**	-8.21	-30.31**	-21.34**	-24.70**
18	NSS 1007A × RSSV 120	9958	27.72**	-17.09**	-20.76**	-10.58	-14.39*
19	NSS 1016A × SSV 84	11076	52.87**	3.47	-11.87	-0.54	-4.78
20	NSS 1016A × M 11	9515	82.04**	42.72**	-24.29**	-14.56*	-18.20**
21	NSS 1016A × CSV 19SS	10359	33.04**	-12.11	-17.57**	-6.97	-10.94
22	NSS 1016A × SSV 74	10740	62.37**	13.74	-14.54*	-3.55	-7.67
23	NSS 1016A × RSSV 76	8325	24.92*	-12.75	-33.76**	-25.24**	-28.42**
24	NSS 1016A × RSSV 120	9283	17.52*	-22.71**	-26.14**	-16.64*	-20.19**
25	RS 1220A × SSV 84	9460	9.97	-11.62	-24.73**	-15.05*	-18.67**
26	RS 1220A × M 11	10843	64.70**	62.65**	-13.72*	-2.63	-6.78
27	RS 1220A × CSV 19SS	11807	29.13**	0.18	-6.05	6.03	1.51
28	RS 1220A × SSV 74	13307	66.93**	40.93**	5.89	19.50**	14.41*
29	RS 1220A × RSSV 76	10843	35.17**	13.63	-13.72*	-2.63	-6.78
30	RS 1220A × RSSV 120	12110	30.84**	0.83	-3.64	8.75	4.11
	S.Em±		672.77	776.84		776.84	
	CD at 5 %		1327.83	1533.25		1533.25	
	CD at 1 %		1752.13	2023.20		2023.20	

MP: Mid Parental heterosis; BP: Better Parental heterosis, STD heterosis: Standard heterosis * Significance at 5% level; ** Significance at 1% level

value of -13.10%. Six hybrids exhibited significant positive mid parental heterosis. The heterosis over better parent ranged from -17.85% (RS 1220A × RSSV 76) to 12.53% (NSS 1016A × SSV74) and only two hybrids (NSS 1016A × SSV 74 and NSS 1016A × RSSV 120) expressed significant positive heterobeltiosis. The extent of percentage of standard heterosis exhibited by the 30 hybrids over check CSH 22SS ranged from -13.79 (RS 1220A × RSSV 76) to 18.02% (NSS 8A × RSSV 120). Seven hybrids out of 30, exhibited the positive significant standard heterosis. Pothisoong and Jaisil (2011) in sweet sorghum observed economic superiority for this trait. The range of standard heterosis over check PAC 52093 was from -3.70 (NSS 8A × RSSV 120) to -29.65% (RS 1220A × RSSV 76). None of the hybrids recorded significant positive standard heterosis. A range of -24.99 (RS 1220A × RSSV 76) to 2.68% (NSS 8A × RSSV 120) for commercial heterosis was exhibited over standard check NSSV 13. None of the hybrids exhibited significant positive heterosis over the standard check NSSV 13 (Table 5).

For bioethanol yield, the range of mid parent heterosis differed from -18.45 (NSS 10A × RSSV 76) to 80.45% (NSS 1007A × CSV 19 SS). Twenty one hybrids exhibited significance in positive direction. Better parental heterosis varied between -36.82 (NSS 1016A × RSSV 120) and 40.54% (RS 1220A × SSV 74). Three hybrids (NSS 8A × SSV 74, RS 1220A × SSV 74 and RS 1220A × RSSV 76) showed significance towards positive direction. A range of -52.58 (NSS 10A × RSSV 76) to 15.26% (NSS 1007A × CSV 19SS) was exhibited over the

Table 5. Mean performance, Relative Heterosis (RH), Heterobeltiosis (HB) and Standard Heterosis (SH) for juice extraction per cent over three locations in sweet sorghum

S. No.	Hybrid	Juice extraction per cent					
		Per se	MP Heterosis(%)	BP Heterosis(%)	STD Heterosis(%)		
					CSH 22SS	PAC 52093	NSSV 13
1	NSS 8A × SSV 84	37.43	-4.66	-4.96	4.93	-14.38**	-8.71
2	NSS8A×M11	38.05	9.20*	-2.79	6.65	-12.98**	-7.21
3	NSS 8A × CSV 19SS	35.17	-7.52	-10.14*	-1.42	-19.56**	-14.23**
4	NSS 8A × SSV 74	39.81	5.07	1.72	11.60*	-8.94*	-2.91
5	NSS 8A × RSSV 76	35.10	-3.15	-10.31*	-1.6	-19.71**	-14.39**
6	NSS 8A × RSSV 120	42.10	13.20**	7.58	18.02**	-3.7	2.68
7	NSS 10A × SSV 84	36.02	-7.02	-8.55	0.97	-17.62**	-12.16**
8	NSS 10A × M 11	36.00	4.9	-5.48	0.91	-17.66**	-12.21**
9	NSS 10A × CSV 19SS	36.13	-3.65	-5.13	1.29	-17.36**	-11.88**
10	NSS 10A × SSV 74	40.03	7.12	5.09	12.21*	-8.45*	-2.38
11	NSS 10A × RSSV 76	35.74	0.06	-6.17	0.18	-18.26**	-12.84**
12	NSS 10A × RSSV 120	37.83	3.18	-0.67	6.06	-13.46**	-7.73
13	NSS 1007A × SSV 84	38.51	0.31	-2.21	7.96	-11.91**	-6.08
14	NSS 1007A × M 11	36.20	6.55	-3.22	1.48	-17.20**	-11.72**
15	NSS 1007A × CSV 19SS	39.99	7.62	6.91	12.10*	-8.53*	-2.47
16	NSS 1007A × SSV 74	37.20	0.47	-0.56	4.27	-14.92**	-9.29*
17	NSS 1007A × RSSV 76	34.73	-1.82	-7.15	-2.64	-20.56**	-15.30**
18	NSS 1007A × RSSV 120	34.59	-4.78	-7.52	-3.03	-20.88**	-15.64**
19	NSS 1016A × SSV 84	36.41	-4.23	-7.54	2.07	-16.71**	-11.20*
20	NSS 1016A × M 11	39.24	16.77**	7.03	9.99	-10.25*	-4.31
21	NSS 1016A × CSV 19SS	37.66	2.38	2.03	5.58	-13.85**	-8.15
22	NSS 1016A × SSV 74	41.25	12.55**	12.53*	15.64**	-5.64	0.6
23	NSS 1016A × RSSV 76	34.61	-1.11	-5.58	-2.97	-20.83**	-15.58**
24	NSS 1016A × RSSV 120	40.47	12.56**	10.39*	13.45**	-7.43	-1.3
25	RS 1220A × SSV 84	35.26	-8.20*	-10.47*	-1.15	-19.35**	-14.00**
26	RS 1220A × M 11	35.15	3.41	-6.11	-1.46	-19.60**	-14.27**
27	RS 1220A × CSV 19SS	37.9	1.95	1.24	6.25	-13.30**	-7.56
28	RS 1220A × SSV 74	37.56	1.39	0.31	5.28	-14.10**	-8.41
29	RS 1220A × RSSV 76	30.76	-13.10**	-17.85**	-13.79**	-29.65**	-24.99**
30	RS 1220A × RSSV 120	39.8	9.51*	6.31	11.57*	-8.96*	-2.93
	S.Em±		1.58	1.82		1.82	
	CD at 5 %		3.11	3.60		3.60	
	CD at 1 %		4.10	4.74		4.74	

MP: Mid Parental heterosis; BP: Better Parental heterosis, STD heterosis: Standard heterosis * Significance at 5% level; ** Significance at 1% level

standard check CSH 22SS and only one hybrid (NSS 1007A × CSV 19SS) exhibited significant positive heterosis over this check. The range of heterosis over the standard check PAC 52093 was from -49.18 (NSS 10A × RSSV 76) to 23.55% (NSS 1007A × CSV 19SS) . Significant and positive heterosis was exhibited by two hybrids (NSS 1007A × CSV 19SS and RS 1220A × SSV 74) over this check. The range of standard heterosis was from -54.36 (NSS 10A × RSSV 76) to 10.94% (NSS 1007A ´ CSV 19SS) and none of the hybrids exhibited significant positive heterosis. The hybrid, NSS 1007A × CSV 19SS demonstrated significantly highest positive standard heterosis of 15.26% and 23.55% over the checks CSH 22SS and PAC 52093 respectively (Table 6). These results are in agreement with Vinaykumar *et al.* (2011) and Pothisoong and Jaisil (2011).

Higher level heterosis in a cross always represents genetically more diverse parents than those crosses, which show little or no heterosis.

From the results, an appreciable level of heterosis over standard checks and better parent was evident for the characters under study. The hybrids, *viz.,* NSS 8A × CSV 19SS and NSS 10A × CSV 19SS for total biomass and fresh stalk yield; NSS 8A × SSV 74 for total biomass, fresh stalk yield and juice extraction per cent; NSS 1007A × CSV 19SS for fresh stalk yield, juice yield, juice extraction per cent and ethanol yield; RS 1220A × RSSV 120 for total biomass, fresh stalk yield and juice extraction per cent and RS 1220A × SSV 74 for fresh stalk yield, juice yield and ethanol yield exhibited significant positive standard heterosis over at least one check. The hybrid, NSS 1007A × CSV 19SS could be suggested for commercial exploitation of heterosis as it exhibited significant and positive standard heterosis for ethanol yield and its contributing traits. In the present investigation, the hybrids *viz.,* RS 1220A × SSV 84 for total soluble solids, NSS10A × CSV19SS and RS 1220A × RSSV 120 for total biomass, RS 1220A × SSV 74 and NSS 8A × CSV19SS for fresh stalk

Table 6. Mean performance, Relative Heterosis (RH), Heterobeltiosis (HB) and Standard Heterosis (SH) for bioethanol yield over three locations in sweet sorghum

S. No.	Hybrid	Bioethanol yield (l ha-1)					
		Per se	MP Heterosis(%)	BP Heterosis(%)	STD Heterosis(%)		
					CSH 22SS	PAC 52093	NSSV 13
1	NSS 8A × SSV 84	849	38.15**	-6.59	-14.86*	-8.74	-18.06**
2	NSS8A×M11	747	26.47*	-13.26	-25.08**	-19.69**	-27.89**
3	NSS 8A × CSV 19SS	1067	59.55**	4.90	6.95	14.64	2.94
4	NSS 8A × SSV 74	950	75.54**	24.66**	-4.76	2.09	-8.33
5	NSS 8A × RSSV 76	741	39.54**	-0.09	-25.74**	-20.40**	-28.52**
6	NSS 8A × RSSV 120	789	19.38*	-21.22**	-20.89**	-15.20*	-23.86**
7	NSS 10A × SSV 84	776	16.98	-14.58	-22.15**	-16.55*	-25.07**
8	NSS 10A × M 11	729	13.90	-15.39	-26.92**	-21.66**	-29.66**
9	NSS 10A × CSV 19SS	908	26.54**	-10.70	-8.95	-2.40	-12.36
10	NSS 10A × SSV 74	793	34.30**	4.02	-20.52**	-14.81	-23.50**
11	NSS 10A × RSSV 76	473	-18.45	-36.21**	-52.58**	-49.18**	-54.36**
12	NSS 10A × RSSV 120	791	11.44	-21.00**	-20.67**	-14.96*	-23.64**
13	NSS 1007A × SSV 84	613	5.13	-32.56**	-38.54**	-34.12**	-40.84**
14	NSS 1007A × M 11	610	9.10	-29.16**	-38.81**	-34.42**	-41.11**
15	NSS 1007A × CSV 19SS	1150	80.45**	13.05	15.26*	23.55**	10.94
16	NSS 1007A × SSV 74	785	54.00**	2.99	-21.31**	-15.66*	-24.27**
17	NSS 1007A × RSSV 76	740	48.21**	-0.18	-25.80**	-20.47**	-28.59**
18	NSS 1007A × RSSV 120	802	27.39**	-19.95**	-19.61**	-13.83	-22.62**
19	NSS 1016A × SSV 84	889	50.31**	-2.25	-10.91	-4.50	-14.25*
20	NSS 1016A × M 11	740	30.46**	-14.07	-25.78**	-20.44**	-28.57**
21	NSS 1016A × CSV 19SS	829	28.50**	-18.48**	-16.88*	-10.90	-20.00**
22	NSS 1016A × SSV 74	822	58.75**	7.84	-17.60*	-11.68	-20.69**
23	NSS 1016A × RSSV 76	643	26.72*	-13.28	-35.54**	-30.91**	-37.96**
24	NSS 1016A × RSSV 120	633	-0.73	-36.82**	-36.55**	-31.99**	-38.93**
25	RS 1220A × SSV 84	824	15.83	-9.40	-17.42*	-11.49	-20.52**
26	RS 1220A × M 11	819	19.21*	-4.90	-17.86*	-11.95	-20.94**
27	RS 1220A × CSV 19SS	883	15.42	-13.18	-11.48	-5.11	-14.80*
28	RS 1220A × SSV 74	1071	67.98**	40.54**	7.38	15.09*	3.35
29	RS 1220A × RSSV 76	897	43.04**	21.01*	-10.05	-3.58	-13.42*
30	RS 1220A × RSSV 120	987	30.34**	-1.45	-1.04	6.08	-4.75
	S.Em±		60.76	70.16		70.16	
	CD at 5 %		119.93	138.48		138.48	
	CD at 1 %		158.25	182.73		182.73	

MP: Mid Parental heterosis; BP: Better Parental heterosis, STD heterosis: Standard heterosis * Significance at 5% level; ** Significance at 1% level

yield, RS 1220A × SSV 74 and NSS 1007A × CSV 19SS for juice yield, NSS 8A ×RSSV 120 for juice extraction percent and RS 1220A × SSV 74 and NSS 1007A × CSV 19SS for ethanol yield manifested high *per se* performance along with high heterosis. Hence, it can be concluded that *per se* performance coupled with heterosis would be more reliable in identification and isolation of superior hybrids, thus weightage should be given to both *per se* performance as well as heterosis.

References

Bartlett, M.S. 1937. Some examples of statistical methods of research in agriculture and applied biology. *J. Royal Stat. Soc.,* **4:** 137-170.

Hayes, H.K., Immer, F.R. and Smith, D.C. 1955. *Methods of Plant Breeding*. Mc. Grow Hill Book. Co. Inc. New York.

Pothisoong, T. and Jaisil, P. 2011. Yield potential, heterosis and ethanol production in F_1 hybrids of sweet sorghum (*Sorghum bicolor* L. Moench). *KMITL Sci. Tech..,* **11:** 17-24.

Ratnavathi, C.V. 2008. Alternative Uses of Sorghum Grain and Other Products. National Research Center for Sorghum, Hyderabad, India.

Reddy, B.V.S., Ramesh, S., Sanjana Reddy, P., Ramaiah, B., Salimath, P.M. and Rajashekhar, K. 2005. Sweet sorghum – alternative raw material for bio-ethanol and bio-energy. *Int. Sorghum and Millets Newsletter*. **46:** 79-86.

Sankarapandian, R., Ramalingam, J., Arumungam Pillai, M. and Vanniarajan, C. 1994. Heterosis and combining ability studies for juice yield related characteristics in sweet sorghum. *Ann. Agric. Res.,* **15 :** 199-204.

Turner, J.K. 1953. A study of heterosis in upland cotton. Combining ability and inbreeding effects. *Agron. J.,* **45**: 487-490.

Vinaykumar, R., Jagadeesh, B.N., Sidramappa Talekar, Sandeep, R.G. and Gururaja Rao, M.R. 2011. Combining ability of parents and hybrids for juice yield and its attributing traits in sweet sorghum (*Sorghum bicolor* (L.) Moench). *E. J. Pl. Br.*, **2:** 41-46.

Received: May 10, 2012; Revised: September 21, 2012; Accepted: February 11, 2013