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Heterosis Studies in Sweet Sorghum [*Sorghum bicolor* (L.) Moench] for Bio-ethanol and Its Related Traits

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Sweet sorghum is a potential multipurpose crop for food, feed, and fuel. The present investigation was conducted to study the possibility of exploiting heterosis in breeding for improved ethanol yield in sweet sorghum. A total of sixteen F_1 hybrids crossed in L x T fashion, 8 parents (4lines x 4 testers) and check CSH-22S were evaluated in 3 locations of A.P namely., Agricultural college farm, Bapatla; Regional Agricultural Research Station, Lam, Guntur; Agricultural Research Station, Garikapadu in RBD fashion for days to 50 % flowering, days to maturity, plant height, number of nodes per plant, stem girth, fresh stalk weight, panicle weight, 1000 grain weight, juice yield, brix %, total soluble sugars, ethanol yield and grain yield. The range of heterosis over mid parent, better parent and commercial check indicated that it was high with respect to ethanol productivity related traits particularly juice yield and brix per cent. However, it was deviating for days to 50 per cent flowering, days to maturity, number of nodes per plant, plant height, and 1000 grain weight which has shown negative heterosis. In hybrids, there is an improvement in the juice, brix per cent and ethanol yield, but heterosis is limited for 1000 grain weight and ultimately grain yield. Out of 16 hybrids, six hybrids have performed well in respect of juice yield, brix and ethanol yield.

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Keywords: Sweet sorghum; heterosis; mid parent; better parent; standard parent; ethanol yield.

1. INTRODUCTION

Human dependency on fossil fuel is at its peak leading to the depletion of fossil fuel resources (petroleum) at an alarming rate. Therefore, in order to cut the gap of energy (fossil fuel) demand created by current day lifestyle, the non-conventional energy source in the form of biofuel is one of the best options. Ethanol alone accounts for about 90 per cent of the total biofuel production in the world (Reddy et. al*.* [1]. Globally, ethanol is produced in various countries in the world and its production was 110 billion litres in 2019. (https://afdc.energy.gov) [2] (www.ers.usda.gov) [3]. When ethanol is blended with 95% gasoline it can reduce about 90% CO_2 and 60–80% SO_2. (Halde et. al.[4]. This helps to solve some of the problems of air pollution, reduces the levels of greenhouse gases that are causing climate change and maintains environmental security.

The bioethanol produced from agriculture sources provide eco-friendly energy (Bhatia et. al. [5]. Corn ethanol in the United States and sugarcane ethanol in Brazil have been in commercial practice for many years and there is a search for new crops as the above mentioned are highly staple crops. USA was the lead producer for ethanol sharing 53% of world production using corn as major raw material. (Hoang and Nghiem [6].

India ranked 6_{th} among the leading ethanol producers in the world. In 2020, India still remained one of the biggest importers of the United States ethanol, with a market share of 99 percent. In 2021, India’s ethanol production was forecast at 3.17 billion L, 7% above 2020 and 2021 average ethanol blending rate in gasoline of India was estimated at 7.5 percent, due to accelerated government efforts to divert more feedstock toward ethanol. (Hoang and Nghiem [6]. The present ethanol production is through sugarcane in India given that water availability is poised to become a major constraint to agricultural production in coming years, high input requiring cultivation of sugarcane becomes difficult and sweet sorghum offers a sustainable choice as it requires minimal water and purchased inputs. (Elangovan et. al. [7]; Santos et.al. [8]. Sweet sorghum is similar to grain sorghum but with rich juicy sugar stalks, it becomes a potential raw material resource for bioethanol production. Unlike sugarcane, it can be grown on poor and marginal soils with minimum inputs and could yield three crops a year.

The previous reports on sweet sorghum have shown the existence of heterosis for traits directly or indirectly related to the bioethanol production, including total soluble sugars, green cane yield, and juice yield (Bunphan et.al. [9]; Reddy et. al. [10]. Thus, the establishment of heterosis-based breeding of sweet sorghum has been shown to be a viable alternative. Since the expression of heterosis is under the influence of genetic diversity of parents all the 16 hybrids generated in L x T mating design needs to be evaluated for identification of desirable heterotic combinations as the heterosis phenomenon is confined only to F_1 generation and mostly governed either by nuclear genes alone or in combination and interaction with cytoplasm demands precise estimation in different mean ways available such that the same can be exploited for developing newly developed hybrids in respect of Stalk and ethanol yield and its attributing characters.

2. MATERIALS AND METHODS

The present study involving 16 F_1 hybrids, 8 parents and one hybrid check CSH-22SS were evaluated in Agricultural College, Bapatla in *Rabi*, 2018 for studying the heterosis pattern. The experiment was carried out in randomised block design with 4 rows of each entry with 3 m row length under spacing of 45 x 15 cm at three locations of A.P namely., Agricultural college farm, Bapatla; Regional Agricultural Research Station, Lam, Guntur; Agricultural Research Station, Garikapadu. *The recommended package of practices was followed during the crop season.* The data was recorded on ten randomly tagged competitive plants in each replication in parents and F_1 ’s avoiding border rows. Data was recorded on days to 50 % flowering, days to maturity, plant height, number of nodes per plant, stem girth, fresh stalk weight, panicle weight, 1000 grain weight, juice yield, brix %, total soluble sugars, ethanol yield. For predicting the total soluble sugars by using juice Brix%, the following regression equation given by Corleto and Cazzato as reported by Reddy et. al*.* [1] was used.

Total Soluble Sugars (TSS) = 0.1516 + (Brix % × 0.8746)

Computed ethanol yield (CEY) is measured using the following formula

Total sugar yield (t/ha) = [(TSS %) /100] X Juice yield (L/ha)/1000
CEY = Total sugar yield (t/ha)/5.68) x 3.78 x 1000 x 0.8
(Smith and Buxton [11].
TSS = Total Soluble Sugars

2.1 Statistical Analysis

The data collected was analysed using windowstat software. Pooled Analysis of variance was done for 3 environments. The treatment mean values for each trait was used for the estimation of heterosis. Heterosis over mid parent (MP), better parent (BP) and standard check (SC) were computed by the formulas suggested by Turner [12] and Hayes et. al*.* [13].

Heterosis per cent over mid parent (%) = $\frac{F1-MP}{MP} x\ 100$

Heterosis per cent over better parent (%) = $\frac{F1-BP}{BP} x\ 100$

Heterosis per cent over standard check (%) = $\frac{F1-SC}{SC} x\ 100$

3. RESULTS AND DISCUSSION

Knowledge on the magnitude of heterosis for studied characters is essential to identify better combinations to exploit them through heterosis breeding. Over dominance is attributed towards heterobeltiosis, while commercial superiority of the hybrid may be assessed by evaluating with a standard commercial check (Swaminathan et. al. [14]. Rather than mid parent heterosis and heterobeltiosis the standard, useful or economic heterosis reflecting the actual superiority over the best existing cultivar to be replaced appears to be more relevant and practical. With this point of views the hybrids generated in the present investigation were evaluated and selected on the basis of their standard heterosis. The check CSH-22SS was chosen for the present study. The value of percentage heterosis of hybrids for all the thirteen characters over mid, better and standard parent are given in the Table 1-8.

The Mid parent heterosis character for days to 50 % flowering ranged from –19.78 (ICSA 14035 x GGUB 28) to 21.24 per cent (ICSA 14029 x IS 29308). With respect to standard heterosis and better parent heterosis cross (ICSA 14029 x IS 29308) has shown high positive heterosis (1.67) while cross (ICSA 14035 x GGUB 28) has shown high negative heterosis (-33.40). Prabhakar [15], Umakanth et. al*.* [16], Ringo et. al*.* [17] had reported similar results for this trait. The F_1 hybrid of (ICSA 14029 x IS 29308), is desirable because of positive standard heterosis which can result in late flowering type which is suitable for sweet sorghum. (In the correlation studies the association of days to 50 % flowering is positively associated with ethanol yield).

The character days to maturity recorded high positive mid parent heterosis (12.15) in cross (ICSA 14035 x SEVS -08) and for better parent heterosis (11.04) in cross (ICSA 14030 x SEVS-08) and for standard parent cross ICSA 14030 x IS 29308 (-0.66). Prabhakar [15], Umakanth et. al*.* [16] had reported similar results for this trait while deviated from the result of Manish et. al*.* [18]. Hybrids of crosses ICSA 14030 x IS 29308 (-0.66) were found to be late maturing when compared to standard check variety and are desirable for sweet sorghum for accumulation of sugars. (In the correlation studies the association of days to maturity is positively associated with ethanol yield)

Average heterosis for plant height ranged from -31.54 to 44.49 % whereas heterobeltiosis for the same traits ranged between -49.49 to 33.17 %. As reported by Madhusudhara and Patil, [19] Short sorghums require relatively shorter period to maturity compared to taller ones and withstands lodging as well as easiness during harvesting for grain purpose. In the present study Hybrid (H-7) exhibited positive significant average heterosis and heterobeltiosis. Tall plants can easily lodge but are beneficial in areas where more priority is for fodder, biomass fuel and thatching. When compared to standard check, none of the hybrids have quoted high positive heterosis, while the results are deviating from the results of Ingle et. al. [20] where positive heterosis was observed for the studied F_1 hybrids.

For the trait number of nodes per plant, the highest Positive significant mid parent heterosis was expressed in the cross ICSA 14035 x IS-29308 (17.83) and in case of better parent heterosis cross ICSA 14030 x ICSV 15006 has resulted in positive significant heterosis (8.96) and in case of standard heterosis none of the crosses have resulted in positive heterosis. Pandey and Shrotria [21] had reported positive result in case of standard heterosis. In sweet sorghum number of nodes per plant contribute to overall plant height indirectly so positive heterosis for this trait is important for yielding high biomass types

Stem girth has reported Mid parent negative heterosis value of (-41.41) in cross ICSA 14030 x SEVS -08, better parent value of (- 40.54) was reported in cross ICSA 14033 x SEVS-08 and in cross ICSA 14030 x IS 29308 has reported negative significant heterosis value (-27.13). Stem girth combined with plant height contribute for fresh stalk yield so high stem girth is desirable. In this study positive significant better parent heterosis was observed for ICSA 14030 x IS 29308 (48.35) and for standard parent heterosis cross ICSA 14033 x ICSV-15006 has shown highest value (37.98). Most of the hybrids have shown positive significant values over the better parent like ICSA 14030 x ICSV 15006 (37.21), ICSA 14035 x ICSV-15006 (24.03), ICSA 14030 x GGUB 28 [21.71], ICSA 14029 x ICSV-15006 and ICSA 14035 x SEVS-08 (20.16). Kumar et. al. [22] quoted similar positive heterobeltiosis results.

Cross ICSA 14030 x SEVS -08 has reported (39.43) highest positive significant heterosis, while cross ICSA 14029 x GGUB 28 (4.85) for better parent and ICSA 14030 x SEVS-08 (17.08) for standard parent in the case of panicle weight. Most of the crosses have reported negative heterosis except ICSA 14029 x GGUB 28 (3.77), ICSA 14029 x ICSV-15006(0.57), ICSA 14030 x ICSV 15006 (2.67), ICSA 14030 x IS 29308 (5.13**)** which reported positive standard heterosis. Panicle weight is desirable as it indirectly increases the grain yield. Jadhav and Deshmukh [23] reported similar result for standard heterosis, and Jaikishan et. al*.* [24] recorded positive and significant mid parent and better parent heterosis

Positive heterosis for 1000 grain weight was observed in all the hybrids with respect to mid parent and better patent heterosis except in ICSA 14033 x GGUB -28 (-3.70). Positive heterosis is desirable for this trait, yet no positive standard heterosis was observed in any one of the hybrids. Vyas et. al*.* [25], Totre et. al*.* [26] observed similar results for mid and better parent heterosis. All the hybrids have shown negative standard heterosis for 1000 grain weight. The cross ICSA 14029 x ICSV-15006 has recorded the lowest positive significant heterosis (1.19). The cross ICSA 14033 x GGUB -28 has shown negative significant better parent heterosis (-3.70). The results were deviating from the results of Gite et. al. [27] and Kalpande *e.t al*. [28].

Among the hybrids studied for Fresh stalk yield mid parent heterosis ranged from -40.99 (ICSA 14030 x IS 29308) to 25.58 (ICSA 14030 x ICSV 15006). Whereas the better parent heterosis too varied significantly and ranged from – 47.97 per cent (ICSA 14030 x IS 29308) to 34.59 per cent (ICSA 14033 x SEVS-08). The standard heterosis was found to be significantly positive. In the hybrid *viz.,* (ICSA 14029 x ICSV-15006 with 41.50 percent followed by ICSA 14030 x ICSV 15006 with 40.10 per cent. Kumar et. al. [22] and Chikuta *et al.* [29] has observed similar results. Fresh stalk weight is directly proportionate to the high biomass production. Hence the positive standard heterosis in this character is a welcoming one.

In the heterosis of juice yield, the hybrid ICSA 14033 x GGUB-28 followed by ICSA 14030 x ICSV 15006 and ICSA 14033 x ICSV 15006 have recorded significantly superior mid parent heterosis in positive direction, whereas the hybrid ICSA 14029 x IS 29308 recorded negatively significant heterosis of 42.17 %. The hybrid ICSA 14033 x GGUB-28 has recorded significantly positive better parent heterosis of 69.44 % followed by ICSA 14033 x ICSV 15006 with 34.92 %. The hybrid ICSA 14029 x IS 29308 followed by ICSA 14035 x IS-29308 and ICSA 14035 x GGUB-28 have recorded significantly negative better parent heterosis of -58.66, -40.93 and -38.05 respectively. 11 out of 16 hybrids have recorded significantly positive standard heterosis. The above presented results are in accordance with Vinaykumar [30], Pfeiffer et. al. [31], Sidramappa et. al. [32], Tariq et. al. [33], and Kumar et. al.[22]. Of the remaining five hybrids ICSA 14029 x IS 29308 and ICSA 14033 x IS -29308 have recorded significantly negative standard heterosis.

Table 1. Range of heterosis % in 13 characters of 16 sorghum [*Sorghum bicolor* (L.) Moench] **hybrids**

S. No.	Character	Mid parent	Better parent	Standard parent
1	DAF 50%	-19.58 to 21.24	-24.42 to 15.37	-33.40 to 1.67
2	DM	-12.91 to 12.15	-13.78 to 11.04	-19.82 to -0.66
3	PH	-31.54 to 44.49	-49.49 to 33.17	-48.57 to -13.37
4	N.N.S	-19.44 to 17.83	-34.12 to 8.96	-36.36 to -13.64
5	SG	-41.41 to -3.73	-40.54 to 48.35	-27.13 to 37.98
6	PW	-34.37 to 39.43	-42.29 to 4.85	-31.47 to 17.08
7	1000 GW	1.19 to 54.29	-3.70 to 30.27	-26.71 to -0.86
8	FSTK	-40.99 to 25.58	-47.97 to 34.59	-36.71 to 41.50
9	JY	-42.17 to 78.52	-58.66 to 69.44	-19.62 to 88.65
10	BRIX %	-25.77 to 23.93	-30.61 to -2.08	-20.51 to 23.08
11	TSS	-26.13 to 17.99	-27.87 to -0.86	-12.66 to 22.75
12	EY	-42.07 to 84.69	-41.81 to 54.74	-17.44 to 125.24
13	GY	-34.01 to 39.03	-47.28 to 12.62	-32.08 to 6.1

DAF 50%= Days to 50% flowering (Days), D.M= Days to maturity (Days), PH= Plant height (cm), N.N.S= Number of nodes per plant, SG= Stem girth (cm), PW= Panicle weight (g), 1000 GW= 1000 grain weight (g), FSTK= Fresh stalk yield (T ha^{-1}), JY= Juice yield (l ha^{-1}), Brix %, TSS = Total soluble sugars (%), EY= Ethanol yield (l ha^{-1}), GY = Grain yield (T ha^{-1})

Table 2. Heterosis (%) over mid parent (MP), better parent (BP) and standard heterosis (STD) for days to 50% flowering, days to maturity in 16 Sorghum [*Sorghum bicolor* (L.) Moench] hybrids

		1. Days to 50% flowering			2. Days to maturity		
S.No	**HYBRIDS**	**MP Heterosis**	**BP Heterosis**	**STD Heterosis**	**MP Heterosis**	**BP Heterosis**	**STD Heterosis**
H-1	**ICSA 14029 x SEVS-08**	7.23**	1.47*	-10.58**	8.54**	3.88**	-0.92
H-2	**ICSA 14029 x GGUB 28**	-12.57**	-17.26**	-27.09**	-8.13**	-9.28**	-13.47**
H-3	**ICSA 14029 x ICSV-15006**	3.96**	-0.42	-12.24**	4.53**	2.22**	-2.51**
H-4	**ICSA 14029 x IS 29308**	21.24**	15.37**	1.67**	6.11**	3.46**	-1.32
H-5	**ICSA 14030 x SEVS -08**	15.48**	4.42**	-7.98**	11.13**	11.04**	-3.04**
H-6	**ICSA 14030 x GGUB 28**	-12.46**	-20.84**	-30.24**	-8.42**	-11.22**	-17.44**
H-7	**ICSA 14030 x ICSV 15006**	10.34**	1.05	-10.95**	9.55**	7.25**	-2.25**
H-8	**ICSA 14030 x IS 29308**	14.58**	4.21**	-8.16**	11.66**	9.62**	-0.66
H-9	**ICSA 14033 x SEVS-08**	7.44**	3.37**	-8.91**	3.46**	-1.37	-5.15**
H-10	**ICSA 14033 x GGUB -28**	-12.47**	-15.79**	-25.9**	-3.63**	-5.22**	-8.85**
H-11	**ICSA 14033 x ICSV-15006**	2.70**	0.00	-11.87**	3.10**	0.41	-3.43**

		1. Days to 50% flowering			2. Days to maturity		
S.No	**HYBRIDS**	**MP Heterosis**	**BP Heterosis**	**STD Heterosis**	**MP Heterosis**	**BP Heterosis**	**STD Heterosis**
H-12	**ICSA 14033 x IS-29308**	9.03**	5.47**	-7.05**	0.57	-2.34**	-6.08**
H-13	**ICSA 14035 x SEVS-08**	11.51**	5.05**	-7.42**	12.15 **	9.71**	0.00
H-14	**ICSA 14035 x GGUB 28**	-19.78**	-24.42**	-33.40**	-12.91**	-13.78**	-19.82**
H-15	**ICSA 14035 x ICSV-15006**	5.52**	0.63	-11.32**	7.83**	7.83**	-1.2*
H-16	**ICSA 14035 x IS-29308**	4.22**	-1.26	-12.99**	2.76**	2.46**	-6.61**

*NOTE: * and ** Significant at 5 and 1 per cent level respectively*
MP = Mid parent; BP = Better parent; STD = Standard heterosis Contd

Table 3. Mean performance and heterosis (%) over mid parent (MP), better parent (BP) and standard heterosis (STD) for plant height, number of nodes per plant in 16 Sorghum [*Sorghum bicolor* (L.) Moench] **hybrids**

		3. Plant height (cm)			4. Number of nodes per plant		
S.No	**HYBRIDS**	**MP Heterosis**	**BP Heterosis**	**STD Heterosis**	**MP Heterosis**	**BP Heterosis**	**STD Heterosis**
H-1	**ICSA 14029 x SEVS-08**	-17.61**	-27.99**	-28.90**	-15.28**	-28.24**	-30.68**
H-2	**ICSA 14029 x GGUB 28**	-27.27**	-45.80**	-46.48**	-19.44 **	-31.76**	-34.09**
H-3	**ICSA 14029 x ICSV-15006**	15.38**	12.26**	-13.37**	0.00	-14.12**	-17.05**
H-4	**ICSA 14029 x IS 29308**	3.49**	-20.71**	-21.71**	-10.49**	-24.71**	-27.27**
H-5	**ICSA 14030 x SEVS -08**	17.48**	7.24**	-20.81**	7.94*	1.49	-22.73**
H-6	**ICSA 14030 x GGUB 28**	-5.74**	-15.44**	-48.44**	-14.29**	-19.40**	-38.64**
H-7	**ICSA 14030 x ICSV 15006**	44.49**	33.17**	-18.80**	14.06**	8.96*	-17.05**
H-8	**ICSA 14030 x IS 29308**	36.49**	27.07**	-22.53**	-12.00**	-17.91**	-37.50**
H-9	**ICSA 14033 x SEVS-08**	-9.74**	-20.03**	-23.51**	5.56	-10.59**	-13.64**
H-10	**ICSA 14033 x GGUB -28**	-25.79**	-44.11**	-46.54**	1.39	-14.12**	-17.05**
H-11	**ICSA 14033 x ICSV-15006**	10.69**	-14.90**	-18.60**	-10.96**	-23.53**	-26.4**
H-12	**ICSA 14033 x IS-29308**	0.47	-22.16**	-25.55**	4.90	-11.76**	-14.77**
H-13	**ICSA 14035 x SEVS-08**	-6.26**	-19.14**	-17.67**	6.15	-18.82**	-21.59**
H-14	**ICSA 14035 x GGUB 28**	-31.54**	-49.49**	-48.57**	-13.85**	-34.12**	-36.36**
H-15	**ICSA 14035 x ICSV-15006**	-3.18*	-27.14**	-25.81**	1.52	-21.18**	-23.86**
H-16	**ICSA 14035 x IS-29308**	7.33**	-18.64**	-17.15**	17.83**	-10.59**	-13.64**

*NOTE: * and ** Significant at 5 and 1 per cent level respectively*
MP = Mid parent; BP = Better parent; STD = Standard heterosis

Table 4. Mean performance and heterosis (%) over mid parent (MP), better parent (BP) and standard (STD) for stem girth (g), panicle weight (g) in 16 Sorghum [*Sorghum bicolor* (L.) Moench] hybrids

		5. Stem girth (cm)			**6. Panicle weight (g)**		
S.No	**HYBRIDS**	**MP Heterosis**	**BP Heterosis**	**STD Heterosis**	**MP Heterosis**	**BP Heterosis**	**STD Heterosis**
H-1	**ICSA 14029 x SEVS-08**	-22.26**	-32.97**	-3.88	-1.36	-14.26**	-17.67**
H-2	**ICSA 14029 x GGUB 28**	-13.84**	-25.54**	6.20*	22.18**	4.85	3.77
H-3	**ICSA 14029 x ICSV-15006**	-7.46**	-22.89**	20.16**	14.43**	-4.10	0.57
H-4	**ICSA 14029 x IS 29308**	-11.39**	-23.08**	8.53**	-4.16	-23.47**	-9.13**
H-5	**ICSA 14030 x SEVS -08**	-41.41**	43.78**	-19.38**	39.43**	21.92**	17.08**
H-6	**ICSA 14030 x GGUB 28**	-11.30**	-14.67**	21.71**	10.95**	-4.21	-5.20
H-7	**ICSA 14030 x ICSV 15006**	-4.58**	-11.94**	37.21**	16.15**	-2.11	2.67
H-8	**ICSA 14030 x IS 29308**	-46.59**	48.35**	-27.13**	10.29**	-11.46**	5.13
H-9	**ICSA 14033 x SEVS-08**	-37.85**	-40.54**	-14.73**	0.89	-0.75	-4.69
H-10	**ICSA 14033 x GGUB -28**	-13.31**	-16.85**	18.60**	-4.56	-7.48*	-8.44**
H-11	**ICSA 14033 x ICSV-15006**	-3.78**	-11.44**	37.98**	-3.67	-9.17*	-4.74
H-12	**ICSA 14033 x IS-29308**	-25.93**	-28.57**	0.78	-7.01**	-17.12**	-1.59
H-13	**ICSA 14035 x SEVS-08**	-3.73*	-16.22**	20.16**	-2.68	-5.69	-9.44**
H-14	**ICSA 14035 x GGUB 28**	-15.89**	26.63**	4.65	0.57	-3.95	-4.94
H-15	**ICSA 14035 x ICSV-15006**	-5.33**	-20.40**	24.03**	-6.37*	-12.97**	-8.73**
H-16	**ICSA 14035 x IS-29308**	-19.12**	-29.12**	0.00	-34.37**	-42.29**	-31.47**

*NOTE: * and ** Significant at 5 and 1 per cent level respectively*
MP = Mid parent; BP = Better parent; STD = Standard heterosis

Table: 5. Mean performance and heterosis (%) over mid parent (MP), better parent (BP) and standard heterosis (STD) for 1000 grain weight, fresh stalk yield (T ha^{-1}) in 16 Sorghum [*Sorghum bicolor* (L.) Moench] **hybrids**

		7. 1000 grain weight (g)			8. Fresh stalk yield (T ha^{-1})		
S.No	**HYBRIDS**	**MP Heterosis**	**BP Heterosis**	**STD Heterosis**	**MP Heterosis**	**BP Heterosis**	**STD Heterosis**
H-1	**ICSA 14029 x SEVS-08**	11.32**	2.44	-22.04**	-14.09**	-21.21**	-1.38
H-2	**ICSA 14029 x GGUB 28**	21.66**	17.69**	-10.44**	-8.15**	15.46**	5.00**
H-3	**ICSA 14029 x ICSV-15006**	1.19	1.16	-23.01**	20.59**	8.64**	41.50**
H-4	**ICSA 14029 x IS 29308**	9.91**	8.14*	-17.70**	-9.34**	-15.75**	2.49
H-5	**ICSA 14030 x SEVS -08**	9.63**	9.62**	-16.58**	-25.55**	-35.16**	-18.84**
H-6	**ICSA 14030 x GGUB 28**	12.95**	18.26**	-10.00**	-2.53	-14.82**	5.79**
H-7	**ICSA 14030 x ICSV 15006**	3.85	12.09**	-14.70**	25.58**	7.57**	40.10**
H-8	**ICSA 14030 x IS 29308**	12.25**	19.39**	-9.14**	-40.99**	-47.97**	-36.71**
H-9	**ICSA 14033 x SEVS-08**	54.29**	30.27**	-0.86	-32.26**	34.59**	-18.12**
H-10	**ICSA 14033 x GGUB -28**	8.02*	-3.70	-26.71**	-22.11**	-24.51**	-6.23**
H-11	**ICSA 14033 x ICSV-15006**	12.70**	4.12	-20.76**	9.11**	3.38*	34.64**
H-12	**ICSA 14033 x IS-29308**	16.59**	5.87	-19.43**	-17.05**	-18.78**	-1.20
H-13	**ICSA 14035 x SEVS-08**	33.66**	9.53**	-16.64**	-8.33**	-15.86**	5.32**
H-14	**ICSA 14035 x GGUB 28**	44.36**	25.11**	-4.79	-27.92**	-33.61**	-17.54**
H-15	**ICSA 14035 x ICSV-15006**	13.67**	2.19	-22.23**	-25.97**	-33.25**	-13.07**
H-16	**ICSA 14035 x IS-29308**	18.08**	4.29	-20.64**	-22.80**	-28.21**	-12.66**

*NOTE: * and ** Significant at 5 and 1 per cent level respectively*
MP = Mid parent; BP = Better parent; STD = Standard heterosis

Table 6. Mean performance and heterosis (%) over mid parent (MP), better parent (BP) and standard check (STD) for Juice yield (l ha^{-1}), brix% in 16 Sorghum [*Sorghum bicolor* (L.) Moench] hybrids

		9. Juice yield (l ha^{-1})			10.Brix %		
S.No.	**HYBRIDS**	**MP Heterosis**	**BP Heterosis**	**STD Heterosis**	**MP Heterosis**	**BP Heterosis**	**STD Heterosis**
H-1	**ICSA 14029 x SEVS-08**	0.04	-24.48**	46.84**	-11.11**	-27.66**	12.82**
H-2	**ICSA 14029 x GGUB 28**	21.04**	-9.15**	76.64**	7.01**	-14.29**	7.69**
H-3	**ICSA 14029 x ICSV-15006**	33.22**	-4.47	85.76**	18.24**	-6.00**	20.51**
H-4	**ICSA 14029 x IS 29308**	-42.17**	-58.66**	-19.62**	7.10**	-13.54**	6.41*
H-5	**ICSA 14030 x SEVS -08**	-14.19**	-27.97**	5.15	-11.95**	-25.53**	-10.26**
H-6	**ICSA 14030 x GGUB 28**	34.61**	12.23**	63.82**	23.93**	-36.73**	-20.51**
H-7	**ICSA 14030 x ICSV 15006**	63.75**	29.23**	88.65**	6.67**	-12.00**	12.82**
H-8	**ICSA 14030 x IS 29308**	1.39	-20.30**	16.35**	16.77**	-2.08	20.51**
H-9	**ICSA 14033 x SEVS-08**	32.71**	26.98**	37.75**	-18.95**	-19.79**	-1.28
H-10	**ICSA 14033 x GGUB -28**	78.52**	69.44**	83.80**	-25.77**	-26.53**	-7.69**
H-11	**ICSA 14033 x ICSV-15006**	51.73**	34.92**	46.36**	-2.04	-4.00	23.08**
H-12	**ICSA 14033 x IS-29308**	-6.60	-17.34**	-10.33*	-25.00**	-25.00**	-7.69**
H-13	**ICSA 14035 x SEVS-08**	-2.15	-22.58**	31.73**	-23.60**	-27.66**	-12.82**
H-14	**ICSA 14035 x GGUB 28**	-21.21**	-38.05**	5.41	-25.27**	-30.61**	-12.82**
H-15	**ICSA 14035 x ICSV-15006**	31.55**	-1.58	67.75**	-6.52**	-14.00**	10.26**
H-16	**ICSA 14035 x IS-29308**	-20.76**	-40.93**	0.51	3.33	-3.13	19.23**

*NOTE: * and ** Significant at 5 and 1 per cent level respectively*
MP = Mid parent; BP = Better parent; STD = Standard heterosis

Table 7. Mean performance and heterosis (%) over mid parent (MP), better parent (BP) and standard check (STD) for Total soluble sugars (%), Ethanol yield (l ha^{-1}) in 16 Sorghum [*Sorghum bicolor* (L.) Moench] hybrids

		11. Total soluble sugars (%)			12. Ethanol yield (l ha^{-1})		
S. No.	**HYBRIDS**	**MP Heterosis**	**BP Heterosis**	**STD Heterosis**	**MP Heterosis**	**BP Heterosis**	**STD Heterosis**
H-1	**ICSA 14029 x SEVS-08**	-9.62**	-25.56**	-12.66**	-2.01	-12.06**	28.01**
H-2	**ICSA 14029 x GGUB 28**	9.20**	-11.16**	7.59**	43.46**	29.96**	89.17**
H-3	**ICSA 14029 x ICSV-15006**	17.99**	-5.95**	20.24**	77.55**	54.74**	125.24**
H-4	**ICSA 14029 x IS 29308**	7.82**	-12.33**	6.34*	-31.13**	-41.81**	-15.30*
H-5	**ICSA 14030 x SEVS -08**	-10.52**	-23.40**	-10.13**	-24.03**	-38.46**	-10.42
H-6	**ICSA 14030 x GGUB 28**	-22.05**	-34.14**	-20.24**	14.53**	-6.25	36.46**
H-7	**ICSA 14030 x ICSV 15006**	6.58**	-11.88**	12.66**	84.69**	44.84**	110.82**
H-8	**ICSA 14030 x IS 29308**	17.41**	-0.86	20.25**	21.77**	-7.75	34.28**
H-9	**ICSA 14033 x SEVS-08**	-17.76**	-15.84**	-1.26	5.39	-10.65*	30.05**
H-10	**ICSA 14033 x GGUB -28**	-24.23**	-23.70**	-7.59**	34.84**	15.44**	68.03**
H-11	**ICSA 14033 x ICSV-15006**	-2.05	-3.98	22.75**	50.90**	24.01**	80.51**
H-12	**ICSA 14033 x IS-29308**	-24.29**	-23.82**	-7.59**	-28.67**	-43.28**	-17.44**
H-13	**ICSA 14035 x SEVS-08**	-24.95**	-25.56**	-12.66**	-23.77**	-19.98**	16.47*
H-14	**ICSA 14035 x GGUB 28**	-26.13**	-27.87**	-12.64**	-42.07**	-38.70**	-10.78
H-15	**ICSA 14035 x ICSV-15006**	-9.46**	-13.86**	10.13**	29.18**	32.25**	92.50**
H-16	**ICSA 14035 x IS-29308**	0.53	-1.91	18.98**	-14.67**	-14.91**	23.86**

*NOTE: * and ** Significant at 5 and 1 per cent level respectively*
MP = Mid parent; BP = Better parent; STD = Standard heterosis

Table 8. Mean performance and heterosis (%) over mid parent (MP), better parent (BP) and standard check (STD) for grain yield in 16 Sorghum [*Sorghum bicolor* (L.) Moench] hybrids

		13.Grain yield (T ha^{-1})		
S. No.	**HYBRIDS**	**MP Heterosis**	**BP Heterosis**	**STD Heterosis**
H-1	**ICSA 14029 x SEVS-08**	-2.18	-14.90*	-19.59**
H-2	**ICSA 14029 x GGUB 28**	3.16	-16.48*	-5.71
H-3	**ICSA 14029 x ICSV-15006**	14.39*	-5.30	0.96
H-4	**ICSA 14029 x IS 29308**	-8.39	-29.34**	-8.97
H-5	**ICSA 14030 x SEVS -08**	39.03*	12.62	6.1
H-6	**ICSA 14030 x GGUB 28**	3.47	-21.42**	-11.29
H-7	**ICSA 14030 x ICSV 15006**	9.77	-14.95*	-9.33
H-8	**ICSA 14030 x IS 29308**	2.18	-25.68**	-4.25
H-9	**ICSA 14033 x SEVS-08**	8.67	0.63	-4.2
H-10	**ICSA 14033 x GGUB -28**	-0.64	-14.89*	-3.92
H-11	**ICSA 14033 x ICSV-15006**	1.77	-10.69	-4.78
H-12	**ICSA 14033 x IS-29308**	-1.63	-20.08**	2.96
H-13	**ICSA 14035 x SEVS-08**	-9.60	-17.96*	-22.48**
H-14	**ICSA 14035 x GGUB 28**	-10.98	-25.13**	-15.48*
H-15	**ICSA 14035 x ICSV-15006**	-12.21*	-24.39**	-19.40**
H-16	**ICSA 14035 x IS-29308**	-34.01**	-47.28**	-32.08**

*NOTE: * and ** Significant at 5 and 1 per cent level respectively*
MP = Mid parent; BP = Better parent; STD = Standard heterosis

The results of heterosis for the brix percentage revealed that cross ICSA 14033 x GGUB-28 has revealed high mid parent heterosis in negative direction (-25.77 percent) while the heterosis in positive direction was 23.93 per cent as recorded by the cross combination of ICSA 14030 x GGUB 28. The magnitude of better parent heterosis ranged from –30.61 (ICSA 14035 x GGUB 28) to -2.08 (ICSA 14030 x IS 29308). Over standard check, the hybrid ICSA 14030 x GGUB 28 displayed highest negative heterosis of –20.51percent, while the hybrid ICSA 14033 x ICSV-15006 with 23.08 per cent standard heterosis in positive direction was on the other extreme. Vinaykumar [30] and Sidramappa et. al. [32] reported similar results Other hybrids which excelled than standard parent are ICSA 14029 x ICSV-15006 (20.51); ICSA 14030 x IS 29308 (20.51); ICSA 14035 x IS-29308 (19.23); ICSA 14029 x SEVS-08; ICSA 14030 x ICSV 15006 (12.82). These hybrids can excel in performance as brix percentage is one of the important direct factor which effects the ethanol yield. The results presented here are in accordance with Sandeep et. al. [34] and Pothisoong and Jaisil [35].

The magnitude of mid parent heterosis for total soluble sugars ranged from –26.13 (ICSA 14035 x GGUB-28) to 17.99 per cent in (ICSA 14029 x ICSV-15006). The better parent heterosis also varied from –27.87 (ICSA 14035 x GGUB 28) - to -0.86 per cent (ICSA 14030 x IS 29308). Heterosis of -12.66 percent over the standard check was observed in the cross ICSA 14035 x SEVS-08 while the heterosis was positive and highest (22.75 per cent) in ICSA 14033 x ICSV-15006.

Mid parent heterosis among the hybrids for ethanol yield ranged from -42.07 (ICSA 14035 x GGUB 28 to 84.69 (ICSA 14030 x ICSV 15006) and the better parent heterosis varied from –41.81 per cent (ICSA 14029 x IS 29308) to 54.74 per cent (ICSA 14029 x ICSV-15006). out of 16 hybrids studied, 12 hybrids have shown positive significant heterosis in desirable direction out of which, highest was found in the hybrid (ICSA 14029 x ICSV-15006) with 125.54 per cent in positive direction while hybrid (ICSA 14033 x IS-29308) was towards other extreme but in negative direction *i.e.,* -17.44 per cent. Vinaykumar et al. [36] and Kumar et. al. [22], Aru et. al. [37] has observed similar results.

For grain yield, heterosis over the mid parent, better parent and standard check were found to be respectively significant with -34.01, -47.28, -32.08 as recorded by the hybrid ICSA 14035 x IS-29308. While significantly highest heterosis in the positive direction was 39.03, 12.62, 6.1 per cent (ICSA 14030 x SEVS -08) for mid parent, better parent and standard heterosis, respectively. Umakanth et. al. [16]. Gite et. al. [27], Kalpande et. al. [28], Khadi et. al. [38] and Prasad et. al. [39] reported similar results. All the 16 hybrids studied most of the crosses had negative standard heterosis as well as better parent heterosis. While positive mid parent heterosis was reported for crosses ICSA 14029 x GGUB 28 (3.16), ICSA 14029 x ICSV 15006 (14.39), ICSA 14030 x GGUB 28 (3.47), ICSA 14030 x ICSV 15006 (9.77), ICSA 14030 x IS 29308(2.18), ICSA 14033 x SEVS-08 (8.67), ICSA 14035 x ICSV-15006 (1.77). The results obtained here are deviating from the results presented by Vinaykumar et. al. [36], Vyas et. al. [25], Kumar et. al. [22], Ingle et. al. [21] for standard heterosis and Chikuta et. al.[29], Meena et. al. [40], Liming et. al. [41] reported similar result for mid parent heterosis.

4. CONCLUSION

The heterosis over mid parent, better parent and commercial check indicated that it was high with respect to ethanol productivity related traits particularly juice yield and brix percent. However, it was deviating for days to 50 percent flowering, days to maturity, number of nodes per plant, plant height, and 1000 grain weight which has shown negative heterosis. In hybrids, there is an improvement in the juice, brix per cent and ethanol yield, but heterosis is limited for 1000 grain weight and ultimately grain yield.

Considering standard heterosis as reference point and based upon the magnitude of standard heterosis in respect of juice yield, brix and ethanol yield, following six hybrids have performed well ICSA 14029 x ICSV-15006; ICSA 14030 x ICSV 15006; ICSA 14035 x ICSV-15006; ICSA 14029 x GGUB 28; ICSA 14030 x GGUB 28 and ICSA 14033 x ICSV-15006. These six hybrid combinations may thus be considered as the combinations which can be used as dual types for both ethanol and grain. Thus they can be exploited for both the economic end products either through hybrids.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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