Original Research Article

Heterosis studies in sweet sorghum [*Sorghum bicolor* (L.) Moench] for ethanol and its related traits.

Abstract: An 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 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. 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. The 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 in respect of juice yield, brix and ethanol yield

Keywords: Sweet Sorghum, Heterosis, Mid parent, Better parent, Standard parent, Ethanol yield

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.,* 2005).

The bioethanol produced from agriculture sources provide eco-friendly energy. The present ethanol production is through sugarcane 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*., 2014; Santos *et al.,* 2015). 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. Hence, in the present study heterosis was studied for 13 quantitative characters. The summary of the results obtained are presented experiment-wise.

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*., 2015; Reddy *et al*., 2007). 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 bringing improvement.

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. 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.* (2005) was used.

$$\text{Total Soluble Sugars (TSS)} = 0.1516 + (\text{Brix \%} \times 0.8746)$$

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

$$\text{Total sugar yield (t/ha)} = [(\text{TSS \%}) /100] \text{ X Juice yield (L/ha)}/1000$$

$$\text{CEY} = \text{Total sugar yield (t/ha)}/5.68) \times 3.78 \times 1000 \times 0.8$$

(Smith, G.A and Buxton. 1993)

TSS = Total Soluble Sugars

1. Days to 50 per cent flowering (days)

The Mid parent heterosis ranged from –19.78 (ICSA 14035 x GGUB 28) to 21.24 per cent (ICSA 14029 x IS 29308). With respect to standard 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). In case of better parent heterosis same crosses have reported similar results. 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. (ICSA 14029 x ICSV 15006) for medium maturing type. Prabhakar (2001), Umakanth *et al.* (2006) had reported similar results for this trait.

2. Days to maturity (days)

The cross (ICSA 14035 x GGUB 28) has reported high negative heterosis (-12.91) (-13.78) and (-19.82) in case of mid parent, better parent and standard parent heterosis respectively, which indicates for early maturing types useful for fodder purpose. While high positive heterosis was reported in cross (ICSA 14035 x SEVS -08) for mid parent (12.15) and in cross (ICSA 14030 x SEVS-08) for better parent (11.04) and cross ICSA 14030 x IS 29308(-0.66) for standard parent. Prabhakar (2001), Umakanth *et al.* (2006) had reported similar results for this trait.

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.

3. Plant height (cm)

Hybrid ICSA 14030 x ICSV 15006 has recorded positive heterosis for mid parent (44.49), (33.17) and better parent respectively. 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*. (2018) where positive heterosis was observed for the studied F_1 hybrids.

High negative heterosis was outlined in the cross ICSA 14035 x GGUB 28 (-31.54), (-49.49), (-48.57) for mid parent, better parent and standard heterosis respectively which means this hybrid is dwarf among the hybrids studied, which is undesirable for high ethanol yield.

4. Number of nodes per plant

Positive significant mid parent heterosis was resulted in the hybrid of 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 (2012) had reported positive result in case of standard heterosis.

For mid parent heterosis hybrid of cross ICSA 14029 x GGUB 28 (-19.44) was found negative significant and for better parent and standard heterosis ICSA 14035 x GGUB 28(-34.12) (-36.36) was found to be negative significant respectively.

5. Stem girth (cm)

Mid parent negative heterosis value of (-41.41) has been reported 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.* (2016) quoted similar positive heterobeltiosis results.

6. Panicle weight (g)

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. 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.

7. 1000 grain weight (g)

Positive heterosis 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.* (2014a) 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).

8. Fresh stalk yield (T ha^{-1})

Mid parent heterosis among the hybrids for Fresh stalk yield ranged from significantly negative -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 per cent followed by ICSA 14030 x ICSV 15006 with 40.10 per cent. Kumar *et al*. (2016) and Chikuta *et al.* (2017) has observed similar results.

9. Juice yield (l ha^{-1})

The hybrids 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. Of the remaining five hybrids ICSA 14029 x IS 29308 and ICSA 14033 x IS -29308 have recorded significantly negative standard heterosis.

10. Brix %

The cross ICSA 14033 x GGUB-28 has revealed high mid parent heterosis in negative direction (-25.77 per cent) 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 –20.51per cent, while the hybrid ICSA 14033 x ICSV-15006 with 23.08 per cent standard heterosis in positive direction was on the other extreme.

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). The results presented here are in accordance with Sandeep *et al.* (2009) and Pothisoong and Jaisil (2011).

11. Total soluble sugars (%)

The magnitude of mid parent heterosis 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 per cent 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.

12. Ethanol yield (l ha^{-1})

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). The standard heterosis was found highest 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.* (2011) and Kumar *et al*. (2016) has observed similar results.

13. Grain yield (T ha^{-1})

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.

In 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.* (2011), Vyas *et al.* (2014a), Kumar *et al.* (2016), Ingle *et al.* (2018) for standard heterosis and Chikuta *et al.* (2017), Meena *et al.* (2020), Liming *et al.* (2020) reported similar result for mid parent heterosis.

Conclusion: 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.

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.

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**
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

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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

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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

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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

Contd…

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

Contd…

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

Contd…

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

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