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EXPLOITATION OF HETEROSIS FOR BIOETHANOL PRODUCTION IN SWEET SORGHUM (*SORGHUM BICOLOR* L. MOENCH.) HYBRIDS

D. M. BAHADURE*, S. MARKER, A.V. UMAKANTH, PRABHAKAR, J. V. PATIL AND G. J. SYNEREM
Field Experimentation Centre, Department of Genetics and Plant Breeding,
Sam Higginbottom Institute of Agriculture, Technology and Sciences, Allahabad - 211 007,
(Uttar Pradesh), INDIA
e-mail: bahaduredm@gmail.com

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***Corresponding author**

ABSTRACT

A study was conducted in sweet sorghum to estimate the magnitude of heterosis for bio-ethanol and biomass yield, thirty F_1 hybrids derived from five Lines x Six testers cross combinations were evaluated in *kharif* 2012 along with their parents and check (CSH 22 SS) for heterosis to identify promising hybrids of sweet sorghum for bio-ethanol characters at three different locations viz: Allahabad (E_1), Solapur (E_2) and Hyderabad (E_3). Heterosis over mid parent, better parent and standard check were studied for bio-ethanol and biomass yield traits. Hybrid NSS 1016 A x UK 81 had shown (354.10% and 282.52%), (507.94% and 365.94%), (306.81% and 214.79%) highest heterobeltiosis and economic heterosis in E_1, E_2 and E_3 respectively. Whereas, for biomass yield trait, the hybrid NSS 8 A x SSV 84 had shown (251.14% and 186.40%), ICSA 675 X UK 81 (285.90% and 244.82%) and PMS71A X SSV 84 (193.80% and 137.56%) had shown highest heterobeltiosis and economic heterosis in environment E_1, E_2 and E_3 respectively. These two hybrids were found to be promising hybrids for further breeding programme as they exhibited significant positive heterobeltiosis and economic heterosis for bio-ethanol and biomass yield related traits. Hence, it can be concluded that heterosis would be more reliable in identification and isolation of superior hybrids.

INTRODUCTION

Sorghum is the fifth major cereal crop in the world and the most important dryland coarse crop grown for food, feed, fuel and fodder. Sweet sorghum is generally cultivated for grain and fodder purpose. Besides these traditional uses, it can be used for manufacturing of several other alternative products such as starch, silage, syrup, jaggery, alcohol, sugar, wine, vinegar, paper, sweeteners and natural pigments (Ratanavathi *et al.,* 2004). Sweet sorghum is similar to the grain sorghum but possess sweet juice in the stalk that can be fermented and distilled to produce ethanol (Mandke and Kapoor, 2004). Ethanol produced from Sweet sorghum is eco-friendly and profitability used as a bio-fuel in automobiles (Roman *et al.,* 1998; Woods, 2001); (Reddy and Reddy, 2003; Reddy *et al.,* 2005). It has capability to influence and improve the rural lively-hoods in India due to the potential industrial use for bio-ethanol production. The National Fuel Policy (2009) aims at promising bio-fuels production to meet India's fuel energy needs and proposed an indicative target of 20% blending of ethanol by 2017 from the current 10% blending with petrol. Hence, Sweet sorghum is considered as a much promising bio-fuel crop that complements with other feed stocks for bio-fuel production (Shinde *et al.,* 2013). Although heterosis is well established in grain and forage sorghum but the reports of heterosis in bio-ethanol yield are limited.

The heterosis or hybrid vigour is the expression of the F_1 hybrid over the parents. Heterosis in sorghum was first observed in 1927, but commercial exploitation was not possible until the discovery of cytoplasmic genetic male sterility (CMS) system. 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 extractive juice yield up to 112.6% further supports breeding for heterosis for genetic enhancement of sweet sorghum (Sankarpandian *et al.*, 1994). Cost of producing hybrids is only justified when their performance surpasses that of their parents and current varieties / genotype. A survey of literature showed extensive reports on heterosis for grain yield but little information of heterosis is available on bioethanol related traits in sorghum (Corn, 2008). Many scientists have reported better parent heterosis values ranging between 24% and 7% for Stem ºBrix and -27 to 43% for Stem biomass production. Therefore, there is a potential to exploit heterosis in new sweet sorghum cultivar development.

At present very few varieties of sweet sorghum are released in 2005. ICRISAT (India) recommended eight pure lines sweet sorghum to public namely, NTS 22, SPV 422, SPV 1611, ICSR 93034, ICSV 93046, ICSV 700, S-35 and E36-1 in 2008, it was reported that the pure line SSV 84 and CSV 19 SS and one hybrid CSH 22 SS were used in the research on a potential energy crop to biomass and bio-fuel production in India (Rani *et al.,* 2013).Thereore, there is a great need of developed the high potential sweet sorghum hybrids, as information on the nature and magnitude of the exploitation of heterosis would help the plant breeders to identify the perfect hybrids for commercially growing to the farmers. So, present investigation was undertaken according to its precision and versatility with an objective of research to estimate the extent and exploitation of heterosis among F_1 sweet sorghum hybrids of various cross combination for biomass and bio-ethanol production.

MATERIALS AND METHODS

Thirty F_1 hybrids were produced by crossing five lines with six testers in L x T mating design (Kempthrone,1957) during *rabi* 2011. These hybrids along with their parents and check (CSH 22 SS) were evaluated in a randomized block Design (Panse and Sukhatme., 1967) in three replications during *kharif* 2012 at Field Experimentation Centre of Department of Genetics and Plant Breeding, Sam Higginbottom Institute of Agriculture, Sciences and Technology (SHIATS), Allahabad, (E_1), Centre on Rabi Sorghum (DSR) Shelgi, Solapur (E_2) and Directorate of Sorghum Research Rajendranagar, Hyderbad, (E_3). Each entry was sown in two rows of 3 m 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 percent using refract meter at physiological maturity stage for calculating the ethanol yield, biomass yield recorded in selected plants by weighing leaves, stems and panicles in kilograms and then convert into t ha^{-1}. The ethanol yield was calculated by using formula reported by (Reddy *et al.* 2005).

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

Heterosis expressed as parent increased or decreased in hybrid (F_1 over its mid parent (Ha) value, better parent (BP) value and standard check value (SC) were calculated as per (Turner 1953, Hayes *et al.,* 1955 and Meredith and Bridges 1972) using the following formula.

$$\text{Relative heterosis (\%)} = \frac{F_1 - MP}{MP} \times 100$$

Where, MP = Mean performance of parent P_1 and P_2

F_1 = Mean performance of hybrid

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

Where, MP = Mean performance of better parent

F_1 = Mean performance of F_1 hybrid

$$\text{Standard heterosis (\%)} = \frac{F_1 - SC}{SC} \times 100$$

Where, SC = Mean performance of standard check

F_1 = Mean performance of F_1 hybrid

RESULTS AND DISCUSSION

To know the potentiality of hybrids, the magnitude and direction of heterosis are important. (Singh *et al.,* 1995)). However, some practical importance, hybrids should be more profitable than the best available commercial variety to the farmers. (Tiwari *et al.,* 2011) and (Padmavati *et al.,* 2013)

Bioethnol yield

The heterosis over mid parent (MP) for bioethanol trait indicated that out of 30 hybrids, all hybrids showed positive significant relative heterosis in environment E_1, E_2 and E_3 respectively (Table 1).

The range of positive relative heterosis varied from 42.89 (PMS 71 A x UK 81) to 536.97% (NSS 8 A x RSSV 138-1) in environment E_1, from 82.53 (NSS 23 A x RSSV 138-1) to 774.43% (NSS 1016 A x UK 81(77.45) in environment E_2 and from 140.84 (NSS 8 A RS 647) to 793.31% (ICSA 675 x SSV 74) in environment E_3. Hybrid NSS 8 A x RSSV 138-1 (536.97%) depicted highest positive significant heterosis for bioethanol yield litre per hectare followed by hybrids NSS 1016 A x RSSV 138-1 (462.47%) and NSS 1016 A x UK 81 (458.63%) in environment E_1. Similarly in environment E_2, hybrid NSS 1016 A x UK 81 (774.45%) depicted highest positive significant heterosis followed by hybrids ICSA 675 x SSV 74 (762.72%) and ICSA 675 x CSV 19 SS (698.71%). Whereas, in environment E_3, hybrid ICSA 675 x SSV 74 (793.31%) exhibited highest positive significant heterosis followed by hybrids ICSA 675 x CSV 19 SS (740.31%) and NSS 8 A x RSSV 138-1 (728.70%).

Positive significant heterosis was well observed in the hybrids viz, NSS 8A X RSSV138-1 in environment E_1, NSS 1016 A X UK 81 in environment E_2 and ICSA 675 X SSV 74 in environment E_3 for bioethanol yield. The quantum of this trait is important, since it directly reflects on the bioethanol yield of sweet sorghum which is our primary concern. The foremost pre-requisite in a hybrid programme is the extent of heterosis. This is mainly because exploitation of hybrid vigour largely depends on the extent of heterosis, earlier reported by (Indhubala *et al.* 2010).

A perusal of estimates of heterobetiosis trait revealed that out of 30 hybrids 26, 27 and 27 hybrids showed significant positive heterobeltiosis for this trait in E_1, E_2 and E_3 respectively. The range of positive heterobeltiosis varied from 38.53 (PMS 71 A x SSV 74) to 354.10% (NSS 1016 A x UK 81) in environment for E_1, from 26.67 (PMS 71 A x SSV 74) to 507.94% (NSS 1016 A x UK 81) in environment E_3. Hybrid NSS 1016 A x UK 81 (354.10%) depicted highest positive significant heterobeltiosis followed by NSS 8 A x RS 647 (266.09%) and ICSA 675 x RS 647 (169.31%) in environment E_1. Similarly in environment E_2, hybrid NSS 1016 A x UK 81 (507.94%) depicted highest significant positive heterobeltiosis followed by hybrids ICSA 675 x RS 647 (227.82%) and NSS 23 A x UK 81 (205.59%). Whereas, in environment E_3. Hybrid NSS 1016 A x UK 81 (306.81%) exhibited highest positive significant heterobeltiosis followed by hybrid NSS 23 A x UK 81 (245.10%) and NSS 8 A x SSV 84 (177.16%) over best check CSH 22 SS. Sixteen hybrids demonstrated positive significant heterobeltiosis in all the environment.

Positive heterobeltiosis was obtained in twenty six, twenty

Table1: Estimates of heterosis (Ha), heterobeltiosis (Hb) and economic hetetrosis (Hc) for Bioethanol yield (L ha^{-1}) and Stalk dry matter yield (t ha^{-1}) in sweet sorghum

S.N.	Hybrids	Env.	Bioethanol yield (lt ha^{-1})			Biomass yield (t ha^{-1})		
			Ha	Hb	Hc	Ha	Hb	Hc
1.	PMS-71A x SSV-74	E_1	119.61**	38.53 **	1.18	85.67**	50.79**	26.94**
		E_2	152.06**	26.67 *	-15.41	234.58**	91.08**	33.73**
		E_3	158.81**	10.15	-30.03 **	294.53**	115.75**	48.47**
2.	PMS-71A x SSV-84	E_1	87.59**	98.03 **	87.59 **	169.85**	202.54**	169.85**
		E_2	189.37**	142.23**	108.29**	153.98**	74.06**	32.40**
		E_3	165.91**	93.87 **	52.55 **	284.94**	193.80**	137.56**
3.	PMS-71A x CSV-19 SS	E_1	74.5 **	20.22	-8.31	125.18**	94.56**	71.27**
		E_2	140.36**	26.98 *	-13.72	146.95**	89.69**	53.98**
		E_3	163.38**	19.61	-22.62 *	283.14**	76.09**	14.31**
4.	PMS-71A x RSSV-138-1	E_1	90.68**	-3.44	-35.35 **	80.79**	24.32 **	-5.27
		E_2	119.64**	3.05	-32.68**	102.92**	13.85*	-20.88**
		E_3	334.50**	62.14 **	-0.34	257.52**	59.43**	2.59
5.	PMS-71A x RS-647	E_1	97.28**	147.20**	97.28 **	163.67**	208.45**	163.67**
		E_2	118.75**	114.02**	109.49**	101.83**	76.24**	56.41**
		E_3	215.33**	121.10**	70.23 **	260.49**	166.77**	111.73**
6.	PMS-71A x UK-81	E_1	42.89*	47.85 **	42.89 *	142.07**	105.49**	78.51**
		E_2	-101.6**	-101.52**	-101.44**	155.18**	162.57**	155.18**
		E_3	163.78**	102.13**	63.83 **	83.87**	20.12**	-10.81
7.	ICSA-675 x SSV-74	E_1	422.97**	121.89**	40.82 **	174.24**	120.14**	83.88**
		E_2	762.72**	132.69**	34.48 **	385.77**	122.41**	44.22**
		E_3	793.31**	112.74**	20.75 *	443.17**	106.97**	27.84**
8.	ICSA-675 x SSV-84	E_1	201.64**	138.40**	97.08 **	58.66**	76.36**	58.66**
		E_2	425.96**	163.57**	75.85 **	169.50**	50.45**	4.35
		E_3	372.92**	110.84**	35.66	299.12 **	122.30 **	54.05 **
9.	ICSA-675 x CSV-19 SS	E_1	303.37**	89.51 **	23.85 *	130.98**	97.36**	72.29**
		E_2	698.71**	128.29**	33.18 **	260.05**	127.95**	66.77**
		E_3	747.31**	117.05**	24.47 *	461.42**	76.57**	4.76
10.	ICSA-675 x RSSV-138-1	E_1	411.21**	69.09 **	1.30	283.03**	160.05**	96.84**
		E_2	515.04**	53.29 **	-12.44	305.78**	82.26**	17.53**
		E_3	633.28**	50.89 **	-15.90 *	319.06 **	27.52 **	-24.80 **
11.	ICSA-675 x RS-647	E_1	172.01**	169.31**	166.67**	87.82**	117.94**	87.82**
		E_2	432.39**	227.82**	136.82**	169.58**	96.97**	55.18**
		E_3	352.20**	92.23 **	22.06	278.08**	103.14**	38.88**
12.	ICSA-675 x UK-81	E_1	92.98 **	48.67 *	20.90	6.99	-10.20	-22.62**
		E_2	289.33 **	128.52 **	61.72 *	338.08**	285.90**	244.82**
		E_3	394.45 **	134.33 **	53.55 *	221.47**	49.65**	-2.47
13.	NSS-23A x SSV-74	E_1	204.61 **	53.14 **	2.28	212.66**	116.92**	66.06**
		E_2	229.68 **	58.55 **	4.37	227.89**	55.67**	2.07
		E_3	234.98 **	39.44 **	-11.95	273.69**	81.75**	20.07**
14.	NSS-23A x SSV-84	E_1	102.70 **	82.02 **	65.16 **	107.79**	106.86**	105.94**
		E_2	178.80 **	125.49 **	89.30 **	167.88**	54.71**	8.76
		E_3	184.73 **	103.91 **	58.82 **	247.31**	139.70**	83.00**
15.	NSS-23Ax CSV-19 SS	E_1	100.95 **	11.27	-23.06 *	79.47**	33.32**	6.05
		E_2	99.62 **	0.99	-32.40 **	155.82**	67.24**	24.23**
		E_3	258.47 **	59.29 **	2.40	341.69 **	79.34 **	12.51 **
16.	NSS-23A x RSSV-138-1	E_1	172.08 **	7.82	-32.77 **	348.51**	159.52**	82.59**
		E_2	82.53 **	-18.13	-47.23 **	190.86**	35.50**	-11.68**
		E_3	250.08 **	27.67 *	-21.93 **	294.38**	55.21**	-3.38

seven and twenty seven in environment E_1, E_2 and E_3, which showed the possibilities of improvement of this trait, which in turn could be of immense value in increasing the bio ethanol yield, earlier reported by (Indhubala *et al.* 2010).

A perusal of estimate of standard heterosis revealed that out of 30 hybrids 19, 16 and 15 hybrids showed positive significant standard heterosis over the best check "CSH 22" SS in environment E_1, E_2 and E_3 respectively. Standard heterosis ranged from 19.00 (NSS 1016A x SSV 74) to 282.52% (NSS 1016 A x UK 81) in environment E_1, from 22.25 (NSS 1016 A x RSSV 138-1) to 365.94% (NSS 1016 A x UK 81) in environment E_2 and from 20.75 (ICSA 675 x SSV 74) to 214.79 (NSS 1016 A x UK 81) in environment E_3. Hybrid NSS 1016 A x UK 81 (282.52%) depicted highest positive significant economic heterosis for bioethanol yield followed by hybrids, NSS 8 A x RS 647 (240.57%) and ICSA 675 x RS 647 (166.67%) in environment E_1. Similarly in environment E_2, hybrid NSS 1016 A x UK 81 (365.94%) depicted highest positive significant economic heterosis followed by hybrids NSS 23 A x UK 81 (181.69%) and ICSA 675 x RS 647 (136.82%). Whereas, in environment E_3, hybrid NSS 1016 A x UK 81 (214.79%) depicted highest positive significant economic heterosis

Table1: Cont........................

S.N	Hybrids	Evn	Ha	Hb	Hc	Ha	Hb	Hc
17.	NSS-23A x RS-647	E_1	85.45 **	104.02**	85.45 **	157.72**	169.37**	157.72**
		E_2	89.18 **	79.57 **	70.90 *	163.05**	98.01**	58.76**
		E_3	149.58 **	71.82 **	31.00	212.29**	108.60**	56.61**
18.	NSS-23A x UK-81	E_1	159.65 **	127.77**	102.86 **	130.91**	68.21**	32.29**
		E_2	233.92 **	205.59**	181.69 **	301.74**	263.28**	231.54**
		E_3	358.31 **	245.10**	176.75 **	279.22**	122.13**	57.06**
19.	NSS-8A x SSV-74	E_1	317.65 **	59.70 **	-1.28	256.03**	79.99 **	20.44 **
		E_2	368.39 **	71.69 **	5.11	368.21**	68.42**	2.68
		E_3	382.78 **	60.78 **	-3.55	291.84**	77.66**	14.87**
20.	NSS-8A x SSV-84	E_1	206.13 **	123.16**	75.58 **	353.72**	251.14**	186.40**
		E_2	360.54 **	199.27**	121.66 **	367.42**	107.92**	33.69 **
		E_3	365.45 **	177.16**	97.33 **	337.15**	183.85**	110.15**
21.	NSS-8A x CSV-19 SS	E_1	335.93 **	85.10 **	17.49	410.53**	179.19 **	92.13 **
		E_2	267.77 **	42.38 **	-11.72	335.24**	121.90**	48.91 **
		E_3	551.66 **	132.49**	41.48 **	295.93**	49.33 **	-7.98 *
22.	NSS-8A x RSSV-138-1	E_1	536.97 **	88.77 **	10.80	554.27**	169.42**	69.64**
		E_2	399.55 **	69.93 **	2.38	510.12**	115.05**	30.53**
		E_3	728.70 **	140.22**	40.47 **	417.32**	89.02**	15.63**
23.	NSS-8A x RS-647	E_1	295.74 **	266.09**	240.57 **	250.61**	188.06**	144.46**
		E_2	170.00 **	110.81**	72.90 *	228.26**	95.87 **	39.58 **
		E_3	140.84 **	37.36	-3.92	128.72**	43.59 **	4.64
24.	NSS-8A x UK-81	E_1	217.03 **	124.98**	74.36 **	294.20**	110.77**	43.84**
		E_2	210.00 **	132.01**	85.37 **	244.04**	152.98**	100.03**
		E_3	276.60 **	136.94**	72.85 **	183.23**	55.35**	7.02
25.	NSS-1016A x SSV-74	E_1	304.34 **	83.88 **	19.00 *	112.30**	55.86**	23.12**
		E_2	601.50 **	133.80**	40.27 **	203.78**	80.53**	28.42**
		E_3	359.57 **	76.92 **	9.55	340.61**	100.17**	29.50**
26.	NSS-1016A x SSV-84	E_1	215.10 **	162.54**	125.01 **	133.37**	142.5 **	133.37**
		E_2	310.32 **	146.32**	75.98 **	107.98**	47.84**	14.67*
		E_3	284.74 **	158.48**	94.62 **	283.37**	149.37**	84.78**
27.	NSS-1016A x CSV-19 SS	E_1	313.84 **	107.96**	38.87 **	187.56**	125.54**	85.53**
		E_2	398.10 **	75.53 **	6.54	117.42**	72.81**	43.39**
		E_3	327.94 **	76.09 **	10.86	231.99**	25.48**	22.64**
28.	NSS-1016A x RSSV 138-1	E_1	462.47 **	100.27**	21.82 **	371.37**	190.10**	109.52**
		E_2	569.44 **	106.75**	22.25 *	309.08**	138.89**	68.70**
		E_3	529.97 **	111.95**	27.41 **	351.90**	65.47**	1.27
29.	NSS-1016A x RS-647	E_1	122.44 **	130.11**	122.44 **	78.41**	94.28**	78.41**
		E_2	159.82 **	88.79 **	48.26	21.06*	9.06	-0.77
		E_3	154.67 **	64.26 **	21.22	220.18**	101.38**	46.88**
30.	NSS-1016A x UK-81	E_1	458.63 **	354.10**	282.52 **	151.46**	93.54**	57.30**
		E_2	774.45 **	507.94**	365.94 **	160.98**	175.84**	160.98**
		E_3	474.84 **	306.81**	214.79 **	172.60**	49.80 **	3.28
SE		E_1	93.84	108.35	–	1.74	2.02	–
		E_2	140.41	162.13	–	2.05	2.37	–
		E_3	119.22	137.66	–	2.24	2.59	–

Ha: Heterosis over mid parent; Hb: Heterosis over better parent, Hc: Heterosis over check (hybrid) * Significance at 5% level; **Significance at 1% level.

followed by hybrids NSS 23 A x UK 81 (176.75%) and NSS 8 A x SSV 84 (97.33%) over the check CSH 22 SS. (Vinaykumar *et al.,* 2011), (Pothisoong and Jaisil, 2013) and (Rani *et al.* 2013) pointed out similar result of significant positive heterobeltiosis and standard heterosis in sweet sorghum. Ten hybrids expressed consistent positive significant economic heterosis in all the environments.Heterosis refer to the increase (or) decreased yield of F_1 over the mean parental value. From the view point of plant breeding, increased yield of F_1over the better commercial variety is more relevant.(Virmani *et al.,*1981) and (Padmavati *et al.*, 2013)

Biomass yield

Among the sweet sorghum hybrids estimates of positive significant mid parent (MP) heterosis for biomass yield revealed that out of 30 hybrids 29, 30 and 30 hybrids showed positive significant relative heterosis in environment E_1, E_2 and E_3 respectively. The range of positive significant relative heterosis varied from 58.66% (ICSA 675 x SSV 84) to 554.27% (NSS 8 A x RSSV 138-1) in environment E_1 from 21.06 (NSS 1016 A x RS 647) to 510.12% (NSS 8 A x RSSV 138-1) in environment E_2, from 83.87 (PMS 71 A x UK 81) to 461.42% (ICSA 675 x CSV 19 SS) in environment E_3. Hybrid NSS 8 A x RSSV 138-1 (554.27%) depicted highest positive significant relative heterosis for biomass yield followed by hybrids NSS 8 A x CSV 19 SS (410.53%) and NSS 1016 A x RSSV 138-1 (371.37%) in E_1. Similarly in environment E_2, hybrid NSS 8 A x RSSV 138-1 (510.12%) exhibited highest positive significant relative heterosis followed by hybrids NSS 8 A x SSV 74 (368.21%) and NSS 8 A x SSV 84 (367.42%). Whereas, in

Table 2: Best hybrids identified on the basis of heterobeltiosis % for bioethanol yield (t ha^{-1})

Env.	Hybrids	Heterobeltiosis (%)	Economic heterosis (%)	*Per se* (t ha^{-1})
E_1	NSS 1016 A x UK 81	354.10**	282.52**	2232.66
	NSS 8 A x RS 647	266.09**	240.57**	1270.33
	ICSA 675 x RS 647	169.31**	166.67**	994.66
E_2	NSS 1016 A x UK 81	507.94**	365.94**	2909.00
	ICSA 675 x RS 647	227.82**	181.69**	1380.66
	NSS 23 A x UK 81	205.59**	136.82**	1758.66
E_3	NSS 1016 A x UK 81	306.81**	214.79**	2071.33
	NSS 23 A x UK 81	245.10**	176.75**	1821.00
	NSS 8 A x SSV 84	177.16**	97.33**	1405.66
E_1	CSH 22 SS +	–	–	1444.66
E_2		–	–	1730.33
E_3		–	–	1418.00

+ Best check CSH 22 SS; *, ** significant at 5% and 1% level of significance of level

Table 3: Best hybrids identified on the basis of heterobeltiosis % for biomass yield (t ha^{-1})

Env.	Hybrids	Heterobeltiosis (%)	Economic heterosis (%)	*Per se* (t ha^{-1})
E_1	NSS 8 A x SSV 84	251.14**	186.40**	52.42
	PMS 71 A x SSV 84	202.54**	169.85**	63.01
	PMS 71 A x RS 647	208.45**	163.67**	61.56
E_2	ICSA 675 x UK 81	285.90**	244.82**	70.57
	NSS 23 A x UK 81	263.28**	231.54**	55.67
	NSS 1016 A x UK 81	162.57**	160.98**	59.81
E_3	PMS 71 A x SSV 84	193.80**	137.56**	81.80
	NSS 8 A x SSV 84	183.85**	115.73**	64.80
	PMS 71 A x RS 647	166.77**	110.15**	76.60
E_1	CSH 22 SS +	–	–	34.52
E_2		–	–	57.53
E_3		–	–	37.68

+ Best check CSH 22 SS; *, ** significant at 5% and 1% level of significance

environment E_3, hybrids ICSA 675 x CSV 19 SS (461.42%) exhibited highest positive significant relative heterosis followed by hybrids ICSA 675 x SSV 74 (443.17%) and NSS 8 A x RSSV 138-1 (417.32%). Twenty nine hybrids demonstrated consistency in positive relative heterosis in all the three environments.

High degree of heterosis was well observed in the hybrids NSS 8A X RSSV 138-1 in environment E_1 and E_2. Whereas hybrid ICSA 675 X CSV 19 SS in environment E_3 for total biomass yield. These hybrids parents could be used for their exploitation through heterosis breeding with regard to biomass yield. This shows the possibilities of improvement reported by (Indhubala *et al.,* 2010).

Data for total biomass yield tons per hectare revealed that out of 30 hybrids, 28, 29 and 30 hybrids showed positive significant heterobeltiosis for this trait in environment E_1, E_2 and E_3 respectively. The range of heterobeltiosis varied from 24.32 (PMS 71 A x RSSV 138-1) to 251.14% (NSS 8 A x SSV 84) in environment E_1, from 13.85% (PMS 71 A x RSSV 138-1) to 285.90% (ICSA 675 x UK 81) in environment E_2 and from 25.48% (NSS 1016 A x CSV 19 SS) to 193.80% (PMS 71 A x SSV 84) in environment E_3. Hybrid NSS 8 A x SSV 84 (251.14%) exhibited highest positive significant heterobeltiosis for total biomass yield followed by hybrids PMS 71 A x RS 647 (208.54%) and PMS 71 A x SSV 84 (202.54%) in environment E_1. Similarly in E_2, hybrid ICSA 675 x UK 81 (285.90%) depicted highest positive significant heterobeltiosis followed by hybrids NSS 23 A x UK 81 (263.28%) and NSS 1016 A x UK 81 (175.84%). Whereas, in environment E_3, hybrids PMS 71 A x SSV 84 (193.80%) exhibited highest significant positive heterobeltiosis followed by hybrids NSS 8 A x SSV 84 (183.85%) and PM 71 A x RS 647 (166.77%). Twenty eight hybrids demonstrated consistency in positive significant heterobeltiosis in all the three environments.

The hybrids NSS 8A X SSV 84 in environment E_1, ICSA 675 X UK 81 in environment E_2, and hybrid PMS 71 A X SSV 84 in environment E_3, showed highest positive significant heterobeltiosis for biomass yield. This shows the possibilities of improvement of this trait, which in turn could be of paramount value in increasing the bioethanol yield. Hence, these hybrids may serve as a source population for realizing superior segregants reported by (Indhubala *et al.,* 2010).

Data for total biomass yield revealed that out of 30 hybrids 28, 23 and 22 hybrids showed positive significant satandard heterosis over the best check "CSH 22 SS" in environment E_1, E_2 and E_3 respectively. Positive significant standard heterosis ranged from 20.44% (NSS 8 A x SSV 74) to 186.40% (NSS 8 A x SSV 84) environment E_1 from 14.67% (NSS 1016 A x SSV 84) to 244.82%) ICSA 675 x UK 81) in environment E_2 and from 14.31% (PMS 71 A x CSV 19 SS) to 137.56% (PMS 71 A x SSV 84) in environment E_3. Data for this trait further revealed that hybrid NSS 8 A x SSV 84 (186.40%) exhibited highest positive significant economic heterosis for total biomass yield tons per hectare followed by hybrids PMS 71 A x SSV 84 (169.85%) and PMS 71 A x RS 647 (163.67%) in environment E_1. Similarly in environment E_2, hybrid ICSA 675 x UK 81 (285.90%) depicted highest positive significant economic heterosis value followed by hybrids NSS 23 A x UK 81

(231.54%) and NSS 1016 A x UK 81 (160.98%). Whereas, in environment E_3 hybrid PMS 71 A x SSV 84 (137.56%) depicted highest positive significant economic heterosis followed by hybrids PMS 71 A x RS 647 (111.73%) and NSS 8 A x SSV 84 (110.15%). Over the best check CHS 22 SS. These results are in conformity with the results are (Pothisoong and Jaisil, 2011) and (Rani *et al.,* 2013). Twelve hybrids demonstrated consistency with regard to economic heterosis in all the three environments.

Higher level of heterosis in a cross always represent genetically more diverse parents than those crosses, which show little or no hybrids. From the results, an appreciable level of heterosis over standard check and better parent was evident for the characters under study. The present investigation revealed that for bioethanol yield Hybrid NSS 1016 A x UK 81 exhibited highest significant positive heterobeltiosis and economic heterosis in environment E_1 (354.10 % and 282.52%), in environment E_2 (507.94% and 365.94%) and in environment E_3 (306.81% and 214.79%) respectively For total biomass yield hybrid NSS 8 A x SSV 84 exhibited highest positive significant heterobeltiosis and economic heterosis (251.14% and 186.40 %) in environment E_1. Similarly hybrids ICSA 675 x UK 81 (285.90% and 244.82%) in environment E_2 and PMS 71 A x SSV 84 (193.80% and 137.56%) in environment E_3 over the best check CSH 22 SS.

The hybrids NSS 1016 A x UK 81 for bioethanol yield and NSS 8 A x SSV 84 ,ICSA 675 x UK 81 and PMS 71 A x SSV 84 for biomass yield could be suggested for commercial exploitation of heterosis as it exhibited significant and positive for heterosisbeltiosis and economic heterosis. Hence, it can be concluded that heterosis would be more reliable in identification and isolation of superior hybrids. These results are in complete agreement with (Kumar *et al.,* 2011), (Pothisoong and Jaisil, 2011) and (Rani *et al.,* 2013).

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