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Heterosis and Inbreeding Depression in Tropical Sweet Sorghum *(Sorghum bicolor* (L.) Moench)

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Abstract

An investigation carried out during two seasons *viz*., rainy 2009 and rainy 2010 to study heterosis and inbreeding depression of four crosses of sweet sorghum (*Sorghum bicolor* (L.) Moench) and their F_2 have revealed positive mid-parent and better parent heterosis for majority of the characters. Sugar yield was found to be most heterotic trait, as all the crosses depicted significant positive heterosis over their mid parent and better parent values in case of all the contributing characters indicating dominance gene action. Further high inbreeding depression for sugar yield reflected high heterosis during the two seasons for all the crosses suggesting the operation of non-additive gene action.

Keywords

Sweet sorghum; Heterosis; Inbreeding depression; Sugar yield

Introduction

There is a renewed interest in using sugars derived from agricultural crops as feedstock's for biofuel production as excessive reliance on energy supplied by fossil fuels is becoming a major economic, environmental and energy security concern. Since biofuels can be produced from a diverse set of crops which hold comparative advantages [1] and bio-fuels are renewable, non-toxic and biodegradable, they contribute to energy security and reducing environmental pollution [2]. Policies to blend petrol with up to 10 per cent ethanol are widely adapted globally, which led to additional ethanol requirement to meet the demands. Sweet sorghum is a multipurpose crop (food, feed, fodder and fuel) that has great potential as an alternative raw material for ethanol production owing to its high biomass production, short duration, rapid growth and low water requirement, tolerance to water logged and saline-alkaline conditions, wider adaptability and high Brix% in stalk juice [3]. Further, Sweet sorghum was found to be best suited for ethanol production because of its higher fermentable sugar content in the stalk compared to sugarcane [2]. The juicy stalks accumulate 10-25 per cent sugar at the time of grain maturity with predominantly reducing sugars *viz*., Glucose and fructose and non-reducing disaccharide *viz*., sucrose.

The sweet sorghum ethanol blended gasohol is environment friendly [4]. The sweet sorghums have not been a major focus of commercial breeding programmes; hybrids have been developed by crossing between grain and sweet sorghums, usually for fodder or dual purpose use (grain and fodder). Thus, increasing stem sugar yields is becoming an important objective in sweet sorghum breeding [5,6]. Sweet sorghum stems are generally taller (1.5 to 3.0 m) and juicier than grain sorghum. Its economic superiority (high ethanol production) is contributed by few characters such as green stalk yield, stalk sugar content (Brix% or stalk sucrose percentage), stalk juice extractability, content of non-reducing and reducing sugars and grain yield. The primary and most essential component of biomass is the stalk. It contributes more than 70 percent of sweet sorghum biomass [7]. Stalk weight is correlated with height, thickness and juiciness and there is significant correlation between brix and total sugar content of the juice, hence total sugar content could be calculated from the brix [8].

Exploitation of heterosis is a quick and convenient way of combining desirable characters. It is important in sweet sorghum, as it may be an indicative of producing transgressive segregants for many quantitative characters in advanced generations. Inbreeding depression is a component which could help in breeding programme by finding out the performance of the trait in segregating generation and its deviation from the first filial generation. Further high heterosis coupled with low inbreeding depression indicates additive genetic variance which can be fixed in the segregating generations.

Materials and Methods

The present study was pursued at International Crops Research Institute for Semi-Arid Tropics (ICRISAT), Patancheru, Hyderabad during 2009 and 2010 rainy seasons. The material for this experiment consisted of seven sweet sorghum parent's *viz*., ICSB 1, ICSB 37, ICSR 77, ICSB 38, ICSB 48, ICSV 25274 and SSV 84 having low and high sugar content that are being maintained at ICRISAT centre, Patancheru. The salient features of these parents (Brix% and important feature) are given in (Table 1).

The four crosses *viz*., ICSB 1 × ICSB 38, ICSB 37 × ICSR 48, ICSB 37 × ICSV 25274, ICSR 77 × SSV 84 were generated using manual emasculation and pollination in rainy 2008 and post rainy 2008 respectively at ICRISAT, Patancheru. These F_1's of four crosses were selfed during post rainy 2008 to obtain F_2 generation. The seven parent's *viz*., ICSB 1, ICSB 37 (common parent in second and third

Table 1: Characteristics of parental lines of sweet sorghum involved in the study.

Parents	Important character	Brix% status
ICSB 1	Medium grain yielding	5.6
ICSB 38	High grain yielding	18.3
ICSB 37	Medium grain yielding	5.5
ICSR 48	High grain yielding	19.7
ICSB 37	Medium grain yielding	5.5
ICSV 25274	High grain yielding	18.4
ICSR 77	High grain yielding and medium maturity	6.2
SSV 84	High grain yielding and late maturity	16.0

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cross), ICSR 77, ICSB 38, ICSR 48, ICSV 25274, SSV 84 along with four F_1s were grown in Randomized Complete Block Design (RCBD) with three replications [9] and F_2generation of all four crosses were raised in separate block during rainy 2009 and rainy 2010 at experimental fields ICRISAT, Patancheru. The maximum temperature of 36.32 and minimum temperature of 19.57 in rainy 2009 while, maximum temperature of 34.82 and minimum temperature of 19.65 in rainy 2010 was prevailed during crop growth period. The parents and F_1s were planted in two rows of 2 m length; F_2s were planted in twelve rows of 2 m length with each row accommodating 20 plants with a spacing of 30 cm × 10 cm in separate blocks. The entries were sown in plots with 2-3 seeds per hill in each row. Thinning was done to retain one healthy plant per hill at 15 and 25 days after sowing. All the crop production and crop protection practices were followed to raise a good and healthy crop.

The data was recorded on ten randomly tagged competitive plants in each replication in parents and F_1'swhereas, 120 competitive plants were randomly selected in each block of F_2generation avoiding border rows. Data was recorded on days to 50% flowering, plant height (cm), stem girth (mm), stalk weight (g), cane weight (g), juice weight (g), juice volume (ml), Brix (%), sucrose (%), juice extraction percent, total soluble sugars and sugar yield (g). The juice extracted after crushing each sampled plant was collected in veils and brought to the laboratory for analysis of sucrose per cent using Rudolph Saccharimeter (Model: A21958 Autopol 880). Sucrose values have been transformed using Arc Sine transformation [10]. Total soluble sugars are the total fermentable sugars such as glucose, fructose, and sucrose etc. including starch in the juice. For predicting the total soluble sugars by using juice Brix%, the following regression equation given by Corleto and Cazzato as reported by [3] was used. Total Soluble Sugars (TSS) = 0.1516 + (Brix % × 0.8746). Sugar yield was calculated by using total soluble sugars (TSS) and juice weight and expressed in grams [11]. Sugar yield = (TSS% × Juice yield)/ 100.

Results and Discussion

Significant mid-parent heterosis as well as better parent heterosis in desirable direction was exhibited by all the characters in general during rainy 2009 and rainy 2010 in all the crosses indicating role of over dominance in the expression of heterosis of these traits (Table 2). Contrastingly non-significant mid-parent heterosis was recorded in respect of brix%, sucrose and total soluble sugars during rainy 2009 and 2010 in cross 1, juice extraction per cent during rainy 2009 and2010 in cross 3 and juice extraction percent during rainy 2009 and 2010 in cross 4. Further better parent heterosis was non-significant for brix% and total soluble sugars in cross 1 during rainy 2009; stem girth and brix% during rainy 2009 and sucrose, total soluble sugars and juice extraction percent during rainy 2010 in cross 3 and for sucrose, juice extraction percent and total soluble sugars during rainy 2009 in cross 4. Desirably negative significant estimates of better parent heterosis were recorded in all the crosses for days to 50% flowering.

The magnitude of inbreeding depression was high in general for majority of the characters including stalk weight, cane weight, juice weight, juice volume, and juice extraction percent over both the seasons in all the crosses. Stem girth was found to have moderate to high inbreeding depression. Major sugar contributing characters such as Brix%, sucrose and total soluble sugars have shown low to moderate levels of inbreeding depression.

Sugar yield was found to be one of the most heterotic traits, as all the crosses depicted significant positive heterosis over their mid parent and better parent values. Among thirteen characters studied, majority of the characters exhibited mid-parent as well as better parent heterosis in desirable direction in all four crosses in both seasons indicating predominant role of non-fixable inter allelic interactions and/or over dominance in the expression of heterosis in respect of these traits (Table 2). Heterosis for end product *i.e.*, sugar yield is being manifested as the cumulative effect of heterosis for component

Table 2: Heterosis for sugar yield and its component characters in four crosses of sweet sorghum during rainy 2009 and 2010.

Season		Days to 50% flowering	Plant height (cm)	Stem girth (mm)	Stalk weight (g/ plant)	Cane weight (g/ plant)	Juice weight (g/ plant)	Juice volume (ml/ plant)	Brix%	Sucrose (%)	Juice extraction percent	Total soluble sugars (%)	Sugar yield (g/ plant)
							ICSB 1 × ICSB 38						
Rainy 2009	MP	-7.55*	18.24*	0.44	132.44**	129.01	263.92**	265.17**	7.56	-2.42	61.03**	7.43	306.39**
	BP	-6.79**	27.52**	25.46**	130.35**	124.66**	232.38**	231.51**	54.19	13.81**	48.75**	52.83	410.38**
Rainy 2010	MP	-6.33*	19.46**	13.64*	119.67**	131.35**	247.27**	225.52**	6.16	10.12	58.52*	-6.05	192.21**
	BP	-1.25**	11.16**	37.69**	114.41**	121.11**	178.54**	166.10**	37.68**	15.88**	34.38**	36.72**	158.94*
							ICSB 37 × ICSR 48						
Rainy 2009	MP	0.46	49.39**	25.01**	166.95**	215.14**	366.33**	366.70**	32.43**	39.24**	45.89**	32.05**	456.37**
	BP	-9.02**	41.65**	17.81*	103.43**	121.52**	225.81**	238.69**	10.19**	20.16*	45.28**	10.09**	248.71**
Rainy 2010	MP	12.29**	55.54**	25.40**	180.86**	217.56**	421.49**	394.63**	38.41**	56.41**	57.21**	37.94**	507.74**
	BP	-3.07**	47.05**	17.60**	118.48**	128.08**	288.24**	264.82**	11.07**	21.82**	69.24**	10.96**	325.64**
							ICSB 37 × ICSV 25274						
Rainy 2009	MP	10.88*	48.62**	20.56*	120.78**	140.55**	116.51**	109.29**	45.79**	34.91*	-1.28	45.21**	141.25**
	BP	-0.04**	6.19**	15.57	38.18**	43.59**	24.68**	19.53**	5.66	-1.06	-12.11**	5.61	29.58**
Rainy 2010	MP	15.37**	46.78**	20.11**	133.44**	168.47**	160.81**	152.28**	44.10**	39.52**	9.06	43.56**	185.71**
	BP	0.91**	5.68**	16.02**	52.36**	64.65**	50.34**	45.22**	7.38**	3.78**	-8.00	7.31**	58.97**
							ICSR 77 × SSV 84						
Rainy 2009	MP	1.63	34.68**	19.56**	100.33**	114.96**	97.82**	92.34**	22.68**	16.7	-5.84	22.43**	122.30**
	BP	13.54**	6.83**	23.16**	47.50**	56.23**	43.33**	42.75**	-2.07**	-2.27	-6.41	-2.05	41.98**
Rainy 2010	MP	0.02	22.37**	31.81**	89.19**	99.54**	87.89*	80.88*	26.15**	35.49**	-4.97	25.86**	131.84**
	BP	14.05**	3.86**	26.13**	34.24**	41.03**	34.43**	29.84**	0.85**	3.68**	-1.67**	0.85**	34.42**

*Significant at 5% level **Significant at 1% level MP = Mid-parent BP = Better parents (ICSB 38, ICSR 48, ICSV 25274, SSV 84)

Table 3: Inbreeding depression for sugar yield and its component characters in four crosses of sweet sorghum during rainy 2009 and 2010.

Season	Days to 50% flowering	Plant height (cm)	Stem girth (mm)	Stalk weight (g/plant)	Cane weight (g/plant)	Juice weight (g/plant)	Juice volume (ml/plant)	Brix%	Sucrose (%)	Juice extraction percent	Total soluble sugars (%)	Sugar yield (g/plant)
ICSB 1 × ICSB 38												
Rainy 2009	-10.44	2.23	24.19	49.47	48.4	65.29	67.42	-17.41	-42.06	36.98	-17.13	58.04
Rainy 2010	-11.01	-19.57	31.36	30.35	24.24	46.03	48.67	-18.46	4.63	31.99	-18.12	33.72
ICSB 37 × ICSR 48												
Rainy 2009	1.32	23.2	25.08	56.85	59.82	68.41	69.35	16.17	18.59	23.14	16.02	71.81
Rainy 2010	8.42	20.59	19.93	48.84	51.58	62.41	61.8	29.27	37.05	27.23	29.01	71.67
ICSB 37 × ICSV 25274												
Rainy 2009	4.16	14.36	7.1	20.93	22.97	22.78	20.29	5.39	10.71	1.43	5.34	25.48
Rainy 2010	2.79	15.69	9.06	27.52	29.15	32.29	30.56	6.21	12.21	6.44	6.15	34.98
ICSR 77 × SSV 84												
Rainy 2009	18.85	44.43	10.52	60.47	63.93	59.68	59.99	33.91	34.36	-4.91	33.61	72.92
Rainy 2010	18.5	41.01	14.7	57.51	61.89	59.51	60.07	41.14	43.23	-1.84	40.79	75.00

traits as hybrids exhibited positive and significant heterosis for sugar yield as well as its component traits *viz*., plant height, stem girth, stalk weight, cane weight, juice weight, juice volume and Brix%.

The magnitude of heterosis for sugar yield and its component traits suggested enough diversity among the parental lines. Incidentally, there has been enough consistency among the performance of the hybrids over the crosses and over the seasons as degree of heterosis did not differ much between crosses and seasons with a very few exceptions which may be due to considerable disharmony between gene combinations in the parents involved and considerable genotype by environment interaction. Low and negative heterosis can be attributed to the presence of large epistatic gene effects or to incomplete dominant gene effects. The results were in accordance with earlier studies [12-21]. One of the characteristics of true heterosis is that increase in vigour is confined to F_1 generation and there would be considerable depression from F_1 to F_2 and later generations. Inbreeding depression was not of the same magnitude for each of the characters in four crosses. However, low inbreeding depression was reported in respect of days to 50 per cent flowering, stem girth, Brix%, sucrose, total soluble sugars and juice extraction per cent in all four crosses. High inbreeding depression was a reflection of high heterosis [22] as reported in respect of other characters during two seasons. Negative estimates of inbreeding depression may be attributed to the occurrence of transgressive segregants in the F_2 population. The formation of new gene combinations as a result of segregation may lead to increased expression of traits in the F_2 population. Low, high and moderate inbreeding depression values were earlier reported by Chiang and Smith [23] Giriraj and Goud [24] Kulkarni and Shinde [25] Meenu Agarwal and Shrotria [18]. Both heterosis and inbreeding depression are the results of dominance type of gene action and heterosis is absent where the traits are governed only by additive gene action [26].

High heterosis coupled with low inbreeding depression in respect of days to 50 per cent flowering, stem girth, Brix%, sucrose, total soluble sugars and juice extraction per cent in all four crosses indicated additive and /or additive × additive variance which is fixable in segregating generations [27]. However, the remaining characters *viz*., plant height, stalk height, mean inter nodal length, stalk yield, biomass, juice volume, juice yield and sugar yield exhibited high magnitude of inbreeding depression accompanied by high better parent heterosis indicated the operation of non-additive gene action including dominance and additive × dominance or dominance × dominance gene interactions which can't be fixed in segregating population. Consistency in the performance of the hybrids over the crosses and seasons was observed.

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