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Genetic studies in sweet sorghum for sugar concentration, juice and ethanol yield

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Abstract

Field experiment was executed to know the nature of gene action for sugar content, juice and ethanol yield in sweet sorghum, using six parameter model of generation mean analysis. The high sugar content and juice yield potential (SSV-84, RSSV-269 and RSSV-493) and low sugar content, agronomical superior (IS 18360, RSSV-260 and RSSV-167) genotypes were hybridized separately, and back crossed with all parental genotypes. Data obtained from various relevant traits of segregating material and parental genotypes (P1, P2, F1, F2, BC1 and BC2), which evaluated under replicated condition and were used for generation mean analysis. The mean analysis of six-generations in all three crosses specifies the predominance effect of additive gene as well as dominance gene for juice and ethanol yield. All the parameters under investigation exhibited the significance of interaction types, either additive x additive, additive x dominance or dominance x dominance. According to sign of (h) and (l) genetic components, both duplicate and complementary types of epistasic interactions were detected in all three crosses with few exceptions. The dominant component with dominance x dominance gene action were detected considerable effect for juice and ethanol yield. An additive component along with additive x additive followed by dominance were observed to be better for the traits like, sugar content, reducing sugar and non-reducing sugar per cent. The present investigation indicates better combinations like cross RSSV-269 x RSSV-260, thereafter cross SSV-84 x IS-18360 relates to maximum sugar accumulation, juice and ethanol production, revealed the possibility of obtaining variants for juice and ethanol yield.

1. Introduction

Sweet sorghum is an especial crop by means of a sugar loaded stalk, as like as sugarcane. In addition, it has quick growth, maximum sugar concentration, and biomass (fodder) production. It has large scale adaptability (Reddy and Reddy, 2003). Availability of irrigation water is happen to a most important constraint to farming in the upcoming years (Rayan and Spencer, 2001), hence sugarcane farming becomes challenging. Sweet sorghum budding a rational crop, substitute to sugarcane in such circumstances. It can be cultivated with fewer irrigation, less rainfall and inputs compare to sugarcane. The concentration of sugar in the sweet sorghum juice varies from 15 to 21 per cent of brix. It has a huge potential for syrup, jaggery and most prominently biofuels production (Ratnavathi *et al*., 2004). There is need to pay an attention to use of crops as a feedstock for biofuels production as dependence on power source of fossil fuels is fetching an economics, environmental and concern of energy security. Biofuels are renewable, non-toxic and recyclable, so they contribute to energy security and eco-friendly (Reddy *et al*., 2008). The Policies regarding blending of petrol by10 per cent of ethanol or bio-fuels are globally adopted, which cause to additional ethanol requirements. Crop cultivations and management cost of sugarcane or sugar beets are higher, has concrete the vision to look for low-cost substitute source for ethanol. The best choice for good potential as a feedstock and ethanol as a biofuel it can be obtained by cultivation of sweet sorghum (Reddy *et al*., 2005). In India, only 20 per cent area of sorghum cultivated by sweet sorghum, would meet up the country need for bioethanol (150 crores of lit. per year) with current permission of up to 10 per cent blending in petrol, exclusive of growing on non-agricultural lands (Shrinivasa Rao *et al*., 2009).

Genotypic improvement with maximum yield potential is depending on acquaintance of genetic effects and interaction involved in different genotypes of particular characters. The particulars of genetic study of sugar concentration in this crop is yet to be studied. Though, previous study indicate the gene action of sugar content depends on the hybrids combinations and is either additive or dominant (Murray *et al*., 2009). Gene action has a crucial role which is to be analyzed accurately for particular breeding techniques for developing high-yielding genotypes. Simultaneously, the inheritance of various qualitative and quantitative characters are also necessary for attaining enhancement in juice and ethanol production by means of specific breeding technique. Different quantitative genetics and biometrical techniques comprise to work out the genetic construction and nature of gene action of various parameters related to juice yield. The Generation mean analysis (Hayman, 1958; Mather and Jinks, 1971) is one of these method, explain information as regards the nature and magnitude of gene action, *viz*., additive and dominance with an definite test for epistasis, *viz*., additive x additive, additive x dominance and dominance x dominance, effective in the inheritance of character.

Most important constraints for this crop are the unavailability of juice as well as ethanol rich varieties and hybrids which are resistant to environmental and biological stress conditions. Strategies to develop high juice and ethanol yielding varieties and hybrids for future is essential now days. Hence, it is necessary to spotout sweet sorghum genotypes or lines having maximum sugar content as well as juice and ethanol yield.

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In this context, understanding the genetics of sugar content, juice and ethanol yield, this study will help to develop hybrids and varieties with maximum sugar content with high juice and ethanol yield. Through this overall analysis, this study was conducted to depict genetics of juice, ethanol and sugar concentration in sweet sorghum.

2. Materials and Methods

2.1 Experimental materials and design

The investigation was conducted at All India Coordinated Sorghum Improvement Project and Research field, Post Graduate Institute, Mahatma Phule Krishi Vidypeeth, Rahuri, during 2017-19. The experimental material for studies was obtained from Senior Scientist and Sorghum Breeder, All India Coordinated Sorghum Improvement Project, MPKV, Rahuri. The six generations (P_1, P_2, F_1, F_2, BC_1 and BC_2) were developed from three crosses. The experimental materials consisted of three high sugar content with juice yielding and three agronomically superior but low sugar content sweet sorghum genotypes.

2.2 Hybridization and development of various generations

Sorghum is an often cross-pollinated crop, in which cross-pollination occurs more than 5 per cent. RSSV-269 x RSSV-260, SSV-84 x IS-18360 and RSSV-493 x RSSV-167 crosses were made by hand emasculation and pollination. Cultivation of parental material was followed in *Rabi,* 2017-18 for generating F_1 and F_1 generation was selfed for generating F_2. Back crosses were made during *Rabi,* 2018-19 at AICRP on Sorghum and final evaluationary experiment of segregating generations and parents (P_1, P_2, F_1, F_2, BC_1 and BC_2) was conducted in *Kharif,* 2019 at Research Farm of Post Graduate Institute, Mahatma Phule Krishi Vidyapeeth, Rahuri.

2.3 Conduct of experiments

Eighteen treatments consisting of six parents, three F_1, F_2, BC_1 and BC_2 respectively, of three cross combinations, *viz*., SSV-84 x IS-18360, RSSV-269 x RSSV-260 and RSSV-493 x RSSV-167 comprised the experimental material. Sowing of P_1, P_2 and F_1 generations was carried out with two rows of 4 m length with a inter row and inter plant distance of 60 x 15 cm, whereas the sowing of F_2 was done in ten rows with 60 x 15 cm spacing, and sowing of BC_1 and BC_2 were done in four lines with 60 x 15 cm spacing. The application of fertilizers was followed in recommended quantity as 35 kg N/ha and 50 kg P_2O_5/ha at the sowing time and half of the N/ha as 35 kg was given 30 DAS. All crop management practices were followed timely for growing sweet sorghum.

2.4 Meteorological data

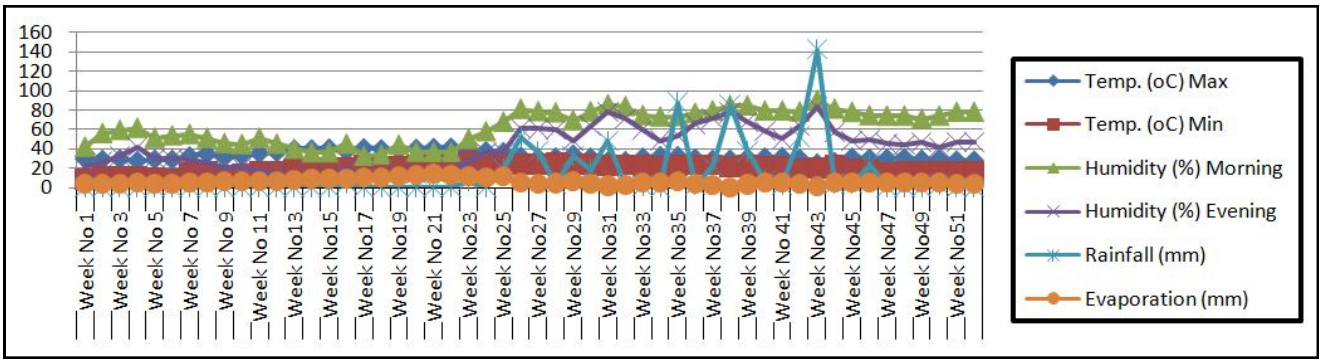

Figure 1: Weather parameters and meteorological variations throughout sweet sorghum growth cycle (Gare *et al.*, 2023)

2.5 Location of experimental field

Experimental field location as Research Farm, of P.G.I., Mahatma Phule Krishi Vidyapeeth, Rahuri locates between 73° 15' 0" to 76° 22' 12" North latitude and 15° 46' 48" to 22° 3' 0" East longitude.

Figure 2: Experimental field location.

2.6 Methods used

For generation mean analysis, five plants were randomly chosen for observational data from parents and F_1, thirty plants from BC_1 and BC_2. For F_2 generation, sixty plants were selected from each replication for the following characters:

2.6.1 Juice yield (ml/plant)

At the physiological maturity, milleable canes were harvested and crushed using a roller crusher. The juice obtained from every cane is collected in measuring jar and the juice yield (ml/plant) is measured and expressed in millilitres**.**

2.6.2 Brix (%)

Hand refractometer with measuring capacity of 0-32 per cent brix was used for measuring brix per cent in juice. By placing one drop of the extracted juice of each cane on hand refractometer and reading observed is expressed as brix per cent.

2.6.3 Reducing sugar (%)

Determination of reducing sugar per cent was carried out by the Nelson Somogyi protocols (Somogyi,1952).

2.6.4 Total sugar (%)

Total sugars were estimated by phenol sulphuric acid method (Dubios *et al*., 1956).

2.6.5 Non-reducing sugar (%)

Non reducing sugar content was obtained by deducting the per cent reducing sugar value from the total sugar.

2.6.6 Ethanol yield (ml/plant)

Ethanol yield ml/plant estimated by the formula.

Ethanol yield (ml/plant) = 5.324 x Total sugar (% in juice) x Juice yield (ml/plant).

2.7 Statistical analysis

Average values of five unsystematically chosen plants for various traits under study were used for statistical analysis. The analysis of generation mean was accomplished for traits studied for all three cross combinations by six generation model. Windostat analytical software was intended for statistical analysis.

3. Results

3.1 Analysis of variance

The genotypes differed significantly for all the traits studied, which indicated a substantial amount of diversity present in the material chosen for the research.

3.2 Mean performance of generations and parents

Performance of generations (F_1, F_2, BC_1 and BC_2) and their parents, of three crosses (SSV-84 x IS-18360, RSSV-269 x RSSV-260 and RSSV-493 x RSSV-167) for juice, ethanol yield and its constituent character in sweet sorghum has been presented in Table 1 and in briefly described as below.

3.2.1 Juice yield (ml/plant)

Juice yield among parents and crosses ranged from 66.20 to 217 ml/plant. In cross I (SSV-84 x IS-18360), the mean value for juice yield estimated maximum in SSV-84 (103) and lowest in IS-18360 (88.86). Among the different generations, F_1 (122) exhibited maximum mean values for juice yield, whereas F_2 (100) and BC_1 (87.56) exhibited lower mean values for juice yield. BC_2 (98.90) generation of this cross showed a lower mean value as compared to BC_1 (87.56). According to data recorded for cross II (RSSV-269 x RSSV-260), it was observed that the parent RSSV-260 (71) recorded a minimum mean value for juice yield as compared to RSSV-269 (130). In the F_1 (217) generation, the mean value for juice yield was maximum as compared to other generations, F_2(77), BC_1 (79), and BC_2 (70) which were recorded minimum values for juice yield. In cross III (RSSV-493 x RSSV-167), parent RSSV-167 (66.20) exhibited minimum juice yield as compared to parent RSSV-493 (70.20). Among the different generations, F_1 (131) exhibited the highest mean value for juice yield, whereas F_2 (80) and BC_1 (105) exhibited lower mean values. BC_2 (97.26) generation of this cross showed minimum juice yield as compared to BC_1 (105).

Among the parents, RSSV-269 (130) recorded the highest juice yield followed by SSV-84 (103). Among the generations of three crosses, F_1 (217) of cross RSSV-269 x RSSV-260 recorded higher juice yield followed by F_1 (131) generation of cross RSSV-493 x RSSV-167 and F_2 (100), and BC_2 (98.90) of cross SSV-84 x IS-18360 recorded higher juice yield and generation of BC_1 (105.13) of cross RSSV-493 x RSSV-167 recorded higher juice yield.

3.2.2 Brix (%)

The percentage of brix content in juice is an important parameter in sweet sorghum. Brix percentage among parents and crosses ranged from 16 to 19 %. In cross I (SSV-84 x IS-18360), the mean value for per cent brix recorded maximum in P_1 (SSV-84) (18) and minimum in P_2 (IS-18360) (17). Among the different generations, F_1 (19) exhibited a higher brix percentage in juice, whereas F_2 (17) and BC_1 (17) exhibited lower mean values for brix per cent. BC_2 (16) generation of this cross showed a lower value as compared to BC_1 (17**)**. Parent RSSV-269 (18.66) recorded a higher value for brix per cent in juice as compared to parent RSSV-260 (16.00) of cross II (RSSV-269 x RSSV-260). In F_1 (18.33) generation, the maximum mean value observed for brix per cent in juice as compared to F_2 (16.66), BC_1(17.00) and BC_2 (16.00) generations, which has recorded lower mean values for this trait. In cross III (RSSV-493 x RSSV-167), parent RSSV-493 (17.46) exhibited higher brix per cent in juice as compared to parent RSSV-167 (15.26). Among the different generations, F_1 (18.00) exhibited a higher mean value, whereas F_2 (16.82) and BC_1 (17.00) exhibited lower mean values for brix per cent. BC_2 (16.93) generation of this cross showed a lower value as compared to BC_1 (17).

RSSV-269 (18.66) recorded the highest brix percentage followed by SSV-84 (18). Among the generations of three crosses F_1 (19), F_2 (17), BC_1 (17) and BC_2 (16) of cross SSV-84 x IS-18360 recorded more per cent of brix in juice, followed by generations of RSSV-269 x RSSV-260 cross.

3.2.3 Reducing sugar (%)

The percentage of reducing sugar among parents and generations ranged from 1.37 to 2.65 per cent. IS-18360 (2.27) exhibited minimum reducing sugar content as compared to SSV-84 (2.65). Among the different generations, F_1 (2.23) exhibited maximum reducing sugar content, whereas F_2 (2.03) and BC_1 (1.90) exhibited minimum. BC_2 (1.68) generation of this cross was recorded as lower reducing sugar content as compared to BC_1 (1.90). Based on data recorded for cross

II (RSSV-269 x RSSV-260), it was observed that parent RSSV-260 (1.37) exhibited minimum reducing sugar content as compared to parent RSSV-269 (1.84). Among the generations, the F_1 (2.00) generation exhibited a higher mean value for reducing sugar. Whereas, F_2 (1.71), BC_1 (1.87), and BC_2 (1.65) exhibited lower mean values.

In cross III (RSSV-493 x RSSV-167), P_2 (RSSV-167) (1.69) exhibited a lower percentage reducing sugar as compared to P_1(RSSV-493) (2.54). Among the different generations, F_1 (2.19) exhibited higher mean values for reducing sugar content, whereas F_2 (1.97) and BC_1 (2.07) exhibited lower mean values. BC_2 (1.65) generation of this cross recorded minimum reducing sugar content as compared to BC_1 (2.80).

The parent SSV-84 (2.65) exhibited more amount of reducing sugar content in juice, followed by RSSV-269 (2.54). Among the crosses, a more amount of reducing sugar percentage was observed in F_1 (2.23), F_2 (2.03), and BC_2 (1.68) of cross SSV-84 x IS-18360 followed by the generation of cross RSSV-269 x RSSV-260 and BC_1 (2.07) generation of cross SSV-493 x RSSV-167.

3.2.4 Total sugar (%)

Sugar percentage in juice is an essential criterion in sweet sorghum, which directly affects on ethanol yield. Percentage total sugar concentration among the generations and parents ranged from 9.92 to 13.24. In cross I (SSV-84 x IS-18360), the per cent sugar was recorded as maximum by P_1 (SSV-84) (11.72) and minimum in P_2(IS-18360) (9.33). Among the different generations, F_1 (11.96) exhibited higher sugar content, whereas F_2 (10.43) and BC_1 (11.05) exhibited lower mean values for sugar content. BC_2 (1.36) generation of this cross showed a lower value as compared to BC_1 (10.43). RSSV-269 (12.35) exhibited maximum mean value for total sugar content as compared to parent RSSV-260 (10.77) of cross II (RSSV-269 x RSSV-260). In F_1 (12.90) generation, maximum total sugar per cent in juice was recorded as compared to other generations, as F_2, (10.55), BC_1 (11.80), and BC_2 (10.50) which were recorded lower mean values for this trait.

In cross III (RSSV-493 x RSSV-167), parent RSSV-493 (13.24) exhibited higher sugar content in juice as compared to parent RSSV-167 (9.91). Among the different generations, F_1 (12.28) exhibited higher mean values, whereas F_2 (11.19) and BC_1 (11.77) exhibited lower mean values for total sugar. BC_2 (10.27) generation of this cross showed a lower mean value as compared to BC_1 (11.77). The parent RSSV-493 (13.24) exhibited more amount of total sugar content in juice, followed by SSV-84 (12.35). Among the crosses, a higher amount of total sugar percentage was observed in F_1 (12.90), BC_1 (11.80) and BC_2 (10.50) of cross RSSV-269 x RSSV-260 followed by the generation of cross RSSV-493 x RSSV-167.

3.2.5 Non-reducing sugar (%)

Non-reducing sugar percentage varied from 7.96 to 10.99 per cent. In cross I (SSV-84 x IS-18360), the mean value for per cent non-reducing sugar was recorded as highest in P_1 (SSV-84) (10.07) and lowest in P_2 (IS-18360) (8.95). Among the different generations, F_1 (10.62) exhibited higher non-reducing sugar percentages in juice, whereas F2 (8.88) and BC_1 (9.76) exhibited lower mean values for non-reducing sugar per cent. BC_2 (8.82) generation of this cross showed a lower value as compared to BC_1 (9.76). Parent RSSV-269 (9.87) recorded highest value for non-reducing sugar per cent in juice as compared to parent RSSV-260 (7.96) of cross II (RSSV-269 x RSSV-260). In F_1 (9.96) generation, the maximum mean value for non-reducing sugar per cent observed as compared to other generations, as F_2, (8.71), BC_1 (9.17), and BC_2 (8.71) which were recorded minimum per cent of non-reducing sugar.

In cross III (RSSV-493 x RSSV-167), parent RSSV-493 (10.70) exhibited higher non-reducing sugar per cent in juice as compared to parent RSSV-167 (8.22). Among the different generations, F_1 (10.09) exhibited a higher mean value, whereas F_2 (9.22) and BC_1 (9.69) exhibited a lower mean value for non-reducing sugar. BC_2 (8.62) generation of this cross showed a lower mean value as compared to BC_1 (9.69). The parent RSSV-493 (10.70) exhibited more concentration of non-reducing sugar in juice, followed by SSV-84 (10.07). Among the crosses maximum amount of non-reducing sugar percentage was estimated in F_1 (10.62), BC_1 (9.76) and BC_2 (8.82) of cross SSV-84 x IS-18360, followed by generations of cross RSSV-493 x RSSV-167 and F_2 (9.22) generation of this cross recorded maximum mean value for non-reducing sugar percentage.

3.2.6 Ethanol yield (ml/plant)

Ethanol yield is the most significant product of sweet sorghum. Ethanol yield among parents and crosses ranged from 4.04 to 14.0 ml/plant. In cross I (SSV-84 x IS-18360), the mean value was recorded as maximum in SSV-84 (8.64) and minimum in IS-18360 (4.04). Among the different generations, F_1 (14.00) exhibited a higher mean value for ethanol yield, whereas F_2(4.40) and BC_1 (4.95) exhibited lower. BC_1 (4.95) generation of this cross showed a higher mean value as compared to BC_2 (3.98).

According to data recorded for cross II (RSSV-269 x RSSV-260), it was observed that parent RSSV-269 (6.48) recorded maximum ethanol yield than RSSV-260 (4.48). In F_1 (7.79) generation, the mean value comparatively maximum as regard as F_2, (5.59), BC_1 (5.18), and BC_2 (5.05), which were recorded minimum values for ethanol yield. Ethanol yield in cross III (RSSV-493 x RSSV-167), parent RSSV-493 (4.88) recorded better than parent RSSV-167 (3.56). Among the different generations, F_1 (8.59) exhibited the highest mean value, whereas F_2 (4.76) and BC1 (6.56) exhibited minimum values. BC_1 (6.56) generation showed better performance as compared to BC_2 (5.38). Among the parents, SSV-84 (8.64) recorded the highest ethanol yield, followed by RSSV-269 (6.48). Among the generations of three crosses F_1 (14), F_2 (4.40), BC_1 (4.95) and BC2 (3.98) of cross SSV-84 x IS-18360 recorded maximum ethanol yield followed by generations of cross RSSV-269 x RSSV-260.

3.3 Scaling tests estimates for presence of epistatic interactions for different traits in sweet sorghum

All three types of epistatic interactions, *viz*., additive x additive (i), additive x dominance (j), dominance x dominance (l) resulted as significance of A and B scales. The test of C significance suggests dominance x dominance interaction. One of scaling tests having significance, indicates the inadequacy of the simple additive dominance model. All the characters studied were found significant Chi-square (÷2) values. Test of A, B, C and D scaling test's results for concerning parameters of juice yield in sweet sorghum have been tabulated in Table 2.

Table 1: Performance of generations and parents for different parameters in sweet sorghum

Generations	Juice yield (ml/plant)	Brix (%)	Reducing sugar (%)	Total sugar (%)	Non reducing sugar(%)	Ethanol yield (ml/plant)
(I) SSV-84 x S-18360						
P_1	103(2.65)	18(0.19)	2.65(0.07)	11.72(0.11)	10.07(0.12)	8.64(0.30)
P_2	88.86(3.87)	17(0.23)	2.27(0.03)	9.33(0.13)	8.95(0.15)	4.04(0.14)
F_1	122(4.93)	19(0.21)	2.23(0.04)	11.96(0.18)	10.62(0.09)	14.00(0.56)
F_2	100(4.60)	17(0.19)	2.03(0.03)	10.43(0.16)	8.88(0.12)	4.40(0.18)
BC_1	87.56(7.38)	17(0.38)	1.90(0.04)	11.05(0.17)	9.76(0.11)	4.95(0.20)
BC_2	98.90(8.22)	16(0.34)	1.68(0.04)	10.36(0.11)	8.82(0.11)	3.98(0.16)
(II) RSSV-269 x RSSV-260						
P_1	130(3.40)	18.66(0.27)	1.84(0.06)	12.35(0.18)	9.87(0.07)	6.48(0.19)
P_2	71(2.09)	16.00(0.23)	1.37(0.03)	10.77(0.16)	7.96(0.13)	4.48(0.25)
F_1	217(7.44)	18.33(0.24)	2.00(0.06)	12.90(0.11)	9.96(0.13)	7.79(0.37)
F_2	77(2.85)	16.66(0.17)	1.71(0.03)	10.55(0.15)	8.71(0.13)	5.59(0.26)
BC_1	79(3.29)	17.00(0.31)	1.87(0.04)	11.80(0.14)	9.17(0.12)	5.18(0.45)
BC_2	70(2.71)	16.00(0.32)	1.65(0.04)	10.50(0.15)	8.71(0.07)	5.05(0.48)
(III) RSSV-493 x RSSV-167						
P_1	69.13(1.30)	17.46(0.23)	2.54(0.06)	13.24(0.16)	10.70(0.11)	4.88(0.13)
P_2	67.40(1.26)	15.26(0.68)	1.69(0.03)	9.91(0.12)	8.22(0.10)	3.56(0.08)
F_1	131(2.59)	18.00(0.19)	2.19(0.10)	12.28(0.40)	10.09(0.29)	8.59(0.33)
F_2	80(3.15)	16.82(0.16)	1.97(0.14)	11.19(0.17)	9.22(0.19)	4.76(0.20)
BC_1	105(4.12)	17.00(0.34)	2.07(0.09)	11.77(0.31)	9.69(0.22)	6.56(0.27)
BC_2	97.00(4.38)	16.93(0.33)	1.65(0.06)	10.27(0.22)	8.62(0.16)	5.38(0.29)

Figure in parentheses indicates standard error (±).

Table 2: Scaling tests estimates for presence of epistatic interactions for different parameters

S. No.	Name of traits	Scaling tests	Cross-I SSV-84 x IS-18360	Cross-II RSSV-269 x RSSV-260	Cross-IIIRSSV-493 x RSSV-167
1.	**Juice yield (ml/plant)**	A	-15.33*	24.33**	-14.00**
		B	-136.66**	-32.00**	-17.66**
		C	16.66	13.66*	13.00**
		D	84.33	10.66**	22.33**
	Chi square (÷2)		**394.75****	**114.30****	**878****
2.	**Brix (%)**	**A**	-1.66*	-3.00**	1.00*
		B	-2.00**	-4.33**	-3.00**
		C	-0.33	1.33	-0.66
		D	1.66**	4.33**	0.66*
	Chi square (÷2)		**72.27****	**27.44****	**6.97****
3.	**Reducing sugar (%)**	**A**	-1.08*	0.433**	-0.53**
		B	-0.69**	-1.03**	-1.49**
		C	-0.057	0.733**	-0.203
		D	0.86	0.66**	0.91**
	Chi square (÷2)		**277.04****	**323.87****	**848.28****

4.	**Total sugar (%)**	**A**	-1.04**	-1.58**	-1.35**
		B	-3.16**	-5.26**	-6.43**
		C	-0.093	1.05**	-0.32
		D	-2.15**	2.53**	3.73**
	Chi square (÷2)		**125.41****	**36.11****	**46.63****
5.	**Non reducing sugar (%)**	**A**	-1.75**	-1.47**	-1.40*
		B	-1.92**	-0.49*	-1.07*
		C	4.74**	-2.90**	-2.22*
		D	0.82**	-0.46	0.126
	Chi square (÷2)		**99.80****	**37.36***	**34.24**
6.	**Ethanol yield (ml/plant)**	**A**	-1.69**	2.23**	-1.47**
		B	-1.02**	-4.37**	-3.30**
		C	1.23	1.42**	0.78*
		D	-3.18	1.78**	2.78**
	Chi square (÷2)		**13.78****	**6.29****	**8.15****

Level of significance for *5% and ** 1%.

3.3.1 Juice yield (ml/plant)

For juice yield 'A' and 'B' were insignificant in SSV-84 x IS-18360. Scaling tests A, B, C and D were significant in the crosses under study. The joint scaling test was found highly significant for all three crosses for juice yield, indicating the existence of epistasis.

3.3.2 Brix (%) and total sugar (%)

A, B, and D tests were found to be significant for percentage of brix in juice in all three crosses. Scaling test 'D', recorded greater magnitude in a positive direction in SSV-84 x IS-18360 and RSSV-269 x RSSV-260. Scaling tests 'A', 'B' and 'D' were positively significant for total sugar in all three crosses, and RSSV-269 x RSSV-260 showed 'C' scaling tests also significant. The joint scaling test for brix (%) and total sugar per cent recorded substantial results in all studied crosses.

3.3.3 Reducing sugar (%) and non-reducing sugar (%)

'A' and 'B' tests were exhibited significant in cross SSV-84 x IS-18360. All four tests 'A', 'B', 'C' and 'D' expressed significant results in a cross, RSSV-269 x RSSV-260 and in RSSV-493 x RSSV-167, scaling test 'C' was observed as non-significant. All four tests 'A', 'B', 'C' and 'D' were statistically positive in cross SSV-84 x IS-18360 for non-reducing sugar. Tests 'A', 'B' and 'C' were observed significant in the crosses, RSSV-269 x RSSV-260 and RSSV-493 x RSSV-167 for non-reducing sugar. The joint scaling test found significant for this character in studied crosses.

3.3.4 Ethanol yield (ml/plant)

For ethanol yield scaling tests 'A' and 'B' were non-significant in SSV-84 x IS-18360. All four tests 'A', 'B', 'C' and 'D' were noteworthy in crosses, RSSV-269 x RSSV-260 and RSSV-493 x RSSV-167. Joint scaling test was highly significant in crosses studied, for ethanol yield indicating that presence of non-allelic interaction.

3.4 Genetic effects for sugar content, juice, ethanol yield and constituent traits of sweet sorghum

The six generations of all three crosses were used for assessment of genetic effects, *viz*., m (mean), d (additive), h (dominance), i (additive into additive), j (additive into dominance) and l (dominance into dominance) for juice, ethanol yield and it is constituent traits. Additive-dominance model does not explicate the genetic control due to highly significant result of joint scaling test. The effects of m (mean), d (additive), h (dominance), i (additive into additive), j (additive into dominance) and l (dominance into dominance) based on six parameter model of generation mean study (Hayman, 1958) for juice, ethanol yield and its constituent traits in sweet sorghum which is represented in Table 3. The parameter m (mean) was significant in studied crosses (RSSV-269 x RSSV-260, SSV-84 x IS-18360 and RSSV-493 x RSSV-167) for all characters, those were studied for sugar content, juice, ethanol yield and component traits of sweet sorghum. Genetic effects projected by using the impeccable model concerning traits associated with juice yield in sweet sorghum has been presented in Table 3.

3.4.1 Juice yield (ml/plant)

In the cross SSV-84 x IS-18360, it was recorded that gene effect for d (additive) (8.76) and h (dominance) (104.1) were estimated positively significant, h (dominance) component with greater magnitude in desirable direction than additive [d] component. The i (additive x additive) (12.0) and j (additive x dominance) (-20.9) interactions estimated non-significant, whereas l (dominance x dominance) (378.7) type of interaction was estimated positively significant. Genetic component h (dominance) and l (dominance x dominance) were observed similar signs, with incidence of complementary interaction. The d (additive) (-11.33) and h (dominance) (2.10) gene effects found to be significantly negative and positive, respectively, in RSSV-269 x RSSV-260. Gene interaction components, i (additive x additive) (-27.80), j (additive x dominance) (-18.83) and l (dominance x dominance) (-91.73) were estimated as significant. Duplicate type of epistasis interaction estimated as per dissimilar signs of h (dominance) and l (dominance into dominance) component noticed in cross RSSV-269 x RSSV-260.

In the cross RSSV-493 x RSSV-167, estimated of genetic parameters, it was noticed that d (additive) (7.86) and h (dominance) (147.8) both parameters were positively significant and 'h' component recorded with higher magnitude in desirable direction than component 'd'. All three interaction components, additive x additive (84.80), additive x dominance (7.00) and dominance x dominance (-90.5) were estimated significant effects for this trait. The dissimilar signs of dominance and dominance x dominance genetic parameters specified the existence of a duplicate type of interaction in an inheritance of juice yield in RSSV-493 x RSSV-167.

3.4.2 Brix (%)

The h (dominance) (0.96) effect estimated as positively significant, whereas, d (additive) (0.60) effect was estimated non-significant in SSV-84 x IS-18360. Interaction, i (additive x additive) (-0.36) and j (additive x dominance) (-0.06) estimated non-significant, whereas j (dominance x dominance) was observed positively significant for brix (%). A complementary epistasis was reported for brix (%) in SSV-84 x IS-18360 as the identical signs of 'h' and 'l' components. RSSV-269 x RSSV-260 cross, estimated non-significant d (additive) (0.78) gene effect; however, effect of h (dominance) (2.20) gene was found positively significant with greater magnitude in desirable direction than the 'd' for brix (%). The effect i (additive x additive) (1.68) and j (additive x dominance) (-0.21) interactions were estimated non-significant, whereas effect l (dominance x dominance) (1.41) gene was recorded as positively significant. A complementary epistasis was evidenced in cross RSSV-269 x RSSV-260, for brix (%), as per the similar signs of 'h' and 'l' components.

The d (additive) gene (0.06) was estimated insignificant in RSSV-493 x RSSV-167; however, effect h (dominance) (2.20) was found positively significant and recorded a greater magnitude in the desirable direction than 'd'. Regarding to interactions effects, i (additive x additive) (0.56) was estimated insignificant, whereas j (additive x dominance) (-1.03) and l (dominance x dominance) (0.30) were effected as negatively and positively significant respectively.

3.4.3 Reducing sugar (%)

Genetic parameters estimates of cross, SSV-84 x IS-18360, the d (additive) (0.35) and h (dominance)(0.98) components were estimated significantly positive and 'h' component recorded in higher magnitude in desirable direction than 'd'. The effect of i (additive x additive) (0.75) interaction was estimated as a significant, whereas j (additive x dominance) and l (dominance x dominance) components effects were observed non-significant. Genetic component h (dominance) and l (dominance x dominance) recorded identical signs, with the incidence of complementary epistasis. The effects of d (additive) (0.22) and h (dominance) (0.58) parameters were estimated as significantly positive and 'h' component with greater magnitude in a desirable direction than [d] in the cross RSSV-269 x RSSV-260. The effect of i (additive x additive) (0.19) and l (additive x dominance) (-0.01) were estimated significant for reducing sugar (%) and l (dominance x dominance) effect was estimated non-significant. Complementary epistasis was evidenced in cross RSSV-269 x RSSV-260, as per the estimate of 'h' and 'l' components, which had similar signs.

Regarding the cross RSSV-493 x RSSV-167, estimates of genetic parameters, it was revealed that d (additive) (-0.42) and h (dominance) (-0.37) were insignificant gene action. The effects of i (additive x additive) (-0.44) was estimated non-significant and j (additive x dominance) (0.48) and l (dominance x dominance) (1.62) were recorded significant positive gene effect. Contrary signs of h (dominance) and l (dominance x dominance) components, indicating occurrence of duplicate interaction for reducing sugar percentage.

3.4.4 Total sugar (%)

Genetic parameters of cross SSV-84 x IS-18360, d (additive) (1.29) and h (dominance) (3.74) were positively significant and 'h' components recorded with greater magnitude in desirable direction than 'd'. The effect of i (additive x additive) and j (additive x dominance) were estimated significantly positive, whereas l (dominance x dominance) effect was found non-significant for total sugar. Genetic components, h (dominance) and l (dominance x dominance) exhibited same signs, signifying the existence of complementary epistasis. Cross, RSSV-269 x RSSV-260, represented that estimates of genetic parameters as d (additive) (0.69) and h (dominance) (2.53) gene action were exhibited significantly positive and effect of 'h' recorded greater magnitude in desirable direction than 'd'. The effect of interaction components i (additive x additive) (1.10), j (additive x dominance) (0.50) and l (dominance x dominance) (1.06) estimated significant for total sugar (%). Genetic parameters, h (dominance) and l (dominance x dominance), exhibited identical signs, with an incidence of epistasis as complementary type.

The effects of d (additive)(1.04) and h (dominance) (1.07) components were recorded as significantly positive and component 'h' observed better than the component 'd' in cross RSSV-493 x RSSV-167. An effect of additive x additive (i) (-0.70) and additive x dominance (j) (-0.16) were estimated insignificant, whereas l (dominance x dominance) (4.35) components were estimated significant. Complementary type of interaction was evidenced in cross RSSV-493 x RSSV-167, as per the estimates of similar signs 'h' and 'l' components.

3.4.5 Non-reducing sugar (%)

The cross SSV-84 x IS-18360, showed d (additive) (2.75) and h (dominance) (1.64) parameters were significantly positive and 'h' component estimated with greater magnitude. Genetic effect of interaction, i (additive x additive) (1.64) and j (additive x dominance) (0.37) were estimated positively significant, whereas, the l (dominance x dominance) (1.45) effect was found non-significant. Similar signs noticed in cross SSV-84 x IS-18360 for genetic component h (dominance) and l (dominance x dominance), indicating incidence of complementary type of interaction. RSSV-269 x RSSV-260 cross, estimates d (additive) (0.46) and h (dominance) (1.97) effects were significant and 'h' component observed with better in desirable direction than 'd'. Regarding to interaction component, i (additive x additive) (0.93) was estimated as completely significant. The gene effect for j (additive x dominance) (-0.48) and l (dominance x dominance) was estimated as insignificant. Genetic parameters h (dominance) and l (dominance x dominance), recorded identical signs with the incidence of complementary epistasis.

The gene effect of d (additive) (1.07) and h (dominance) (0.38) were estimated significantly positive for non reducing sugar (%) in RSSV-493 x RSSV-167. The effect of interaction components (additive x additive) (-0.25) and (additive x dominance) (-0.16) were estimated insignificant, as effect of l (dominance x dominance) (2.72) estimated positively significant. Epistasis as complementary type was noticed in cross RSSV-493 x RSSV-167, as per similar signs of 'h' and 'l' components.

3.4.6 Ethanol yield (ml/plant)

It was observed that d (additive) (1.02) and h (dominance) (8.75) components were estimated as significantly positive and effect 'h' components were found greater magnitude in desirable direction than 'd' in cross SSV-84 x IS-18360. Effect of interaction, i (additive x additive) (0.17) was estimated insignificant, whereas j (additive x dominance) (-1.23) and l (dominance x dominance) (24.58) were estimated significant gene effects. Similar type of signs were noticed in h (dominance) and l (dominance x dominance) components, it showed the effect of complementary interaction of epistasis in combination SSV-84 x IS-18360 for ethanol yield. Genetic effect of d (additive) (-0.31) component was insignificant, whereas h (dominance) (1.30) was estimated as significantly positive and observed by means of greater magnitude in desirable direction than [d] in the cross RSSV-269 x RSSV-260. Among interactions, the gene effect of *C-I, C-II and C-III: Cross 1, 2 and 3, respectively, m (mean), d (additive), h (dominance), i (additive x additive), j (additive x dominance) and l (dominance x dominance)i (additive x additive) (-1.03) and j (additive x dominance) (-1.33) parameters were estimated as insignificant for ethanol yield (ml/plant), even as the effect of l (dominance x dominance) (6.19) was estimated as significantly positive. The contrary signs of h (dominance) and l (dominance x dominance) parameters indicated the existence of a duplicate epistasis in the inheritance of ethanol yield.

Table 3: Estimates effects of genetic components for juice, ethanol yield and its constituent traits in sweet sorghum crosses

Character	Cross	Components						Type of epistasis
		m	d	h	i	j	l	
Juice yield (ml/plant)	C-I	77.75**(2.85)	8.76**(4.26)	104.1**(16.20)	12.0(14.25)	-20.9(4.71)	348.7**(25.67)	Complementary
	C-II	100.1**(4.60)	-11.33**(11.05)	2.10**(2.9)	27.80**(28.76)	-18.83*(11.29)	-91.73*(49.11)	Duplicate
	C-III	80.0**(3.15)	7.86*(6.0)	147.8**(17.6)	84.80**(17.4)	7.00*(6.08)	-90.5**(27.73)	Duplicate
Brix (%)	C-I	16.5**(0.19)	0.60(0.52)	0.96**(1.32)	-0.36(1.29)	-0.06(0.54)	5.96**(2.28)	Complementary
	C-II	16.47**(0.17)	0.78(0.44)	2.75**(1.18)	1.68(1.14)	-0.21(0.48)	1.41**(0.02)	Complementary
	C-II	16.82**(016)	0.06(0.48)	2.20**(1.25)	0.56(1.18)	-1.03*(0.60)	0.30**(2.21)	Complementary
Reducing sugar (%)	C-I	1.67**(0.037)	0.35**(0.065)	0.98**(0.20)	0.75**(0.19)	0.132(0.08)	0.46(0.32)	Complementary
	C-II	1.71**(0.03)	0.22**(0.06)	0.58*(0.21)	0.19**(0.12)	-0.01*(0.07)	1.01(0.33)	Complementary
	C-III	1.97**(0.15)	-0.42**(0.11)	-0.37**(0.65)	-0.44**(0.64)	0.48*(0.11)	1.62**(0.78)	Duplicate
Total sugar (%)	C-I	10.55**(0.15)	1.29**(0.21)	3.74**(0.76)	2.40**(0.75)	0.50*(0.24)	1.91(1.11)	Complementary
	C-II	10.43**(0.16)	0.69**(0.20)	2.53**(0.18)	1.10**(0.78)	0.50**(0.22)	1.06**(1.13)	Complementary
	C-III	11.19**(0.17)	1.04**(0.38)	1.07**(1.20)	-0.70(1.0)	-0.16(0.39)	4.35**(1.88)	Complementary
Non reducing sugar (%)	C-I	8.88**(0.12)	0.93**(0.16)	2.75**(0.59)	1.64**(0.58)	0.37*(0.19)	1.45(0.85)	Complementary
	C-II	8.71**(0.13)	0.46**(0.14)	1.97**(0.63)	0.93**(0.86)	-0.48(0.61)	1.04(49.11)	Complementary
	C-III	9.22**(0.19)	1.07**(0.27)	1.38**(1.0)	-0.25(0.95)	-0.16(0.28)	2.72**(1.48)	Complementary
Ethanol yield (ml/plant)	C-I	4.40**(0.18)	1.02**(0.26)	8.75**(1.07)	0.17(0.89)	-1.23**(0.31)	24.58**(1.73)	Complementary
	C-II	5.60**(0.26)	-0.31(0.66)	1.30**(1.74)	-1.03(1.69)	-1.33(0.68)	-6.19**(2.97)	Duplicate
	C-III	4.76**(0.20)	1.17**(0.40)	9.21**(1.19)	4.85**(1.14)	0.51(0.41)	-3.11*(1.93)	Duplicate

In cross, RSSV-493 x RSSV-167, estimates of genetic parameters, Gene effect of d (additive) (1.17) and h (dominance) (9.21) parameters were estimated significantly positive and 'h' component recorded in greater magnitude in desirable direction than 'd'. The effect of interaction, j (additive x dominance) (0.51) estimated insignificant for this trait, whereas i (additive x additive) (4.85) and l (dominance x dominance) (-3.11) interaction were estimated significantly positive and negative, respectively. Significant opposite signs were noticed for genetic components h (dominance) and l (dominance x dominance), it was proposed that an occurrence of duplicate epistasis interaction in cross RSSV-493 x RSSV-167 for ethanol yield

4. Discussion

The generation mean study is an important for the revealing and assessment of additive, and non-additive gene interactions**.** The average performance of F_1 was better than the particular mid-parent value as well as better-parent values for the characters under studied**.** The similar outcomes were reported by Semenova 1988; Adhilakshmi *et al.* 2010); Sudhir Kumar *et al.* (2011) and

Karande *et al*. (2018) indicating the existence of incomplete and over-dominance in genetic of juice yield of sweet sorghum. The mean values of F_2 generation were lesser than the F_1 and mid-parental values and it was comparable to the better parent means in respective of the traits studied, which also indicates the principal effect of non-additive gene which involved dominance as well as epistatis gene interaction. Earlier**,** scientists Sudhir Kumar *et al*. (2011) and Karande *et al*. (2018) revealed similar types of interactions.

In sweet sorghum juice yield and sugar concentration are negatively associated traits, that will affect on ethanol productivity of genotypes. For higher ethanol productivity, it is to be needed higher amount of sugar accumulation with maximum juice yield. As per present investigation results, we can be proposed best genotypes for juice yield as well as sugar accumulation in juice are RSSV-269 and SSV-84, which will be utilized in future breeding programme of sweet sorghum for developing high ethanol yielding lines, varieties and hybrids. Considerable effects of additive and dominance gene for juice and ethanol yield were observed in all three crosses, indicating the predominance role of additive and non-additive gene action in inheritance of juice yield in sweet sorghum. The RSSV-269 x RSSV-260 and RSSV-493 x RSSV-167 were recorded significant for all interaction components. It was indicating that prevalence of additive x additive followed by the additive x dominance and dominance x dominance gene interaction effects for juice yield in sweet sorghum based on the present results. It has indicated that the genetics of the juice and ethanol yield is expressed due to the effect of dominant gene in sweet sorghum. Amongst, the epistasis interaction (dominance x dominance), was found to be positive for juice and ethanol yield. It was detected that extent of (dominance x dominance) interaction was significant and better as compared to the both (additive x additive) and (additive x dominance) clarifying the occurrence of allied pair of genes for juice and ethanol yield in RSSV-269 x RSSV-260 and RSSV-493 x RSSV-167. Earlier scientist Vemanna *et al.* (2014) has also described the comparable type of results.

The results expressed for estimates of genetic parameters for sugar content in all three crosses, it was observed that both additive [d] as well as dominance [h] gene action were significant and [h] component observed with better in enviable direction as compared to the additive [d]. Significant effect of additive and dominant gene for sugar content earlier proposed by Saxena *et al*. (1999); Audilakshmi *et al*. (2010) and Sudhir Kumar *et al*. (2011). The cross combination RSSV-269 x RSSV-260, estimated better performance as regard as sugar accumulation in juice and additive x additive [i] interaction was estimated in significant direction. Hence, dominance with additive x additive interaction having major role in expression of total sugar content. Similar results were proposed by Vinaykumar (2009) and Sudhir Kumar *et al*. (2011). As regarding brix per cent of juice, non additive gene action were found significant in studied crosses, similarly Vemanna *et al*. (2014) reported non-additive gene action for this trait. While Umakanth *et al*. (2012) noticed that additive gene action for brix per cent and sugar yield.

Briefly, the generation mean analysis of the crosses studied in present research investigation has let out that the occurrence of epistatis for different traits under study. Kearsy and Pooni (1996) proposed the presence of duplicate interaction in the related crosses as it reduces the expression of heterosis; therefore, we need to reduce the dominance and epistasis effects by selfing in early generations, and it will be effective for selection of high juice and ethanol yielding genotypes. Inter mating of selected progeny after biparental mating and selection in subsequent segregating generations can be adopted for evolving high juice yielding lines and varieties in sweet sorghum.

Thus, the investigation indicates better cross combinations like as cross RSSV-269 x RSSV-260; thereafter, cross SSV-84 x IS-18360 relate to maximum sugar accumulation, juice and ethanol production, revealed the possibility of obtaining variants for juice and ethanol yield. Study also revealed that traits like juice and ethanol yield in sweet sorghum crop were controlled by non-additive gene action in cross combination 1st and 2nd [SSV-84 x IS-18360 and RSSV-269 x RSSV-260]. However, in cross III (RSSV-493 x RSSV-167), the additive x additive [i] gene action estimated significant in the desirable direction with evidence of duplicate epistasis, as per the dissimilar sign of dominance [h] and dominance x dominance [l] gene interactions. It was reported that the predominance of dominance with additive x additive genetic effects governed the expression of ethanol yield in sweet sorghum.

5. Conclusion

Analysis of variance in favor of generations (F_1, F_2, BC_1 and BC_2) and parents exhibited significant differences for juice, ethanol yield and its constituent characters. The average performance of parental lines as well as segregating generations of crosses studied for various characters were exhibited significant. Scaling tests were observed significant for juice yield, its component traits and resulted in additive-dominance model does not elucidate the genetic control. The performance of F_1 hybrids were better in relation to average mid-parent values and it was also comparable to average value of top parent, in considerable trends with respect of all characters in the present research investigation indicating incidence of both over and partial dominance. Overall performance of F_2 generation was found to be pooreras compared to F_1 in all three crosses studied. The backcross generation of crosses performing as good as their respective parents.

For juice yield and ethanol yield, the h (dominant) gene action with l (dominance x dominance) interaction was observed significant. Breeding methods like, heterosis breeding or recurrent selection for SCA can be used for improvement of these traits. The additive (d) gene action with i (additive x additive) interaction followed by h (dominance) was exhibited significantly better for the traits, *viz*., sugar and non-reducing sugar. For these characters, selection can be incorporated in early segregating generations by selfing.

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Conflict of interest

The authors declare no conflicts of interest relevant to this article.

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