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GENOTYPE BY SOWING DATE INTERACTION EFFECTS ON SUGAR YIELD COMPONENTS IN SWEET SORGHUM (*Sorghum bicolor* L. Moench)

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SUMMARY

Sweet sorghum (*Sorghum bicolor* (L.) Moench) has a good potential as a raw material for ethanol production. However, continual supply of feed stock to the distillery is a major constraint in sweet sorghum based ethanol production. The main goals of this research were to determine genotype by sowing date interactions for sugar yield components and to identify high yielding and stable or specifically adapted genotypes for cultivation across the year *via* ANOVA (analysis of variance) and GGE (genotype + genotype by environment) biplot analysis. Given that sugar yield and quality varies with different sowing dates, 3 hybrids and 2 varieties of sorghum were planted at International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) research farm, India on first of every month from January to December in a split plot design considering sowing date as main plot and genotypes as sub plot. The experiment was repeated for 3 consecutive years between 2007 and 2010 and observations were recorded for sugar yield and contributing traits. Date of sowing was the most important source of variation, accounting for 58 to 94% of the G+S+GS for sugar yield and related traits. Of the 12 monthly sowings, May, June and July sowings recorded highest sugar, cane and juice yields and the yields decreased with delay in sowing there on. The genotypes SPV 422 and ICSSH 30 recorded high sugar yield while ICSSH 24 was stable performer with comparative sugar yield. 'Which-won-where' analysis has demarcated the sowing dates into 2 groups and based on mean performance for sugar yield and GGE biplot analysis, the genotype SPV 422 was suitable for sowing from September to March and the genotype ICSSH 30 was suitable for sowing from April to August. However, brix was more of a genetic trait less influenced by the date of sowing.

Keywords: Sweet sorghum, sowing date, sugar yield, G×E interaction, GGE biplot biofuel

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INTRODUCTION

Sorghum (*Sorghum bicolor* (L.) Moench) is the fifth most important crop in acreage next only to wheat, rice, maize and barley in the world (Dillon *et al.*, 2007). Sweet sorghum is a new bioenergy crop that accumulates sugars in its stalk apart from producing grain and readily serves as an alternate feed stock for ethanol production. It is also known as "sugarcane of the desert" as it can survive in the marginal areas of the semi-arid tropics where other crops fail to thrive (Reddy *et al.*, 2012). Sweet sorghum is best suited for ethanol production due to its higher reducing sugar content compared to sugarcane (Huligol *et al.*, 2004). The major constraints in sweet sorghum ethanol production include non-availability of sufficient feedstock to the industry during the sugarcane crushing period. In order to meet the industry demand, raw materials (stalks) need to be available for a long period, and hence there is a need to develop and evaluate sweet sorghum cultivars for photoperiod and temperature insensitivity and high stalk and sugar yields (Reddy *et al.,* 2012).

Previous work on sowing dates (Balole, 2001; Almodares and Darany, 2006) has shown that earlier sowings of sweet sorghum generally have higher yields of stalk and sugar. In areas environmentally similar to Hyderabad, India, highest green cane yield (0.7 kg plant^{-1}) and percent juice extractability (33%) was observed in June sowing followed by February and December (Shinde *et al*., 2003; Ratnavathi *et al.,* 2012). Higher yields of stalks (44 t ha^{-1}) and sugar (7.4 t ha^{-1}) was obtained with sowing around mid-May in Iran (Almodares and Darany, 2006), May in the Lower Rio Grande Valley of south Texas (U.S.) (Hipp *et al.,* 1970), and April in Texas, U.S. (Burks *et al.,* 2013). Significant differences among the sweet sorghum genotypes, sowing dates and their interaction was reported in earlier studies (Reddy *et al.,* 2007). Apart from the juice yield, quality was also found to vary with different sowing dates in a year (Poornima *et al.,* 2008). However, sowing date experiments for all the year round cultivation of sweet sorghum has not been reported earlier. Hence, evaluation of sweet sorghum under staggered sowing in different seasons is urgently needed to meet the continuous supply of feedstock to the distillery (Reddy *et al.,* 2007).

A number of statistical methodologies have been developed and used to analyze crossover but repeatable GE (genotype × environment) interactions (Van Eeuwijk *et al.,* 1996). The ANOVA enables to partition the total variability into the different components (i.e., years, environments, genotypes and their interactions) but it leaves out some of the valuable information on the patterns of genotypes, environments and GE interactions (Gomez and Gomez, 1984). Yan *et al.* (2000) combined G and GE or GGE (genotype plus genotype by environment interaction) and repartitioned non-crossover GE interaction and crossover GE interaction for cultivar evaluation using biplot technique. In agronomic trial context, the generic term "environment" is replaced by treatment factors such as mineral fertilizers management, plant spacing or sowing date (Balalic *et al.,* 2008). Piepho (1998) emphasized that models for understanding genotypic performance under different environments can also be used for comparing different agronomic treatments.

This paper therefore attempted to apply the ANOVA and the biplot technique to determine genotype by sowing date interactions for sugar yield components and identify high yielding and stable or specifically adapted genotypes for cultivation across the year.

MATERIALS AND METHODS

Plant material

The material for the present study consisted of 5 genotypes which included 3 ICRISAT-bred A_1 cytoplasm based hybrids (ICSSH 24: ICSA 675 × SPV 422, ICSSH 21: ICSA 38 × NTJ 2 and ICSSH 30: ICSA 724 × SSV 74) and 2 open-pollinated varieties (ICRISAT-bred variety - SPV 422 and Indian national program released variety - SSV 84) of sweet sorghum. The parental material used in the development of these hybrids were screened and identified as sweet sorghum types (> 15% Brix) at ICRISAT. These hybrids and varieties were relatively photoperiod insensitive and significantly varied for flowering time, plant height, stalk weight, °Brix, juice yield and sugar yield across 3 years (2005-2007) and 2 seasons (rainy and post rainy) in earlier studies conducted at ICRISAT (Rao *et al*., 2011).

Experiment

The experimental site is located at an altitude of 545 m above mean sea level, latitude of 17.53 °N and longitude of 78.27 °E. The 5 sweet sorghum genotypes were sown on first of every month for 3 consecutive years from April 2007 to April 2010. Each genotype was planted in 4 rows of 4m length with a spacing of 75 cm between rows and 10 cm between plants in a row in vertisols of the ICRISAT, Patancheru, India. The experiment was laid out in a split plot design with 3 replications considering sowing dates as the main plot and genotypes as the sub plot. Randomization was done using GenStat v. 10

statistical package. Fertilization was done at the rate of 64 N: 28 P_2O_5 (kg ha^{-1}), 28 kg of N and entire P_2O_5 as basal and the remaining nitrogen as top dressing at 30 days after germination. Plots were kept weed-free with chemical control and manual weeding. Timely crop protection practices were taken up and supplemental irrigation was given whenever the precipitation was low to raise a healthy crop.

Meteorological observations were recorded in the automatic weather station at ICRISAT, Patancheru, India. Temperatures were recorded by maximum and minimum thermometers. Fiber Glass Reinforced Rain gauge was used for recording rainfall. Relative humidity was obtained using the hygrometric tables for the given dry bulb and wet bulb temperatures. Duration of bright sunshine was measured by using a Campbell sunshine recorder.

Data collection

Observations were recorded for the middle 2 rows in each entry and in each replication for the traits viz., days to 50% flowering (days taken by 50% of the plants in a plot to flower), plant height (average height in m from the base of the plant to the tip of the panicle), stalk weight (weight in t ha^{-1} of the stalks without panicles harvested at physiological maturity), cane weight (stalk weight after removal of leaves and sheath), juice weight (weight of juice in t ha^{-1} extracted by crushing the canes), juice volume (quantity of juice extracted measured on volume basis and expressed in kl ha^{-1}), bagasse weight (weight of stalks after juice extraction in t ha^{-1}), Brix and sugar yield (calculated as per Putnam *et al*. (1991) as a product of Brix in % and juice weight and expressed in t ha^{-1}). As all the entries did not flower at the same time, the maturity observations were recorded at 40 days from the flowering date for a genotype in each replication.

Biometric-genetic analysis

ANOVA for individual years were done following standard procedure for analyzing split plot design. Homogeneity of residuals variance was determined by Bartlett's homogeneity test. Genotype and sowing date were regarded as fixed effects whereas year and replication were treated as random effects. Later, combined analysis of variance for 3 years was performed on the original dataset to partition out environment (E), genotype (G) and the GE interaction (Yan *et al.*, 2000). The GenStat v. 10 statistical package was used to run ANOVA and generate biplots.

RESULTS

Weather

The total rainfall received during the 3 years was similar amounting to 923 mm, 913 mm and 1011 mm for the years 2007-08, 2008-09 and 2009-10, respectively. There was a gradual though marginal increase of maximum and minimum temperatures, pan evaporation and sunshine hours from 2007-2008 and 2009-2010 (Table 1). The climate was similar for the 3 consecutive years at ICRISAT, Patancheru (data not shown). About 77% of the rainfall was received in 4 months i.e., from June-September and these months also recorded less number of sunshine hours (4.4 to 5.7). May recorded the highest number of sunshine hours (9.5) followed by April (9.2), January (8.8) and February (8.8). The months, December and January recorded a low minimum temperature of 13.3 ºC.

Analysis of variance

Results of ANOVA for the yearly data is presented in Table 2, which gives an overall picture of the relative magnitudes of the G (genotype), S (sowing date), and GS (genotype × sowing date) variance terms. Date of sowing was always the most important source of variation, accounting for 58 to 94% of the G+S+GS. In 2007-2008, the influence of sowing date was relatively greater than the other 2 years for sugar yield, juice volume and plant height while in 2008-09, the influence was more for Brix and days to 50% flowering. In 2008-09 and 2009-10, the influence of sowing date was more for cane weight compared to 2007-08 while for bagasse, the sowing date influenced most in 2009-10 compared to the other 2 years (Table 2). Gauch and Zobel (1997) reported that normally in MET data, environment accounts for about 80% of the total variation. Rakshit *et al*. (2012) also reported as high as 83% of variation being explained by environment for sorghum grain yield MET data. Genotype × sowing date was greater than G in all the 3 years for the traits sugar yield, juice volume, bagasse and brix. The large GS relative to G suggests the possible existence of different mega-environments (Mohammadi *et al.*, 2009). However, G was greater than GS in all the 3 years for plant height, in 2 years for days to 50% flowering and in 1 year for cane yield. Similarly, from the combined ANOVA, it is observed that the variance due to sowing dates was larger than the variance due to genotypes, year and other interaction effects (Table 3). Hence the results are discussed with respect to the sowing date.

Table 1. Mean monthly rainfall, minimum and maximum temperatures, mean pan evaporation, sunshine hours and relative humidity for the years 2007-2010 recorded at ICRISAT, Patancheru, India.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
Rainfall (mm)	13.0	18.7	56.2	25.7	14.9	110.3	78.2	341.7	199.1	56.0	32.8	2.5	949.2*
Pan evaporation (mm)	4.4	5.9	7.5	9.7	11.6	8.2	6.3	4.4	3.6	4.3	4.1	3.7	6.2
Maximum temperature	29.1	32.0	35.0	38.6	39.3	34.5	31.9	30.0	29.9	30.7	29.5	29.0	32.5
Minimum temperature	13.3	16.8	19.2	23.0	24.8	23.9	23.2	22.3	21.8	18.9	15.8	13.3	19.7
Relative humidity (high)	90.0	84.2	73.8	70.8	64.0	81.6	84.6	90.4	93.4	90.7	90.8	93.5	84.0
Relative humidity (low)	36.2	32.5	27.5	29.1	33.1	50.4	58.4	66.4	67.0	48.3	45.0	39.5	44.4
Bright sunshine hours	8.8	8.8	8.3	9.2	9.5	5.7	4.4	4.6	5.3	7.5	8.1	8.3	7.4

*Total rainfall received in a year

Table 2. ANOVA and proportion of variation (G + S + GS) explained by genotype (G), sowing date (S) and GS interaction for various sugar yield contributing traits.

Year	Source	Sugar yield (t ha^{-1})		Bagasse (t ha^{-1})		Brix (%)		Cane weight (t ha^{-1})		Days to 50% flowering		Juice volume (kl ha^{-1})		Plant height (m)	
		%	MSS	%	MSS	%	MSS	%	MSS	%	MSS	%	MSS	%	MSS
2007-08	S	93	45.2**	87	609.9**	85	176.5**	58	319.9**	62	762.9**	88	886.1**	86	4.2**
	G	1	1.0*	2	44.4**	6	31.4**	27	221.8**	34	636.3**	3	87.0**	10	1.3**
	GS	6	0.8**	11	19.9**	9	4.8**	15	21.0	4	13.2**	9	21.8**	5	0.1*
2008-09	S	89	19.8**	86	464.8**	87	158.0**	86	2083.9**	94	4551.3**	80	432.5**	77	2.4**
	G	4	2.1**	4	54.0**	4	17.7**	6	393.8**	3	456.1**	8	113.5**	14	1.1**
	GS	7	0.5*	10	14.3*	9	4.5	9	56.0*	2	31.4**	12	17.1*	9	0.1*
2009-10	S	80	15.3**	92	1203.4**	72	67.6**	86	3043.8**	87	3697.2**	82	422.6**	73	3.1**
	G	7	3.7**	2	76.2**	7	18.7**	6	560.9**	5	551.5**	8	115.8**	23	1.9**
	GS	13	0.7	6	21.8	20	5.0**	8	72.1**	8	93.4**	10	13.5**	4	0.1*

% - % of G+S+GS; MSS – Mean sum of squares

Table 3. Combined ANOVA for sugar yield and related traits across 12 dates of sowing at ICRISAT, Patancheru evaluated for 3 consecutive years (2007-10).

Source of variation	d.f.	Mean sum of squares						
		Days to 50% flowering	Plant height (m)	Cane weight (t ha^{-1})	Juice volume (kl ha^{-1})	Bagasse (t ha^{-1})	Brix (%)	Sugar yield (t ha^{-1})
Year	2	2736.26**	1.76**	1286.79**	50.33*	1913.05**	84.14**	4.93**
Sowing date	11	7520.09**	7.68**	13769.68**	1360.60**	1747.57**	252.12**	61.39**
Year × Sowing date	22	1604.34**	0.63**	1531.99**	190.32**	312.56**	65.06**	8.09**
Residual	72	15.04	0.06	150.3	14.582	13.28	3.893	0.70
Genotypes	4	1751.97**	4.15**	1198.77**	259.40**	174.96**	67.15**	6.48**
Year × Genotypes	8	18.97	0.10**	113.04	32.64**	11.81	4.86	0.58
Sowing date × Genotypes	44	67.13**	0.08**	189.72**	21.92**	29.52**	5.94**	0.77**
Year × Sowing date × Genotypes	88	34.00**	0.05	152.05**	15.47**	15.3**	4.89**	0.70**
Residual	288	13.23	0.04	64.97	8.34	10.41	2.706	0.44

*$P < 0.05$, **$P < 0.01$

Mean performance of genotypes across the sowings dates

Sowing date and genotype-wise means for all the traits over 3years are presented in Table 4. The overall sugar yield increased when the genotypes were sown from January to May (1.38 to 3.83 t ha^{-1}), remained constant from May to July (3.72 to 3.83 t ha^{-1}) and decreased thereafter till December (2.26 to 0.67 t ha^{-1}) (Figure 1a and Table 4). However the crop sown during April and May took 100 to 116 days to flower which ultimately increased time taken to reach maturity showing significant influence of climatic factors on response of genotypes (Figure 1e). Hence the harvest window did not follow the sowing window for the crop sown in the months of April and May indicating longer life cycles of April and May sown crops. Hence, stalks from 2 sowings were ready for harvest during the month of October (Table 4). When the per day sugar yield was taken into account, the May, June and July sowings recorded between 27.3 and 30.7 kg of sugar per hectare per day followed by March, April and August sowings with 17.5 to 19.3 kg. The crop sown from October to December had lowest sugar yields (0.67 to 1.03 t ha^{-1}) and per day sugar yields (5.9 to 8.2 kg ha^{-1}). When sown from March to July, the genotypes had highest cane weight (43.1 to 52.1 t ha^{-1}) (Figure 1b) and juice yield (14.6 to 22.4 kl ha^{-1}) (Figure 1c). During the remaining months, i.e., from August to February, the genotypes had half the cane weight (17.8 to 29.9 t ha^{-1}) and juice yield (7.0 to 12.1 kl ha^{-1}). However, no such trend was noticed for Brix which was low when sown in the month of October (9.5) and ranged from 13.7 to 18.6 during the remaining months (Figure 1d). Over the years and over sowing dates, the genotypes ICSSH 30 and SPV 422 were most productive for sugar yield followed by ICSSH 24 (Figure 1a). Besides, ICSSH 30 was early flowering (79 days) and superior among all the genotypes for plant height (2.6m), cane yield (36.5 t ha^{-1}), juice yield (14.2 kl ha^{-1}) and bagasse yield (18.6 t ha^{-1}). The variety, SPV 422 had the highest brix of 16.4. Though the effect of genotypes, their first order interaction with year and sowing date; second order interaction with both year and sowing date was significant, it was far less than the effect due to sowing date (Table 3).

Mean performance vs. Stability of the genotypes

Performance and stability of genotypes were visualized graphically through GGE biplot (Figure 2). This can be evaluated by average environment coordination (AEC) method (Yan, 2002). For this, sowing date centered, genotype metric biplots are presented in Figures 2a, 2b, 2c, 2d and 2e. The first 2 PCs explained 89.9% for sugar yield, 94.5% for cane yield, 91.7% for juice volume, 95.8% for brix and 94.1% for days to 50% flowering. As the first 2 PCs explained more than 60% of the (G+GE) variability in the data, the biplot adequately approximated the variability in G × E data (Yan *et al*., 2010). In Figures 2a, 2b, 2c, 2d and 2e, the line with single arrow head is the AEC abscissa. It passes through the biplot origin and marker for average environment and points towards higher mean values (Yan, 2001). The perpendicular lines to the AEC passing through the biplot origin are referred to as AEC ordinate represents the stability of genotypes. The greater the absolute length of the projection of a cultivar, the less stable it is. Furthermore, the average yield of genotypes is approximated by the projections of their markers to the AEC abscissa (Kaya *et al*., 2006). The AEC ordinate separates entries with below-average means from those with above-average means. Based on the mean performance, SPV 422 followed by ICSSH 30 and ICSSH 24 performed above average for sugar yield (Figure 2a). On the other hand, SSV 84 was the poorest yielder. Either direction away from the biplot origin, on this A-axis, indicates greater G×E interaction and reduced stability (Yan, 2002). Thus ICSSH 24 followed by ICSSH 21 were more stable across the sowing dates. It may be observed that SPV 422 and ICSSH 30 were least stable for sugar yield with higher projection from the AEC abscissa. For broad selection, the ideal genotypes are that have both high mean yield and high stability. In the biplot, they are close to origin and have the shortest vector from the AEC abscissa. Thus ICSSH 24 is an ideal genotype in the current study. For cane weight and juice volume, ICSSH 30 was the best performing genotype while SSV 84 was the poorest yielder. ICSSH 24 was the stable performer for these 2 traits (Figure 2b and Figure 2c). SPV 422 followed by SSV 84 had the highest

Table 4. Mean performance across monthly sowings for sugar yield and related traits in 5 sweet sorghum genotypes evaluated in monthly intervals for 3 consecutive years (2007-10)**.**

Sowing date/Genotype	Harvesting date	Days to 50% flowering	Plant height (m)	Cane weight (t ha^{-1})	Juice volume (kl ha^{-1})	Brix (%)	Bagasse (t ha^{-1})	Sugar yield (t ha^{-1})	Per day sugar yield (kg ha^{-1})
January	May	75	2.2	21.1	8.5	16.4	11.8	1.38	12
February	June	75	2.5	25.7	8.7	17.1	15.3	1.55	13.4
March	July	94	2.3	43.1	14.7	15.9	21.9	2.55	19
April	September	116	2.7	45.9	14.6	17.2	27.3	2.73	17.5
May	October	100	2.9	52.1	22.4	16	22.8	3.83	27.3
June	October	87	3	47.9	19.6	16.9	22.4	3.74	29.4
July	November	81	3	46.6	19.1	18.6	23.2	3.72	30.7
August	December	78	2.4	29.9	12.1	15.9	13.4	2.26	19.3
September	January	75	2.1	23	8.6	14.1	11.5	1.26	11
October	February	74	1.8	17.8	7	9.5	9.9	0.67	5.9
November	March	86	1.9	19.2	7.4	13.7	10.6	1.03	8.2
December	April	78	2.2	20	7	13.8	11.3	0.93	7.9
lsd (5%)		2.0	0.1	3.2	1.6	0.8	1.5	0.4	-
ICSSH 24		85	2.2	32.3	12.7	15.7	16.3	2.2	17.6
ICSSH 21		84	2.6	33.0	12.7	14.4	16.8	2.0	16.5
ICSSH 30		79	2.6	36.5	14.2	14.9	18.6	2.3	19.5
SPV 422		90	2.3	34.2	12.9	16.4	17.2	2.4	18.2
SSV 84		86	2.2	27.4	9.9	15.8	15.1	1.8	14.0
lsd (5%)		1	0.1	1.5	0.8	0.4	0.9	0.2	-
Mean		85	2.4	32.7	12.5	15.4	16.8	2.1	17.1

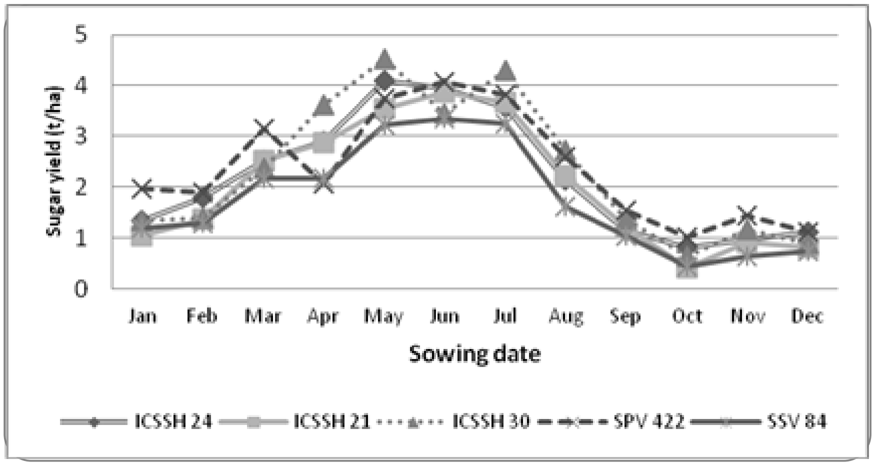

Figure 1a

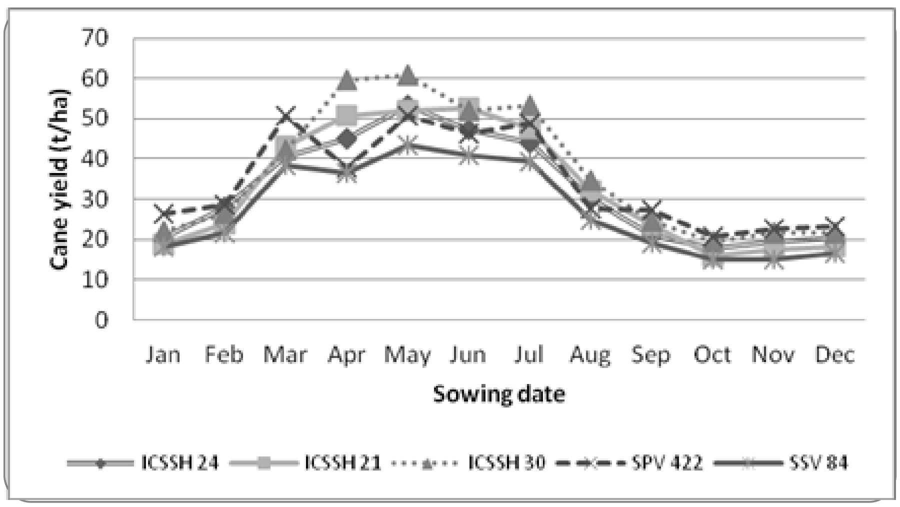

Figure 1b

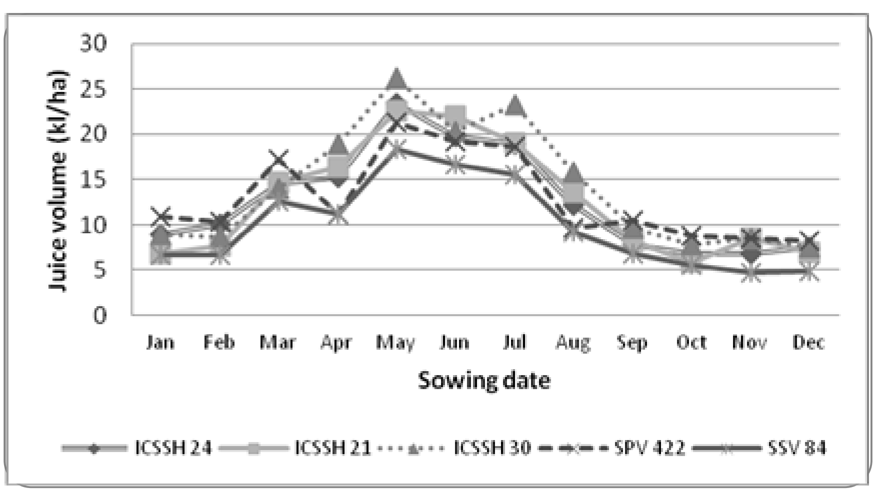

Figure 1c

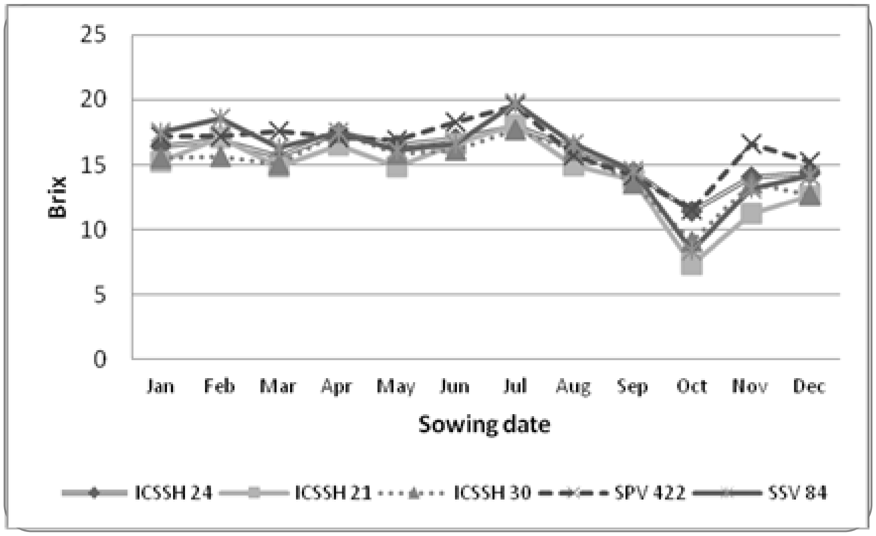

Figure 1d

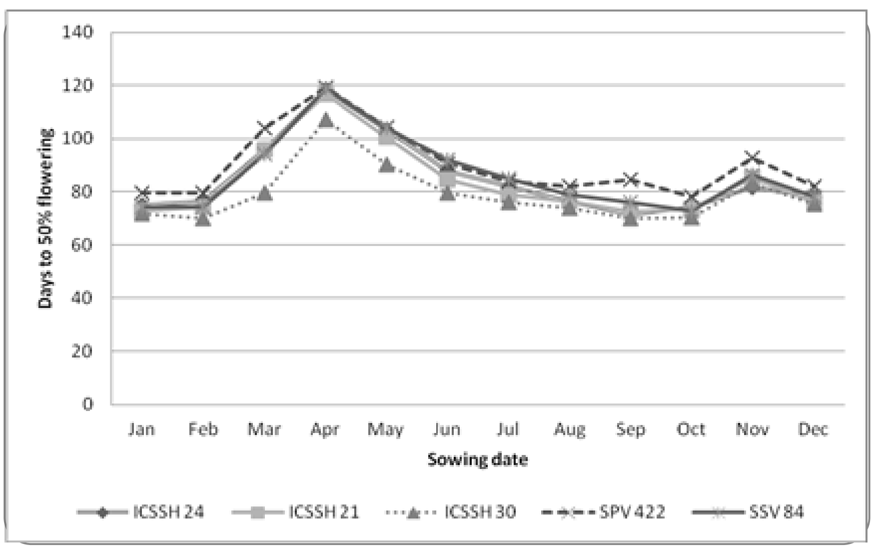

Figure 1e

Figure 1. Differences among the five sweet sorghum genotypes across 12 dates of sowing for a: Sugar yield, b: Cane yield, c: Juice volume, d: Brix and e: days to 50% flowering.

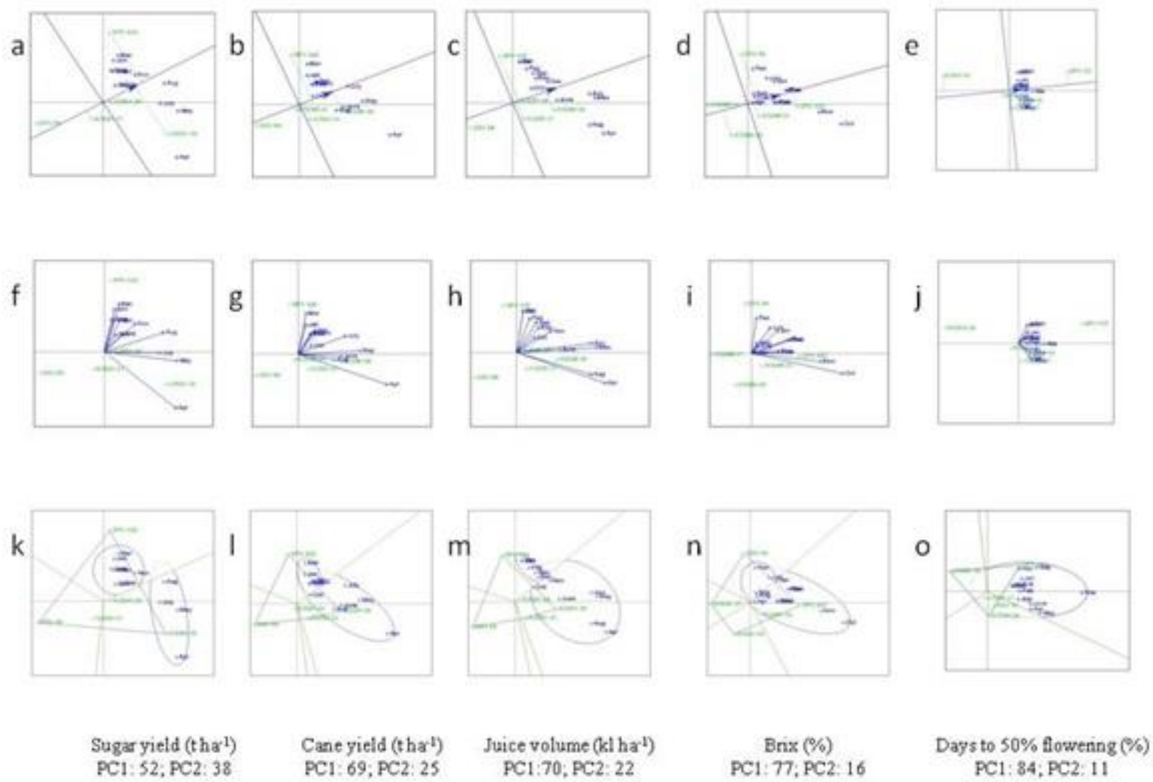

Figure 2. GGE biplots for sugar yield, cane yield, juice volume, brix and days to 50% flowering, at 12 sowing dates: January (Jan), February (Feb), March (Mar), April (Apr), May, June, July, August (Aug), September (Sep), October (Oct), November (Nov), December (Dec) for genotypes ICSSH 21, ICSSH 24, ICSSH 30, SPV 422, SSV 84. a-e: Mean vs. stability of the genotypes; f-j: Relation among the test locations; k-o: Polygon view of the GGE biplot for the which-won-where pattern for genotypes and sowing dates (ovals representing possible mega-environments).

brix while ICSSH 21 followed by ICSSH 24 were stable for brix (Figure 2d). ICSSH 30 followed by ICSSH 21 were early flowering while ICSSH 21 was stable for days to 50% flowering (Figure 2e).

Sowing date evaluation

Like in the previous section, the relationships among the sowing dates were studied by sowing date centered preserving of data. Combined analysis over 3 years for sugar yield (Figure 2f), cane yield (Figure 2g), juice volume (Figure 2h), brix (Figure 2i) and days to 50% flowering (Figure 2j) showed that the majority of the angles between their vectors are acute. Acute vector angles are indicative of closer relationship among the environments (Yan and Tinker, 2006). The sowing dates which differed widely are April with March and January sowings for sugar yield (Figure 2f), cane yield (Figure 2g) and juice volume (Figure 2h). While for brix (Figure 2i), October and February sowings were wide apart. For days to 50% flowering April and May sowings were wide apart from September and November sowings (Figure 2j). Thus majority of the sowing dates were highly correlated. As none of the vectors showed obtuse angles, no inverse relationships were seen between the sowing dates.

Which wins where

Which-won-where graph is constructed first by joining the farthest genotypes forming a polygon.

Subsequently perpendicular lines are drawn from the origin of the biplot to each side of the polygon, separating the biplot into several sectors with one genotype at the vertex of the polygon. These lines are referred to as equality lines (Yan, 2001). Genotypes at the vertices of the polygon are either the best or poorest in one or more environments. The genotype at the vertex of the polygon performs best in the environment falling within the sectors (Yan, 2002; Yan and Tinker, 2006). Which-won-where biplots for sugar yield, cane weight, juice volume, brix and days to 50% flowering over 3 years are presented in Figure 2k, 2l, 2m, 2n and 2o, respectively.

The corner genotypes for sugar yield were SPV 422, SSV 84 and ICSSH 30 (Figure 2k). These are either the best or the poorest genotypes at some or all sowing dates; they can be used to identify possible mega-environments (Yan *et al.*, 2000). The variety, SPV 422 is the vertex genotype in the sector located in which the sowing dates of January, February, March, June, September, October, November and December are located. Hence, this genotype is a winner in these sowing dates. The genotype ICSSH 30 is a vertex genotype in the sowing dates of April, May, July and August. Hence, this genotype is a winner in these sowing dates. However, SSV 84, although a vertex genotype, did not project to sectors where any of the sowing dates are located and is, therefore, universal loser. Genotypes within the polygon, ICSSH 21 and ICSSH 24, were less responsive to the sowing dates than the vertex genotypes. When the sugar yield contributing traits such as cane yield (Figure 2l), juice yield (Figure 2m) and brix (Figure 2n) were observed, it is seen that for cane yield, ICSSH 30 is a “winner” genotype in April, May, June, July and August sowing dates and SPV 422 is a winner in the rest of the sowing dates. The juice yield followed similar trend as that of cane yield. For brix, SPV 422 and SSV 84 were winner genotypes and ICSSH 21 and ICSSH 30 were loser genotypes. The non-responsive genotype was ICSSH 24 which did not fall into any of the vertices. For days to 50% flowering, SPV 422 is a highly responsive genotype across all sowing dates while all other genotypes are comparatively less responsive (Figure 2o).

DISCUSSION

Sweet sorghum is a potential raw material for ethanol production that on blending in petrol is expected to meet the energy demand and address the environmental issues (Reddy *et al.,* 2011). Performance of sweet sorghum varies under different environmental conditions (Ratnavathi *et al.,* 2012) and according to Balole (2001), physiological mechanisms in sorghum plants are capable of sensing the differences in day length. Hence the present study was conducted to determine genotype by sowing date interactions for sugar yield components and identify high yielding and stable or specifically adapted genotypes for cultivation across the year to increase number of days of factory operation. The important attributes of sweet sorghum as a bio energy crop are cane yield, juice yield, brix, sugar yield and days to 50% flowering. From the combined analysis of variance across years, it was observed that the sowing date contributed largely to the total variation than the year. Similarly, Vange and Obi (2006) observed higher variance due to sowing date compared to year for grain yield in rice. The higher mean sum of squares due to sowing date compared to the year denotes that the traits are more influenced by sowing date as compared to yearly climatic variations. Also the higher genotype effects as compared to its interaction effects with year and sowing date denotes that the genetical variation is more as compared to environmental influence. Of the 12 monthly sowings, May, June and July sowings recorded highest sugar, cane and juice yields and the yields decreased with delay in sowing there on. The July and August sowings were earlier reported to yield high sugar as compared to September, October, November and December sowings in India (Reddy *et al.*, 2007). Similarly, highest fresh stalk yields were observed in the May in comparison to June sowings in Iran (Almodares and Darany, 2006) and April, June and July sowings in Arizona (Teetor *et al.,* 2011). Broadhead (1972) concluded that sweet sorghum needs a long growing season and the yield declines with late sowing. Similar trend of influence on sowing datewas not observed for brix value which was highest in the month of July followed by April and February. Similar reports existed for nonsignificant influence of sowing date on the brix value (Balole, 2001). Brix was considered as a varietal character and less influenced by environment (Ratnavathi *et al.,* 2012).

Of the genotypes evaluated, SPV 422 and ICSSH 30 recorded high sugar yield while ICSSH 24 was stable performer with comparative sugar yield. ICSSH 30 was a better performer for other traits as well. Significant genotypic effects for sugar yield and related parameters were recorded earlier in 7 hybrids and 3 varieties of sweet sorghum evaluated from July to December sowings (Reddy *et al.,* 2007). Responses of genotypes to environment (photo-sensitivity) seem to effect the accumulation of sugars in the stalk. The genotypes evaluated in the study performed well from March to August for sugar yield. With reduction in sunshine hours (in post rainy season from September to February), there is drastic reduction in the sugar yields. Therefore, cultivars that are suited to sow from September to February or photo-sensitive genotypes can be bred to widen the harvest window. Otherwise, photo-insensitive genotypes that can perform consistently all the year round can be developed. From the current study, the genotype SPV 422 gave a total sugar yield of 12.1 t ha^{-1} when pooled over September to March sowings which was 25% higher than the nearest best performing genotype, ICSSH 24 which gave a sugar yield of 9.7 t ha^{-1}. Thus, SPV 422 can be utilized for cultivation during post rainy season. Also, timing of crop establishment can have a wide range of effects on the crop yield and composition (Cogdill, 2008). The low temperatures below 10 ^{o}C at sowing prolongs seed germination and at flowering affects the seed set percentage in sorghum (Reddy *et al.,* 2003). In the current study, when the minimum temperatures in the first 90 days of the crop was considered, the March to August sowings which gave sugar yield above mean, had average minimum temperature ranging from 21 to 24 ^{o}C while the September to February sowings had average minimum temperature ranging from 14.1 to 19.7 ^{o}C. Hence, varieties with good seedling vigor and cold tolerance are suitable for September to February sowings. In the Lower Rio Grande Valley of south Texas (U.S.), Hipp *et al.* (1970) found the highest sugar yield in May, and that solar radiation received between the boot and the early seed stages accounted for 75% of the variation in yield among sowing dates. The May sowing date had the greatest solar radiation in June, July, and August, when the plants were developmentally between the boot and seed stages. Late sowing also exposes the crop to pests and diseases which are dominant at the end of the crop season (Almodares *et al.,* 2008). However, in the current experiment, suitable crop protection measures were undertaken to minimize the damage due to biotic stresses.

The knowledge of GEI can help to reduce the cost of extensive genotype evaluation by eliminating unnecessary testing dates and by fine-tuning breeding programs. Also from the GGE biplot, it can be seen that the genotypes SPV 422 and ICSSH 30 had good sugar, cane and juice yields but were least stable for sugar yield with higher projection from the AEC abscissa. The genotype ICSSH 24 was on par with them with stable performance for these traits across the sowing dates. The variety, SPV 422 is suitable for the sowing dates of January, February, March, June, September, October, November and December while the genotype ICSSH 30 is suitable for the sowing dates of April, May, July and August. The polygon also reflects that SSV 84 and ICSSH 21 are poor yielding genotypes not suitable for any of the sowing dates though ICSSH 21 was more stable across the sowing dates. The genotype SSV 84 was found to be poor stalk yielding genotype not suitable for rainy and post rainy seasons in earlier studies (Rao *et al.,* 2011). Thus it is evident that the highest sugar yielders (SPV 422 and ICSSH 30) were not stable, while the stable one, ICSSH 21 was among poorest yielders. The genotype ICSSH 24 was a high yielding and stable for sugar yield. High performing and stable genotypes were observed in different crop species including barley (Dehghani *et al.,* 2006), maize (Setimela *et al.,* 2007) wheat (Kaya *et al.,* 2006), lentil (Sabaghnia *et al.,* 2008), rapeseed (Dehghani *et al.,* 2008), chick pea (Ebadi Segherloo *et al.,* 2010) and sorghum (Rakshit *et al.,* 2012).

Using biplots, relationship between the testing environments can be understood easily considering the angle between their vectors. Absence of wide obtuse angles between environment vectors (Figure 2e) indicates presence of positive correlations among the test environments and also an indicative of non-existence of crossover GE (Yan and Tinker, 2006) suggesting ranking of genotype does not change with sowing dates. One of the most attractive features of a GGE biplot is its ability to show the which-won-where pattern of a genotype by environment dataset (Yan and Tinker, 2006). The graphical representation showed that the variety, SPV 422 is the 'winning' genotype for the sowing dates of January, February, March, June, September, October, November and December while ICSSH 30 is a winner in the sowing dates of April, May, July and August.

CONCLUSION

This study has clearly brought about the importance of sowing date compared to the year in influencing the sugar yield components in sweet sorghum. The high yielding and stable genotypes were identified for growing across the year. 'Which-won-where' analysis has demarcated the sowing dates into 2 groups and suitable high yielding genotypes were identified for each group. Non-inverse relationships were observed between the sowing dates. For obtaining higher sugar yields, genotypes tolerant to lower temperatures during the early 90 day crop growth period should be cultivated.

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