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Sweet Sorghum Planting Effects on Stalk Yield and Sugar Quality in Semi-Arid Tropical Environment

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ABSTRACT

Sweet sorghum [*Sorghum bicolor* (L.) Moench] has potential as a bioenergy crop for producing food, fiber, and fermentable sugar. Unlike dryland grain sorghum, little information is available on the influence of staggered planting and genotypes, especially in semiarid tropical environments. The objectives of the present study were (i) to quantify the effects of planting time and genotype on stalk and biomass yields, juice sugar quality, and (ii) to identify the most productive genotypes and planting windows for sustainable feedstock supply. Four commercial sweet sorghum genotypes (SSV84, SSV74, CSV19SS, and CSH22SS) were planted on five planting dates (1 June, 16 June, 1 July, 16 July, and 1 August) during the rainy (June–October) season of 2008 and 2009 in Hyderabad (17°27′ N, 78°28′ E), India. Planting in early and mid-June produced significantly ($P \leq 0.05$) higher fresh stalk yield and grain yield than later planting dates. Commercial hybrid CSH22SS produced significantly more stalk, grain, sugar, and ethanol yield over genotypes SSV84 or SSV74. Based on the stalk yield, juice sugar quality, sugar, and ethanol yields, the optimum planting dates for sweet sorghum in semiarid tropical climate is early June to early July. Planting sweet sorghum during this time allows more feedstock to be harvested and hence extends the period for sugar mill operation by about 1 mo, that is, from the first to the last week of October.

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Abbreviations: Tb, base temperature; Tmax, maximum temperature; Tmin, minimum temperature.

Sweet sorghum is an important crop grown in a wide range of environments in Asia, Africa, and the Americas, well adapted for areas between 40°N and 40°S latitudes. Sweet sorghum accumulates fermentable sugars (10–20%) in the stalk and thus has an advantage for producing grain for food and bioethanol from stalk juice without compromising food security (Reddy et al., 2005). Sweet sorghum crop could be a biofuel feedstock for ethanol production in India (Hunsigi et al., 2010; Ratnavathi et al., 2010) and around the world (Rooney et al., 2007; Erickson et al., 2011; Whitfield et al., 2012). Sweet sorghum requires relatively little N (Dercas et al., 1995) and water (Mastrorilli et al., 1995; Curt et al., 1995) and is relatively more tolerant to drought and salinity, among other environmental stresses, in semiarid climates (Almodares and Hadi, 2009; Vasilakoglou et al., 2011). In India, sweet sorghum is primarily grown in the rainy season (June–October) and is planted during the first fortnight of June (SrinivasaRao et al., 2009). The monsoon in the tropical India starts during the early to mid-June and ceases by late September or early October. The sweet sorghum planting normally coincides with monsoon onset and harvesting with monsoon recession under dryland conditions. Normally, sweet sorghum is harvested during the first week of October (~115–120 d after planting). Sugarcane, in contrast, is planted between December and February and harvested between late November and mid-April in the following year (~12–14 mo from planting). Sugar mills in India operate from mid-November to early April (~4.5 mo) and sit idle for rest of the year. The sweet sorghum feedstock can go to the sugar mills before sugarcane processing begins in mid-November. Thus, staggering sweet sorghum plantings with sugarcane can help supply feedstock for the ~1.0 mo period from the first to last week of October at the sugar mills in semiarid tropical Indian conditions (15°–24° N latitude).

The biofuel industry requires the constant availability of biomass during most of the year, so a major constraint in that industry is lack of feedstock, especially from sweet sorghum, during a time best suited for biofuel processing industry (SrinivasaRao et al., 2009). Therefore, it is important to develop crop production practices that extend the feedstock availability as long as possible. Planting at different dates during the year is one option (Burks et al., 2013). In a study of monthly plantings of sweet sorghum in a temperate climate, May plantings produced high fermentable sugars, sugar, and ethanol yields (Teetor et al., 2011; Han et al., 2012). Similarly, Erickson et al. (2011) reported that early plantings (early April and May) produced higher sugar yields in both primary and ratoon-crop than late planting (June) in Florida. Strong interactions among genotypes, planting date, and timing of harvest were observed on both yield and composition of sweet sorghum juice **(**Tew and Cobill, 2006). Ferraris and Charles-Edwards (1986) reported that delayed planting decreased sugar concentrations at all stages of crop growth;

cultivar Wray yielded 10.0 t ha^{-1} of sugar when planted early in the season but only 3.0 t ha^{-1} with late planting in southeast Queensland, Australia. Currently, the biofuel industry is promoting and commercializing sweet sorghum as one feedstock for bioethanol production in India and elsewhere (PrajIndustries Limited, 2012; TataChemicals Limited, 2012; AgriFuels Limited, 2012). However, they seek management options that can extend milling operations with minimum yield losses.

Staggered planting can help lengthen the time the feedstock can be used (Schaffert, 1992). However, much information on the impact of planting date on stalk and sugar yields are available on sweet sorghum genotypes grown in temperate climatic conditions (Han et al., 2012; Burks et al., 2013), but information is very limited on genotypes adapted to a semiarid tropical environment, particularly India. In addition, information on the effects of biweekly staggered planting on fresh stalk yield, sugar quality traits, sugar, and ethanol yields have not been adequately studied in semiarid tropical climates (SrinivasaRao et al., 2009). Information on genotype or germplasm is needed because tropical environments differ from temperate ones in both phenology and yield. Both photoperiod and temperature interact, thus further influencing yield especially for very late plantings. Furthermore, evaluating sweet sorghum across planting dates and identifying the best planting window in the rainy season (June–November) will not only benefit the sweet sorghum biofuel processing industry, but also allow farmers to plan planting and harvest operations for continuous feedstock supply (Rao et al., 2008).

Thus, the primary objectives of this research were to (i) evaluate commercially available sweet sorghum genotypes for their response to variable planting dates (weather); (ii) quantify the effects of planting date and genotype and their interaction on phenology, stalk, and biomass yields, juice sugar quality traits, sugar, and ethanol yields; and (iii) identify best genotype and planting and harvest window for extended feedstock supply.

MATERIALS AND METHODS

Sweet Sorghum Genotypes and Experimental Design

Four commercial sweet sorghum genotypes, three varieties (SSV84, SSV74, and CSV19SS) and one hybrid (CSH22SS), were evaluated in this study. Table 1 provides the pedigree details of genotypes. The experimental design was a split-plot with three replications, with planting dates assigned to main-plots, genotypes to sub-plots, and plots arranged in a randomized complete block design (RCBD). The plot size was 5.0 m by 3.6 m (18 m^2) each with 6 rows 5 m long.

Experimental Site and Environmental Conditions

The plots were planted on 1 June, 16 June, 1 July, 16 July, and 1 August during the rainy seasons of 2008 and 2009 at the experimental farm at the Directorate of Sorghum Research, Hyderabad, India (17° 27′ N, 78° 28′ E, altitude: 524.6 m amsl). Soil at the experimental site was a clay loam (profile depth ≥ 1.0 m; clay 50.1%; silt 29.2%; coarse sand 6.1%; organic carbon 0.51%; pH 7.5; field capacity 36.5%; wilting point 18.8%; bulk density 1.28 g cc^{-1}; electrical conductivity 0.138 dS m^{-1}; soil available N at 158.7 kg ha^{-1}, P at 15.8 kg ha^{-1}, and Kat 672 kg ha^{-1}). The environmental conditions during 2008 and 2009 cropping seasons are in Fig. 1. Accumulated thermal time was calculated from sowing to physiological maturity for each planting date. The accumulated thermal time (°Cd) was computed by averaging weekly maximum (Tmax) and minimum (Tmin) temperatures and subtracting base temperature (Tb, 10°C).

Crop Husbandry and Data Collection

Two seeds were hand-planted at 5-cm soil depth and thinned to 10 plants m^{-2} at 5-leaf stage. A seeding rate of 10 kg ha^{-1} and plant spacing of 60 cm between the rows and 15 cm within the row was followed in both the years. Herbicide atrazine (2-chloro-4-ethylamino-6-isopropylamino-1, 3, 5-triazine) at 1 kg a.i. ha^{-1} was applied 1 d after sowing (pre-emergence) to control weeds. Hand-weeding and intercultivation operations were done twice between 5-leaf and panicle initiation. The recommended dose of fertilizer was applied (80–40–40 kg N–P_2O_5–K_2O ha^{-1} in the form of urea, single superphosphate, muriate of potash, respectively) with half the N and all P and K as basal; the rest of the N was side-dressed at panicle initiation. Recommended and need-based crop protection measures were taken to control pests and diseases. The crop planted on 1 June in both the years was sprinkler irrigated uniformly for germination and seedling establishment because very little rainfall occurred (Fig. 1). All subsequent plantings were raised under natural rainfall conditions in both years. Approximately 50 mm irrigation water was applied to bring the soil near to field capacity.

Phenology and Plant Height

Days to 50% flowering (anthesis) was measured on 10 tagged plants in each treatment plot as the time from date of seeding to the time that 50% of the plants in a plot extruded anthers in the mid-sections of the panicle (Vanderlip and Reeves, 1972). Days to physiological maturity was recorded when dark-spot (black-layer) appeared at the basal portion of seed (hilum) of the 10 tagged plants. At physiological maturity, plant height was recorded on the 10 tagged plants by measuring the height from the base of the plant to the tip of the panicle.

Total Biomass, Stalk and Grain Yield

At physiological maturity, 10 representative plants from the four central rows of each plot were sampled in all three replications for measuring fresh total biomass and stalk yield. After cutting the plants at ground level, total fresh biomass weight was recorded. The leaves along with sheath were then stripped and panicles with last internode (peduncle) were separated; the fresh weight of stripped stalk (hereafter referred as fresh stalk yield) was then recorded. Grain yield was estimated from the 10 tagged plants (panicle). The panicles were dried, threshed, weighed, and grain yields (kg ha^{-1}) computed; yields were adjusted to 14.5% moisture content.

Juice Extraction and Juice Yield

Stalk juice was extracted by passing the stalks through a power operated three-roller horizontal sugarcane machine miller soon after harvest. The stripped stalks were passed through the mill at least twice, and all extractable juice was removed from stalks, and weighed immediately. The extracted juice was filtered through Whatman filter paper immediately to remove large solids. Then 100 mL of the fresh juice was transferred to standard glass test tubes and processed immediately to estimate ^{o}Brix. Soluble sugars were subsequently determined. Juice extraction rate (%) was computed by dividing weight of fresh juice by weight of fresh stalks and multiplying by 100. Juice yield (Mg ha^{-1}) was computed by multiplying juice weight from 10 plants by plants per hectare.

Juice Sugar Quality Traits

Juice °Brix (a measure of the mass ratio of total soluble solids to water) of the extracted juice was determined using a digital hand-held refractometer (Digital hand-held pocket refractometer PAL-1, Atago, Tokyo, Japan). This is referred as juice brix hereafter. Total soluble sugars were estimated by phenol sulfuric acid method using glucose as standard (Dubois et al., 1956). Reducing sugars in the fresh stalk juice were estimated by using the 3, 5 dinitrosalicylic acid (DNSA) reagent method (Miller, 1959). Reducing sugar content was calculated for glucose equivalents by comparing the absorbance with a standard curve of glucose. Sucrose content was directly measured using NIR Saccharimeter 880D (Optical Activity Limited, Cambridgeshire, UK) without using lead acetate clarification; this is hereafter referred to as juice sucrose content.

Total Sugar and Computed Ethanol Yield

Total sugar yield, which is a product of total soluble sugar percent in the juice, juice extraction ratio, and total juice weight, was estimated at physiological maturity according to Tsuchihashi and Goto (2004) and Murray et al. (2008). Ethanol yields were computed from total sugar yields using the procedure described by Smith and Buxton (1993).

Statistical Analyses

The data were analyzed using ANOVA following the procedure for split-plot design as outlined by Gomez and Gomez (1984). The results were analyzed separately by year and combined (both the years pooled). Results of both experiments (years) separately or combined showed similar responses and significance for all the traits. Therefore, the mean responses across the experiments (years) are presented. Least significant difference (LSD) values were calculated at 0.05 probability level wherever the *F* test was significant. Data analysis was performed using WINDOSTAT statistical software (Windostat, 2011).

RESULTS AND DISCUSSION

Environmental Conditions

Rain was not uniformly distributed in 2008. With a total rainfall of 803 mm over the growing season, the crop received high rainfall during the mid-season (August), 18% higher than the long-term average (683 mm) (Fig. 1). In 2009, total rainfall was 621 mm, with one peak during pre-flowering (August) and one during hard-dough stage (early October) (Fig. 1). In both years, mid- to late October was dry during the grain-filling period for the crops planted on 16 July in 2008 and 1 August in 2009. Weekly mean Tmin and Tmax ranged from 13.9 to 27.8°C to 26.6 to 36.4°C in 2008 and 14.9 to 25.2°C to 28.4 to 36.9°C in 2009 during the crop growing period (Fig. 1). The accumulated thermal (°Cd) time from planting to physiological maturity decreased from 1 June to 1 August planting in both years (Fig. 2). Accumulated thermal time decreased for 16 July and 1 August plantings over 1 June planting, falling from 15.7 to 20.4% in 2008 and from 15.2 to 19.3% in 2009.

Phenology and Plant Height

Planting dates, genotypes, and their interaction on days to 50% flowering and physiological maturity all had significant effects. Across genotypes, the mean days to flowering was higher (86 d) for the 1 June planting than subsequent plantings but the same for16 June and 1 July plantings (Table 2). On the other hand, crops planted on 16 July and 1 August went to 50% flowering in 11 and 12 d less than 1 June plantings (Table 2). Among genotypes, CSV19SS took significantly fewer days to flower (77 d). The trend in days to physiological maturity followed that of days to flowering. Days to flowering and maturity in later plantings (16 July and 1 August) were reduced because of the decline in photoperiod and accumulated thermal time from planting to physiological maturity (Fig. 2).

Significant decreases (34%) in plant height were found in crops planted in August (Table 3). In general, a longer season increased plant height. Almodares and Darany (2006) also reported increased plant height in sweet sorghum with earlier planting dates. Among the sweet sorghum genotypes, CSH22SS was the tallest.

Fresh Total Biomass and Fresh Stalk Yield

Planting date also had significant effects (Table 3), as did genotype (Table 4), on total fresh biomass and fresh stalk yield, but not on the interactions of planting date and genotype. Early plantings (1 June and 16 June) had similar and significantly more biomass (80.5 and 70.6 t ha^{-1}, respectively) than all later plantings (Table 3). Among genotypes, CSH22SS (with 59.6 Mg ha^{-1}) and SSV74 (with 55.6 Mg ha^{-1}) produced more fresh stalk yields than the other two genotypes.

Similarly, the earliest planting (1 June) gave highest fresh stalk yield of 58.1 Mg ha^{-1}. The decrease in stalk yield across the planting dates ranged from 24 to 69% (Fig. 3). Planting on 1 July decreased stalk yield by 47%, on 16 July by 63%, and on 1 August by 69% over planting on 1 June (Table 3). The commercial hybrid, CSH 22SS produced significantly ($P \leq 0.05$) more (18.0%) stalk yield over inbred SSV74. The stalk yield did not differ significantly among inbred genotypes SSV74, SSV84, and CSV19SS.

Earlier reports from temperate climates showed biomass and stalk yield of sweet sorghums decreased when planted late (June and July) rather than early (April and May) (Teetor et al., 2011; Han et al., 2012; Burks et al., 2013). Our results show that planting sweet sorghum in the first fortnight (1–16 June) was optimal for maximum stalk yield under semiarid tropical conditions, with marginal decreases when planted a little later, on 1 July. The onset of monsoon season in the semiarid tropical India is from the first to second week of June, and the monsoon ceases by late September or early October. Growing the sweet sorghum before early June is not possible because, unlike temperate climates, no rainfall occurs from March to May (data not presented in Fig.1). Maximum air temperature is also very high from March to May (35.0–42.0°C). Planting in July decreases yield of sweet sorghum because daylength decreases during the growing period. The maximum daylength at Hyderabad is ~13.5 h in June, decreasing to ~10.5 h in December. Sorghum is a short day plant, with panicle initiation when daylength reaches ≤12.0 in tropical climate (Miller et al., 1968). This suggests that planting sweet sorghum can be staggered from 1 June to 1 July, and thus feedstock can be made available for milling for 1 mo during October. Higher total biomass and stalk yield of sweet sorghum from early planting may be due to higher total accumulated thermal time (Fig. 2) and higher ambient air and soil temperatures associated with longer daylength during pre-flowering stages. Additionally, the proposed planting window from I June to 1 July would make possible milling of sweet sorghum during October for the biofuel industry before sugarcane processing starts under semiarid tropical conditions (Hunsigi et al., 2010).

Grain Yield

Planting dates, genotypes, and their interactions significantly affected grain yield (Table 2). Across planting dates and genotypes, the mean grain yield ranged from 0.51 to 5.38 Mg ha^{-1}. High grain yield of 3.76 Mg ha^{-1} was realized in 1 June planting followed by large decreases (60.0–80.0%) in subsequent plantings. Interaction between plantings and genotypes revealed that CSH22SS recorded its highest yield (5.38 Mg ha^{-1}) in the 1 June planting and remained consistently high across planting dates. Limited to no information is available on how planting date affects grain yield performance of sweet sorghum grown in temperate climatic conditions, possibly because most sweet sorghum genotypes are photoperiod sensitive and late maturing, producing very little or no grain under the long-day conditions of temperate environments. Research in temperate climates emphasizes syrup and ethanol production from sweet sorghum more than grain production (Ferraris, 1981). However, in semiarid tropical climate of India, sweet sorghum is grown both for biofuel (ethanol from stalk juice) and food (roti, an unleavened bread from sorghum flour) (Reddy et al., 2005; SrinivasaRao et al., 2009). Hence, both high stalk yield and high grain yield require equal emphasis in developing sweet sorghum genotypes especially for the semiarid tropical conditions of India.

Juice Extraction and Juice Yield

Average percentage of juice extraction across the years did not differ significantly among planting dates and genotypes (Tables 3 and 4) or their interactions. Planting dates and genotypes showed significant effects on juice yields, but their interactions were not significant (Table 3). Juice yield was higher for the 1 June planting; the mean increase for 1 June planting was 43.2% over the 16 June planting and 78.2% over the 1 July planting. Juice yield decreased more from the 16 June planting date to the 1 August planting date, ranging from 30.0 to 72.0% (Fig. 3). Among genotypes, hybrid CSH22SS displayed 21.2% more juice yields than SSV74.

The decrease in juice yield associated with delayed plantings was mainly due to shorter day-length and less availability of accumulated thermal time (Fig. 2) during the crop growing period. Teetor et al. (2011) also observed significant decreases in juice yields under staggered monthly plantings in temperate Arizona conditions.

Juice Sugar Quality Traits

The juice sugar quality was estimated in terms of juice °Brix, total soluble sugars (TSS), reducing sugars (RS), and sucrose content, which showed only genotypes had any significant effect while planting dates (Tables 3 and 4) and their interactions did not. Among the genotypes, juice °Brix, TSS, and sucrose content was similar in SSV84, SSV74, and CSH22SS (15.9, 16.0, and 16.1%, respectively), while CSV19SS showed relatively lower quality traits.

Total Sugar and Computed Ethanol Yields

Planting dates and genotypes significantly affected sugar and computed ethanol yields (Tables 3 and 4), while the interaction effects were nonsignificant. Mean sugar yields ranged from 0.56 to 4.14 Mg ha^{-1}, and ethanol yields ranged from 302 to 2202 L ha^{-1} across planting dates and genotypes Sugar yields increased by 26.4%, and ethanol by 28.0% from the 1 June planting to the 16 June planting, but the treatments were not statistically different. Both sugar and ethanol yields decreased by 23.0% from the 16 June planting to the 1 July planting, but again neither were statistically different (Table 3). The mean decrease (39.0%) from the 1 June planting to the 1 July planting in both sugar and ethanol yield was significant (Fig. 3). Furthermore, both sugar and ethanol yields decreased markedly from the 1 June planting to the 16 July planting (65.0%) and from the 1 June planting to the 1 August planting (72.0%). Commercial hybrid CSH22SS produced 29.0% more ethanol than SSV84 and 63.0% more ethanol than CSV19SS, a significant increase (Table 4). Among the varieties, SSV74 yielded 16.6% more ethanol than SSV84 and 49.2% more than CSV19SS. Our results on sugar and ethanol yields revealed that although sugar and ethanol yields decreased from 1 June to 1 July, planting sweet sorghum from 1 June to 1 July remains feasible in semiarid tropical rainy season climates. This should extend the milling period for biofuel processing facilities by about 1 mo from the first to last week of October; continuous supply of feedstock is necessary to sustain the viability of sweet sorghum ethanol value chain.

Sweet sorghum produced higher sugar and ethanol yields in early plantings (April–May) in temperate (Teetor et al., 2011; Han et al., 2012) and Mediterranean climates in Egypt (Abd El-Razek and Besheit, 2009). Burks et al. (2013) suggested that at College Station, TX, planting both early maturing hybrids and using later planting dates would extend the harvest season of sweet sorghum, which is complementary to sugarcane harvest. Early plantings (1 June) showed higher sugar yields through increased stalk yield, juice extraction, and juice yield, but the sugar concentration (Juice °Brix) did not improve to parallel stalk and juice yields (Table 3). Thus, future genetic improvement of sweet sorghum for sugar and ethanol yields should aim to combine both high juice sugar concentration and stalk yield apart from greater grain yields. This can be achieved by agronomic practices that consider more adaptive cultivars and optimal planting dates.

CONCLUSIONS

This research suggests that the planting window for sweet sorghum can extend from the first week of June to the first week of July in the semiarid tropical rainy season climatic conditions of India. This will help facilitate continuous feedstock supply for another month, that is, from first to last week of October, at sweet sorghum biofuel processing facilities. Commercial hybrid CSH22SS provided the highest yield followed by variety SSV74 for staggering of planting under dryland conditions. The additional milling operation time before sugarcane processing begins in mid-November is very useful especially in semiarid tropical India, where sugarcane and sweet sorghum can be grown in the similar agro-climatic conditions. Furthermore, the advantage of sweet sorghum is that it can be grown in dryland conditions without any supplemental irrigation during the monsoon, unlike sugarcane where more irrigation is required.

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Fig. 1. Weekly total rainfall (mm), mean minimum (Tmin) and maximum (Tmax) temperatures (°C) recorded at Agricultural Research Station, Rajendranagar (17°27’ N, 78°28’ E, Altitude: 524.6 m amsl) weather station (approximately 200 m from the study site) from last week in May to the last week in November (a) 2008 and (b) 2009.

Fig. 2. Accumulated thermal time (°Cd) calculated based on maximum (Tmax), minimum (Tmin), and base (Tb) temperatures during the crop growing periods of (solid bars) 2008 and (gray bars) 2009.

Fig. 3. Mean reduction (as percent of 1 June) for sweet sorghum phenology, stalk, juice, grain and ethanol yields, depicted as pooled mean data for 2008 and 2009.

Table 1. Pedigree details of sweet sorghum genotypes used in this research.

Genotypes	Pedigree	Remarks
SSV84	Selection from IS 23568 (PAB84)-Zera-zera landrace, Ethiopia	Time to flowering is 84 d and fresh stalk yield is 35.6 Mg ha^{-1} based on 52 multi-environment tests at the standard planting date in June second week. It is the

		India's first sweet sorghum variety developed at Mahatma Phule Agricultural University, Rahuri, India in 1992, and possessing high Juice °brix at physiological maturity.
SSV 74	Selection from 23558 (PAB74)-Zera-zera landrace, Ethiopia	Time to flowering is 76 d and fresh stalk yield is 40.5 Mg ha^{-1} based on 52 multi-environment tests at the standard planting date in June second week. High brix, inbred variety adapted to rainy season. It is the sweet sorghum-cum-forage variety released by University of Agricultural Sciences, Dharwad, India.
CSV19SS	RSSV2 × SPV 462	Time to flowering is 78 d and fresh stalk yield is 36.8 Mg ha^{-1} based on 52 multi-environment tests at the standard planting date in June second week. Inbred variety developed at Mahatma Phule Agricultural University, Rahuri, India. Released for cultivation in India in 2005 as inbred variety, and had tolerance to shoot fly.
CSH22 SS	ICSA 38 × SSV 84	Time to flowering is 82 d and fresh stalk yield is 46.5 Mg ha^{-1} based on 52 multi-environment tests at the standard planting date in June second week. This hybrid was developed at Directorate of Sorghum Research, Rajendranagar, Hyderabad, released for general cultivation in India during 2005, and possessing tolerance to shoot fly.

Table 2. Influence of planting dates, genotypes and their interaction on phenology and grain yield of sweet sorghum genotypes grown under rainfed conditions in semiarid environment at Hyderabad, India. Data are pooled means of 2 yr.

	Genotypes				**Mean**
Planting dates	**SSV84**	**SSV74**	**CSV19SS**	**CSH22SS**	
	Duration to 50% flowering, days				
1 June	88	87	82	86	86
16 June	83	81	80	82	82
1 July	85	81	79	80	81
16 July	78	75	72	77	75
1 August	74	75	72	74	74
Mean	82	80	77	80	

LSD (P = 0.05)

Genotypes (G): 0.7

Planting dates (P): 1.7

G × P interaction: Significant.

	Duration of physiological maturity, days				
1 June	128	126	123	127	126
16 June	123	121	119	122	121
1 July	125	121	119	120	121
16 July	118	115	112	118	116
1 August	114	115	111	115	114
Mean	122	120	117	120	
LSD (*P* = 0.05)					
Genotypes (G): 0.8					
Planting dates (P): 2.4					
G × P interaction: Significant					
	Grain yield, Mg ha^{-1}				
1 June	4.32	3.26	2.09	5.38	3.76
16 June	1.11	1.78	0.87	2.19	1.49
1 July	0.98	1.03	0.76	1.51	1.07
16 July	0.86	0.89	0.61	1.30	0.92
1 August	0.68	0.86	0.51	0.99	0.76
Mean	1.59	1.57	0.97	2.27	
LSD (*P* = 0.05)					
Genotypes (G): 0.06					
Planting Dates (P): 0.31;					
G × P interaction: Significant					

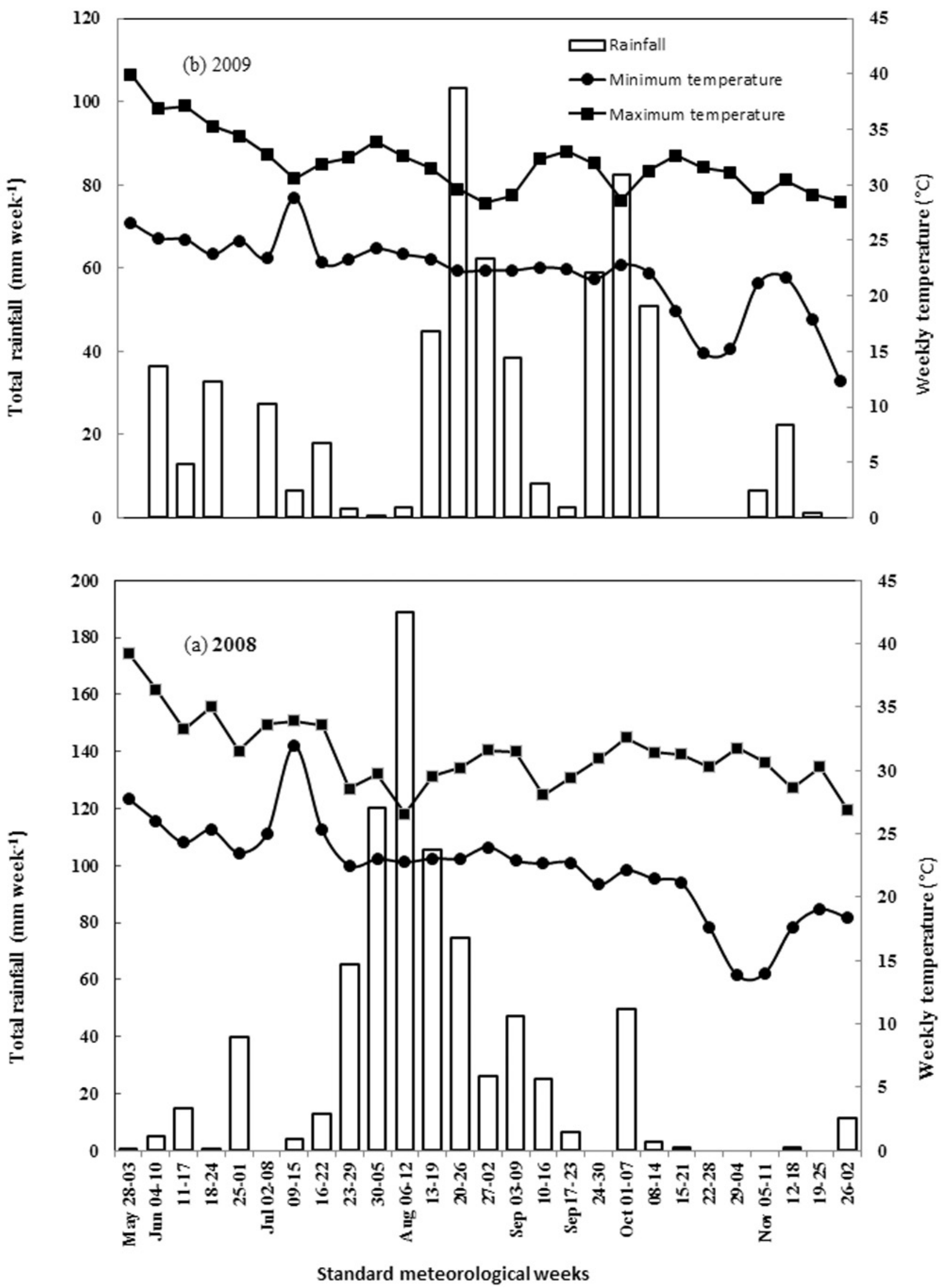
Table 3. Influence of planting dates on various traits of sweet sorghum genotypes grown under rainfed conditions in semiarid environment at Hyderabad, India. Data are pooled means of 2 yr, and averaged across genotypes.

	Planting dates					**LSD**
Traits	**1 June**	**16 June**	**1 July**	**16 July**	**1 August**	**(*P* = 0.05)**
Plant height, cm	363	378	303	268	240	106
Fresh total biomass, Mg ha^{-1}	80.5	70.6	50.6	29.4	28.3	18.5
Fresh stalk yield, Mg ha^{-1}	58.1	44.0	30.7	21.5	18.0	16.7
Juice yield, Mg ha^{-1}	27.8	19.4	15.6	10.2	7.9	12.3
Juice extraction, %	48.5	46.8	51.2	50.0	43.3	NS
Juice ° Brix, %	14.9	16.5	16.2	15.3	15.0	NS
Total soluble sugars, %	12.6	13.4	13.1	10.8	11.1	NS
Reducing sugars, %	1.47	1.50	1.58	2.05	1.68	NS
Sucrose content, %	10.9	11.8	11.2	8.5	9.3	NS

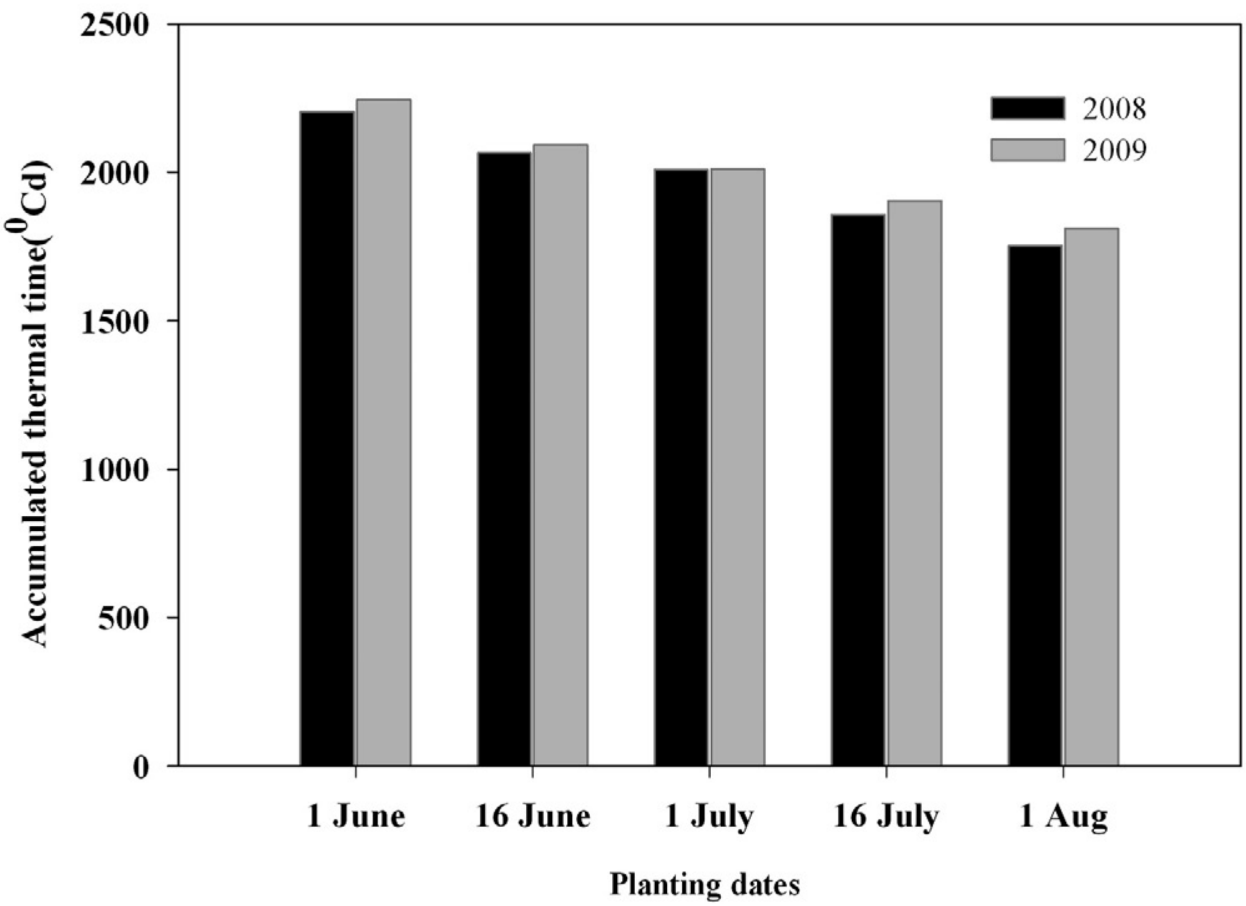
Sugar yield, Mg ha^{-1}	3.30	2.61	2.01	1.17	0.93	0.80
Ethanol yield, L ha^{-1}	1758	1373	1070	624	495	423

Table 4. Influence of genotypes on various traits of sweet sorghum grown under rainfed conditions in semiarid environment at Hyderabad, India. Data are pooled means of 2 yr, and averaged across planting dates .

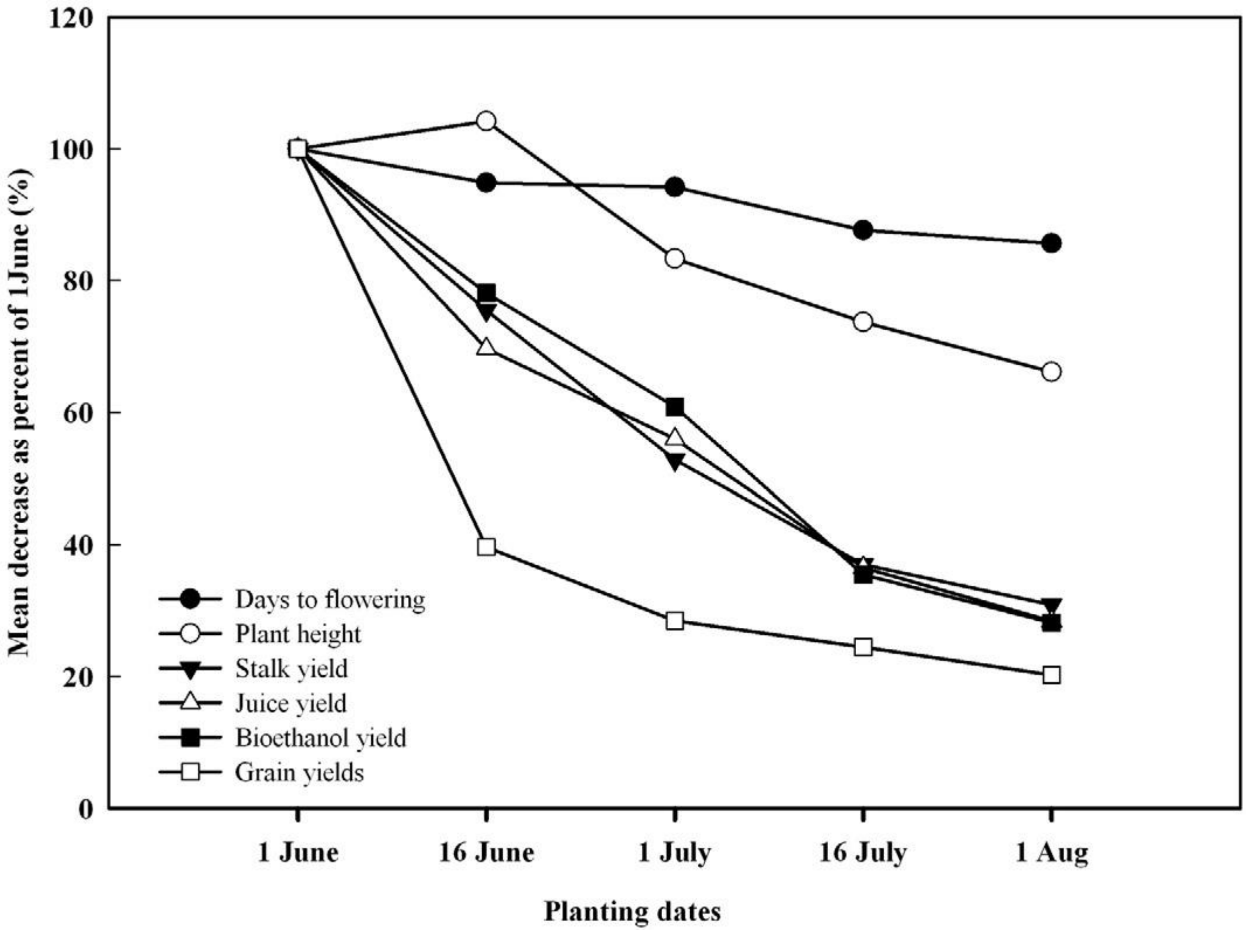
	Genotypes				**LSD (*P* = 0.05)**
Traits	**SSV84**	**SSV74**	**CSV19SS**	**CSH22SS**	
Plant height, cm	288	312	309	332	21.2
Fresh total biomass, Mg ha^{-1}	46.8	55.6	45.5	59.6	7.0
Fresh stalk yield, Mg ha^{-1}	31.5	34.7	30.7	40.8	5.0
Juice yield, Mg ha^{-1}	15.1	15.6	14.1	18.9	2.44
Juice extraction, %	47.5	49.5	46.0	48.8	NS
Juice °Brix, %	15.9	16.0	14.3	16.1	0.9
Total soluble sugars, %	12.7	12.8	10.7	12.7	1.0
Reducing sugars, %	1.94	1.85	1.32	1.50	0.38
Sucrose content, %	10.5	10.7	9.2	10.9	1.0
Sugar yield, Mg ha^{-1}	1.88	2.20	1.50	2.43	0.30
Ethanol yield, L ha^{-1}	1004	1171	785	1296	161



(b) 2009
Rainfall
Minimum temperature
Maximum temperature
Total rainfall (mm week-1)
Weekly temperature (°C)
(a) 2008
May 28-03
Jun 04-10
11-17
18-24
25-01
Jul 02-08
09-15
16-22
23-29
30-05
Aug 06-12
13-19
20-26
27-02
Sep 03-09
10-16
Sep 17-23
24-30
Oct 01-07
08-14
15-21
22-28
29-04
Nov 05-11
12-18
19-25
26-02
Standard meteorological weeks



2500
2000
1500
1000
500
0
Accumulated thermal time(^{0}Cd)
2008
2009
1 June
16 June
1 July
16 July
1 Aug
Planting dates


120
100
80
60
40
20
0
Mean decrease as percent of 1June (%)
Days to flowering
Plant height
Stalk yield
Juice yield
Bioethanol yield
Grain yields
1 June
16 June
1 July
16 July
1 Aug
Planting dates