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RESEARCH ARTICLE

Comparative Performance of Sweet Sorghum Hybrids and Open Pollinated Varieties for Millable Stalk Yield, Biomass, Sugar Quality Traits, Grain Yield and Bioethanol Production in Tropical Indian Condition

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Abstract Sweet sorghum (*Sorghum bicolor* (L.) Moench) is an important bioenergy crop that has ability to produce both food (grain) and biofuel (from stalk juice). The objectives of the present investigation were (1) to assess the comparative performance of sweet sorghum experimental hybrids with open pollinated varieties (OPVs) for stalk yield, juice sugar quality traits, grain and bioethanol yields, and (2) to identify the best performing genotypes across the locations for both bioethanol and grain yields. Sixteen experimental sweet sorghum genotypes were evaluated during kharif season, 2007 at thirteen tropical Indian locations under dryland condition. Significant ($P \leq 0.05$) differences were observed for stalk and sugar related traits. Fresh biomass varied from 39.0 to 67.0 t ha^{-1} and hybrids as a group produced 11.0 % more than OPVs. Millable stalk yield ranged from 29.4 to 46.5 t ha^{-1} among hybrids and OPVs with a mean of 40.2 t ha^{-1}. Grain yield ranged from 1.14 to 2.25 t ha^{-1}, and hybrids produced 38.0 % more grain yield than OPVs. Among all test genotypes, SPSSV30 alone recorded significantly superior juice °Brix, and total soluble sugars (TSS) than checks. Juice °Brix content has shown very strong positive correlations ($R^2 = 0.7956$, $P \leq 0.01$) with TSS. In total sugar and bioethanol yields (range 1.66–2.53 t ha^{-1} and 925–1,440 L ha^{-1}, res.), genotypes SPSSH 27, PAC52093 and SPSSH 24 in hybrid group, and SPSSV 20, SPSSV 15 and SPSSV 27 in OPV group were superior. Hybrids have recorded 10.0 and 18.0 % higher sugar and bioethanol yields, respectively than OPVs. The promising OPVs identified from this study could be the potential donors for further improvement of sweet sorghum for biofuel production. The results emphasized the importance of sweet sorghum hybrids over OPVs for stalk and bioethanol yields especially in the future climate change scenario.

Keywords Sweet sorghum · Bioethanol · Juice °Brix · Total soluble sugar content · Grain yields

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Introduction

Sweet sorghum (*Sorghum bicolor* (L.) Moench) is the bioenergy crop which accumulates large amounts of fermentable sugars (10–20 %) in its stalks as similar to sugarcane (Hunter and Anderson 1997) and is grown for syrup (as in USA) and biofuel production around the world (Han et al. 2012; Whitfield et al. 2012). Production and use of domestic energy resources including renewable is accorded the high priority to ensure India's energy security (MNRE 2009). In India, sugarcane molasses is the primary feedstock for ethanol production, while its reduced availability, variable and high cost (Shinoj et al. 2011) has necessitated to look for alternate feedstock's such as sweet sorghum (Prasad et al. 2007).

Production of ethanol from molasses alone is insufficient to meet the requirement of ethanol for doping with petrol @10 %, as the scope for increasing sugarcane area beyond the current 4.0 million ha in India is bleak due to depleting water reserves and shrinking land area available for cultivation (Anonymous 2006a). Sweet sorghum is cultivated in a wide range of environments in Africa, China, USA, India, Mexico, etc., and adapted well between

40°N and 40°S latitudes (Dogget 1988). The crop can be grown and utilized for food, biofuel, fodder, and fiber (Li 1997; Woods 2001) and one of the most efficient dryland crops to convert atmospheric CO_2 into sugar (Schaffert and Gourley 1982). Therefore, researchers and policy makers and producers in India and around the world are exploring alternative bioenergy feedstock for ethanol production. Considering these advantages, sweet sorghum has emerged as the best alternative bioenergy feedstock for ethanol production in India (Reddy et al. 2005; Shukla et al. 2006; Hunsigi et al. 2010; Rao et al. 2008; Ratnavathi et al. 2011).

In earlier studies, some aspects of sweet sorghum production management practices, and cultivar characterization for phenology, brix content, stalk yield, biomass, sugar content and bioethanol production potential (Singh and Singh 1986; Reddy et al. 2005; Rajvanshi and Nimbkar 2008; Umakanth et al. 2012; Zegada-Lizarazu and Monti 2012) have been reported. Murray et al. (2008) have identified the quantitative trait loci (QTL) that influence yield and altered the composition of stem sugar and grain without pleiotropic effects and suggested that total non-structural carbohydrate yield could be increased by selecting for major QTLs from both grain and stem sugar types. Smith and Buxton (1993) reported that sweet sorghum gave an average ethanol yield of 3,100 L ha^{-1} with fresh biomass yields of 89.2 and 65.5 t ha^{-1} for irrigated and dryland sites, respectively, when grown in a temperate climate. Researchers in the past too evaluated the large number of sweet sorghum germplasm and high yielding cultivars for stalk and sugar related traits and identified the potential donors for crop improvement (Seetharama et al. 1987; Balaravi et al. 1997a; Reddy et al. 2005; Rajvanshi and Nimbkar 2008).

Earlier emphasis on sweet sorghum improvement had primarily focused on improving inbred cultivars for biomass and sugar content (Balaravi et al. 1997b; Rajvanshi and Nimbkar 2008). Efforts to evaluate and develop sweet sorghum hybrids that can yield high stalk, sugar and grain yields across both rainy and postrainy seasons have shown limited success (Sanjana Reddy et al. 2011; Umakanth et al. 2012). Blümmel et al. (2009) compared the sweet sorghum hybrids and open pollinated varieties (OPVs) for grain, stover, juice extract and bagasse traits. Information on comparative performance of sweet sorghum hybrids and OPVs for high biomass and bioethanol yields is not available comprehensively especially under tropical Indian conditions. The objectives of the present investigation were (1) to assess the comparative performance of sweet sorghum test hybrids and OPVs for days to flowering, stalk yield, biomass, juice quality traits, grain yield and bioenergy production, and (2) to identify potential genotypes for high biomass, bioethanol (biofuel) and grain yields (food).

Materials and Methods

Plant Material and Experimental Design

Sixteen initial and advanced sweet sorghum genotypes comprising seven experimental OPVs (SPSSV15, SPSSV20, SPSSV27, SPSSV28, SPSSV4, SPSSV29, and SPSSV30), and six hybrids (PAC52093, SPSSH19, SPSSH24, SPSSH25, SPSSH26, and SPSSH27) along with two varietal (SSV 84 and CSV19SS) and one hybrid check (CSH 22SS) were planted at thirteen dryland locations during rainy season (*Kharif*) 2007. The pedigree details of experimental materials are listed in Table 1. Each genotype was planted in 6 rows of 5 m length (plot size 5.0 m × 3.6 m = 18 m^2) in a randomized complete block design with a plant spacing of 60 cm between the rows and 15 cm within the row.

Experimental Sites and Environmental Conditions

Thirteen test locations where experiments conducted are Parbhani (19°08′N, 76°50′E), Rahuri (19°47′N, 74°32′E), Akola (20°42′N, 77°02′E) and Phaltan (19°47′N, 74°32′E) in Maharashtra, Coimbatore (11°00′N, 77°00′E) in Tamil Nadu, Sameerwadi (16°21′N, 75°17′E), Almel (16°49′N, 75°43′E) in Karnataka, Hyderabad (17°27′N, 78°28′E), Perumallapalle (16°42′N, 77°58′E) Rudrur (18°40′N,

Table 1 Pedigree details of sweet sorghum experimental hybrids and open pollinated varieties tested at thirteen locations under tropical dryland conditions, rainy (*Kharif*) season, 2007

Name	Pedigree details	Cultivar type
SPSSV 15	AKSSV 16 × RSSV 10-10-8-1-1	Experimental variety
SPSSV 20	ICSV 93046	Experimental variety
SPSSH 19	ICSA 324 × SSV 74	Experimental hybrid
PAC52093[a]	PAC 52093	Experimental hybrid
SPSSV 27	NSS 223 × NARI-111	Experimental variety
SPSSV 28	AKSSV 16 × RSSV 10-6-9-5-6	Experimental variety
SPSSV 4	PVR 453	Experimental variety
SPSSV 29	NSSV 260	Experimental variety
SPSSH 24	ICSA 38 × NTJ 2	Experimental hybrid
SPSSH 25	ICSA 675 × SPV 422	Experimental hybrid
SPSSH 26	NSS-1023A × NARI-SS-34	Experimental hybrid
SPSSH 27[a]	JKSH 02	Experimental hybrid
SPSSV 30[a]	SPSSV30	Experimental variety
SSV84	Variety check	Variety check
CSV19SS	Variety check	Variety check
CSH22 SS	Hybrid check	Hybrid check

[a] Pedigree details not available (private sector contributed entries)

78°06′E), and Anakapalle (18°N, 83.0°E) in Andhra Pradesh, Pantnagar (28°30′N, 78°81′E) in Uttarakhand, and Ludhiana (30°55′N, 75°52′E) in Punjab.

Crop Husbandry

The soil texture where crops were planted varied between sandy loam and clay loam across locations with profile depth of ~1.0 m. The crop was grown under dryland natural rainfall condition during rainy season (June to October) at all locations. The seeds were sown by hand dibbling with uniform depth of 5 cm during second week of June 2007 in 3 replications. Atrazine (@1 kg a i ha^{-1}) was applied one-day after sowing (pre-emergence) to control the initial weed flora. At 20-days after emergence (DAE), the seedlings were thinned to one plant and an optimum plant population of about 11 plants m^{-2} was maintained. Hand-weeding and intercultivations were done twice between 15 and 35 DAE. Recommended dose of fertilizer was applied (@80:40:40 kg N:P_2O_5:K_2O ha^{-1} in the form of urea, single super phosphate, muriate of potash, respectively) with half N and complete P and K as basal, and balance N was side-dressed at 35 DAE. Furadan 3G (@20 kg ha^{-1}) was applied in furrows at planting to control the shoot fly (*Atherigona soccata* R). Need based minimal plant protection measures were followed to control the major insect pests of sorghum.

Data Collection

Day to Flowering, Millable Stalk Yield, and Biomass

Data on days to flowering and physiological maturity, and plant height was measured as per standard procedures. At physiological maturity, ten competitive plants from central four rows of each plot were sampled in all three replication for measuring fresh millable stalk yield and biomass. After cutting the plants at ground level, fresh biomass of ten whole plants (leaves, stalks, and panicles) was weighed immediately and fresh biomass was calculated. The leaves along with sheath were stripped and panicle with last internode (peduncle) was separated and the fresh weight of stripped stalk was estimated. The stalk juice was extracted with a power operated three-roller sugarcane machine miller without imbibition water and weighed immediately. The extracted juice was filtered with standard Whatman filter paper immediately to remove large solids. The 100 mL of the fresh juice was transferred to standard glass test tubes and the tubes were stoppered for estimation of juice °Brix and total sugar soluble sugar analysis subsequently.

Juice °Brix, Total Soluble Sugars, Sugar and Bioethanol Yields

Juice °Brix was determined with digital pocket handheld refractometer (Digital pocket refractometer PAL-1, Atago, Tokyo, Japan). Total soluble sugars (TSS) were estimated by phenol sulfuric acid method using glucose as standard (Dubois et al. 1956). Total sugar yield which is a product of TSS percent in the juice, juice extraction ratio and total juice weight which is also a function of total fresh stalk weight and plants ha^{-1} was estimated at physiological maturity (Tsuchihashi and Goto 2004; Murray et al. 2008). Bioethanol yields were computed as per the procedure of Smith and Buxton (1993). Grain yield was estimated after field drying the panicles and the yields were adjusted to 14.5 % moisture content. The data were analyzed according to the Fisher's method of analysis variance (ANOVA) techniques (Gomez and Gomez 1984). Least significant difference (LSD) values were calculated at 5 % probability level, wherever 'F' test was significant. The data analysis was performed using WINDOSTAT statistical software (Windostat 2011). Pooled mean data for each trait were presented in the tables and figures for discussion and interpretation in the remainder of the text.

Results and Discussion

Environmental Conditions

Total rainfall, weekly mean minimum and maximum temperatures recorded during the crop growing period (standard meteorological week 24–44) was in the range of 520–1,418 mm, 14–24 and 29–36 °C, respectively across the locations during *Kharif* 2007 crop season. The total rainfall received at all the locations was adequate at most of the locations. There was a declining trend in mean temperatures especially in October coinciding grain-fill period of the crop.

Phenology and Plant Height

Mean days to flowering and physiological maturity differed significantly ($P \leq 0.05$) and varied from 77 to 91 and 113 to 119 days, respectively. PAC52093 (77 days) and SPSSV30 (78 days) were found to be earliest ones among the test entries (Table 2). Further, the variation in mean days to flowering at different centres revealed that in general, cultivars planted at lower latitudes in southern India such as Coimbatore, Sameerwadi, Akola, Perumallapalli, Hyderabad, and Phaltan flowered early (74–80 days) compared to delayed flowering (92–100 days) at higher latitudes planting such as at Pantnagar, and Ludhiana (data not shown). Days to maturity was also followed the similar trend to that of flowering at all locations. This situation indicates that sweet sorghum cultivars being relatively photoperiod sensitive tend to delay flowering when planted under long day conditions of subtropical northern India. This delay in flowering leads to producing greater crop height and more biomass, but grain yielding potential may reduce because of more vegetative growth. Mean days to flowering between varieties and hybrids varied marginally (83 days in OPVs vs. 81 days in hybrids). Genetic differences in phenology among sweet sorghum germplasm were also reported (Chaudhari et al. 1993; Seetharama et al. 1987). In multilocation trials, considerable variation in crop phenology was also observed among sweet sorghum germplasm (Anonymous 2006b).

Among the cultivars, plant height differed significantly ($P \leq 0.05$) and ranged from 283 cm (SPSSH 25) to 358 cm (SPSSH 19) with an average of 330 cm (Table 2). Mean plant height did not differ between hybrid (331 cm) and OPVs (331 cm) group. In experimental OPVs, SPSSV 28, and SPSSV 4 grew taller than check SSV 84, while in hybrids, SPSSH 19 and SPSSH 26 were superior to check CSH22 SS (Table 2). Variation in plant height among sweet sorghum was also reported (Channappagoudar et al. 2007).

Fresh Biomass and Millable Stalk Yield

Significant ($P \leq 0.05$) differences were observed for fresh biomass and stalk yields (Table 2). Fresh biomass varied from 39.0 to 67.0 t ha^{-1} with a mean of 58.0 t ha^{-1} across the locations. In hybrids, SPSSH 27 was on par with check CSH22 SS. In OPVs too, SPSSV 20 was on par with check CSV19 SS. Hybrids as a group produced 11.0 % more fresh biomass than OPVs (hybrids 60.0 vs. OPVs 54.0 t ha^{-1}).

Table 2 Variability for days to flowering, plant height, fresh stalk yield and biomass in sixteen sweet sorghum genotypes grown under tropical dryland conditions, rainy (*Kharif*) season, 2007

Genotype	Days to 50 % flowering (days)[a]	Plant height at maturity (cm)[b]	Millable stalk yield at physiological maturity (t ha^{-1})[c]	Fresh biomass at physiological maturity (t ha^{-1})[d]
Open pollinated varieties				
SPSSV 15	82	326	40.7	55.4
SPSSV 20	87	335	42.8	63.2
SPSSV 27	79	329	41.6	57.6
SPSSV 28	82	344	41.1	60.0
SPSSV 4	91	338	41.8	60.7
SPSSV 29	79	324	32.5	45.3
SPSSV 30	78	319	29.4	39.2
Mean	83	331	39	54
Hybrids				
PAC52093	77	311	41.8	59.2
SPSSH 19	80	358	44.1	58.6
SPSSH 24	83	340	43.9	60.8
SPSSH 25	84	283	39.8	58.2
SPSSH 26	79	353	42.1	57.7
SPSSH 27	82	341	40.9	67.5
Mean	81	331	42	60
Variety check				
SSV84	88	293	37.0	56.8
CSV19SS	81	333	37.7	61.7
Hybrid check				
CSH22 SS	85	345	46.5	65.6
Grand mean	82	330	40.2	58.0
LSD ($P = 0.05$)	5.0	17.0	5.5	23.5
CV (%)	6.51	5.61	17.6	22.3

[a] Mean of 11 locations

[b] Mean of 11 locations

[c] Mean of 13 locations

[d] Mean of 6 locations

The greater biomass production by test hybrids over test OPVs indicated the expression of heterosis for biomass production. Planting hybrids will not only produce high biomass, but also create uniformity in terms of harvesting operations. Present results are in conformity with those of Smith et al. (1987) and Smith and Buxton (1993) who reported the fresh biomass of sweet sorghum in the range of 65.0–90.0 t ha^{-1} from temperate climatic conditions.

Fresh millable stalk yield ranged from 29.4 to 46.5 t ha^{-1} with an average value of 40.2 t ha^{-1} (Table 2). In hybrids, none was superior to check for millable stalk yields. Among the experimental OPVs, SPSSV 20, SPSSV 27, SPSSV 28, and SPSSV 4 produced higher (11.0–13.5 % more) millable stalk yield than check CSV19 SS (Table 2). Interestingly, experimental hybrids as a group had shown 8.0 % superiority in millable stalk yield over their OPV counterparts.

The higher stalk yields of hybrids over OPVs might be due to the expression of positive heterosis for leaf area and crop growth rate. Variation among sweet sorghum cultivars for fresh millable stalk yield (range 22.0–46.5 t ha^{-1}) was reported by Singh and Singh (1986), Seetharama et al. (1987), Balaravi et al. (1997b), Channappagoudar et al. (2007), Woods (2001) in the tropical climatic conditions. While, Almodares et al. (2008) have reported significant differences in fresh millable stalk yield (range 53–72 t ha^{-1}) at physiological maturity in a set of cultivars and lines in Iran. On the other hand, the fresh stalk yields reported from the temperate climatic conditions were much higher (range 50–90 t ha^{-1}) than those documented in tropical (Smith et al. 1987; Smith and Buxton 1993; Murray et al. 2008). High stalk yield realization in the temperate climatic conditions may be due to longer photoperiod (15–16 h) that results in greater solar radiation interception and dry matter production apart from high soil moisture and fertility than tropical climates.

Grain Yield

Grain yield differed significantly ($P \leq 0.05$) among the cultivars and was ranged from 1.14 to 2.25 t ha^{-1} with a mean of 1.66 t ha^{-1} (Table 3). In hybrid group, entries SPSSH 25, SPSSH 24, SPSSH 27 and PAC52093 produced 18–37 % higher grain yields than check CSH22 SS. Similarly, entries SPSSV 29, and SPSSV 15 yielded 23 and 11 % higher than check SSV84 (Table 3). Comparison between hybrids and OPVs indicated that hybrids produced 38 % more grain yield than their OPVs counterparts suggesting that planting hybrids will give both high food (grain) and biofuel feedstock (fresh stems) than varieties (Table 2). Earlier studies have also reported the variation in grain yielding ability among the sweet sorghum test cultivars (AICSIP 2006). The grain yield range obtained in the current study is in close agreement with those of Channappagoudar et al. (2007), Singh and Singh (1986), Parvatikar and Manjunath (1991), Agnal et al. (1997) who reported the grain yield range of 1.36–2.88 t ha^{-1} in semi-arid tropical Indian conditions. The grain yielding ability of sweet sorghum is much lower than that of grain sorghum cultivars grown in the similar agroecology (sweet sorghum 1.5–2.0 t ha^{-1} vs. grain sorghum 3.5–4.0 t ha^{-1}) (Anonymous 2006b). This low grain yields of sweet sorghum are due to excessive height and vegetative biomass production leading to low harvest index (HI) than grain sorghum which are usually semi-tall with high HI. Thus, improving the HI of sweet sorghum without decreasing biomass will be the goal of crop improvement aimed at producing sweet sorghum for both food and biofuel in developing countries such as India (Rao et al. 2008). On the other hand, grain yield of sweet sorghum reported in China was as high as

Table 3 Genetic variation for grain yields, juice brix, total soluble sugars, and total sugar yields in sixteen sweet sorghum genotypes grown under tropical dryland conditions, rainy (*Kharif*) season, 2007

Genotype	Grain yield(t ha^{-1})[a]	Juice °Brix (%)[b]	Total soluble sugars (%)[c]	Total sugar yield (t ha^{-1})[d]
Open pollinated varieties				
SPSSV 15	1.65	16.7	13.4	1.96
SPSSV 20	1.50	16.1	13.1	2.14
SPSSV 27	1.52	16.7	13.4	2.00
SPSSV 28	1.14	16.8	13.0	1.73
SPSSV 4	1.15	15.8	12.6	1.77
SPSSV 29	1.85	17.3	14.4	1.66
SPSSV 30	1.24	19.6	16.4	1.83
Mean	1.44	17	13.8	1.9
Hybrids				
PAC 52093	2.02	16.7	13.7	2.37
SPSSH 19	1.59	16.8	13.3	2.00
SPSSH 24	1.93	15.9	13.8	2.24
SPSSH 25	2.25	16.8	14.0	2.12
SPSSH 26	2.12	17.3	14.6	2.07
SPSSH 27	1.99	16.5	14.0	2.53
Mean	1.98	17	13.9	2.2
Variety check				
SSV84	1.49	17.0	13.9	1.76
CSV19SS	1.40	16.8	13.7	1.71
Hybrid check				
CSH22 SS	1.64	16.3	12.9	1.99
Grand mean	1.66	16.8	13.8	1.99
LSD ($P = 0.05$)	0.57	1.0	1.3	0.45
CV (%)	32.7	6.81	9.15	22.23

[a] Mean of 8 locations

[b] Mean of 12 locations

[c] Mean of 10 locations

[d] Mean of 9 locations

7.5 t ha^{-1} (Zhu 1997), but such high grain yields are yet to be realized in tropical countries such as India.

Juice °Brix and Total Soluble Sugars

Juice °Brix recorded at physiological maturity varied (15.9 and 19.6 %) significantly ($P \leq 0.05$) among the cultivars with a mean of 16.8 %. Among the test OPVs, cv. SPSSV 30 (19.6 %) alone recorded significantly superior juice °Brix compared to the best check SSV84. The hybrids are not superior to OPVs in stalk juice °Brix (Table 3) as there was no difference observed between the two groups. Previous studies too showed the large genetic in variation in juice °Brix among the sweet sorghum cultivars (Blum et al. 1975; Almodares et al. 1994a; Channappagoudar et al. 2007; AICSIP 2006). Interestingly, juice °Brix content has shown very strong positive correlations with TSS ($R^2 = 0.7956$, $P \leq 0.01$) suggesting that juice °Brix could be used as surrogate trait for estimation of TSS in screening large number of breeding materials and segregating populations. Seetharama et al. (1987), Tsuchihashi and Goto (2004) have too reported the high positive correlation between juice °Brix and TSS in the juice.

Significant ($P \leq 0.05$) differences were observed for total soluble sugars (range 12.6–16.4 %) with an average of 13.8 %. Open pollinated variety SPSSV 30 alone has shown significant superiority (18.0 % more) over best check SSV84 among all test cultivars. The hybrids are not superior to OPVs in TSS as there was no difference observed between the two groups (Table 3). Varietal difference in TSS among sweet sorghum cultivars were reported by Subramanian et al. (1987), Almodares et al. (1994b), Channappagoudar et al. (2007).

The main marketable product is the sugar content in the stalk. Therefore, the selection of cultivars with high sugar content is desirable. The present results indicated that there is not much improvement in either in juice °Brix or total soluble sugar content in the newly developed hybrids and OPVs as most genotypes maintaining same level of sugar content as that of check SSV 84 (pollinator parent of CSH 22SS, first sweet sorghum hybrid) one of the first sweet sorghum varieties released in 1992. Much of the sweet sorghum improvement in the past was due to improvement in stalk yield with minimal increase in stalk sugar content. Thus, the breeding objective should be developing genotypes with both improved sugar content as well as stalk yield with high per day productivity besides greater grain yields (Sanjana Reddy et al. 2011; Srinivasa Rao et al. 2009).

Total Sugar Yields

Total sugar yields differed significantly ($P \leq 0.05$) and were ranged from 1.66 to 2.53 t ha^{-1} with a mean of 1.99 t ha^{-1}. Among the test hybrids, SPSSH 27 (27.0 % more), PAC52093 11 (19.0 %), and SPSSH 24 (13.0 %) were superior to check CSH22 SS (Table 3). In test OPVs too, SPSSV 20 (22.0 %), SPSSV 15(11.4 %) and SPSSV 27 (13.6 %) produced greater sugar yields than best check SSV84. Hybrids as group have recorded 10.0 % more sugar yields than OPVs (Table 3). These results are in conformity with those reports of Woods (2001), Reddy et al. (2005), Tsuchihashi and Goto (2004), Anonymous (2006b) in tropical climates. However, the total sugar yields reported from temperate climatic conditions were in the higher range of 4.0–10.7 t ha^{-1} (Ferraris 1981; Smith et al. 1987; Smith and Buxton 1993; Tew et al. 2008).

Bioethanol Yields

Bioethanol yields differed significantly ($P \leq 0.05$) and were ranged from 925 to 1,440 L ha^{-1} with mean of 1,123 L ha^{-1} (Fig. 1). In test hybrids, SPSSH 27 (27.0 % more), PAC 52093 (17.0 %) and SPSSH 24 (10.0 %) produced high bioethanol yields than check CSH22 SS. Among the test OPVs, SPSSV 15 (15.0 %), SPSSV 20 (23.0 %) and SPSSV 27 (14.0 %) were superior for bioethanol yields than the best check SSV 84 (Fig. 1). Significant cultivar difference in bioethanol yields was observed in the multi-environment and multi-year sweet sorghum trials organized previously (AICSIP 2006). Furthermore, the test hybrids as a group recorded 18.0 % higher bioethanol yields than OPVs indicating the superiority of hybrids for over OPVs. Bioethanol yield reported from temperate climatic conditions (Monk et al. 1984; Kresovich and Henderlong 1984; Smith et al. 1987; Woods

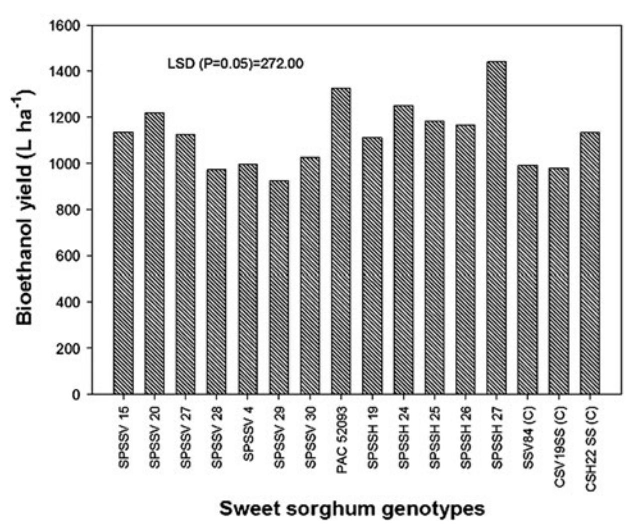

Fig. 1 Gentic differences in bioethanol yields among sixteen sweet sorghum experimental hybrids and open pollinated varieties grown under Indian tropical dryland conditions during rainy (*Kharif*) season, 2007 (average data of eight locations)

2001; Tew et al. 2008) were much higher (range 2,129–5,696 L ha^{-1}) than the yields obtained from the present experiment (range 925–1,440 L ha^{-1}). This could be due to variation in climatic factors such photoperiod, temperature and solar radiation which may vary according to the latitude, besides variation in soil moisture availability and soil fertility. Long photoperiods (15–16 h), deep soils, coupled with high soil organic matter content in temperate climatic conditions might have resulted in high biomass production and sugar yields. The yield of crops at any given location (latitude) is due to the effects of photoperiod and temperature and their interaction (Craufurd and Wheeler 2009).

It was concluded that the OPVs identified from this study could form the potential donors for further improvement of sweet sorghum for biofuel production. The superior hybrids (SPSSH27 and PAC52093) from this study may be tried on-farm in farmer fields, besides direct introduction for pilot cultivation in the command areas of biofuel industries. The results emphasized the importance of sweet sorghum hybrids over OPVs for stalk and bioethanol yields especially in the future climate change scenario.

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