Sugar Tech (July-Sept 2013) 15(3):311–315
DOI 10.1007/s12355-013-0220-2

RESEARCH ARTICLE

Effect of Different Crushing Treatments on Sweet Sorghum Juice Extraction and Sugar Quality Traits in Different Seasons

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Received: 31 January 2013 / Accepted: 22 May 2013 / Published online: 23 June 2013

Abstract Sweet sorghum (*Sorghum bicolor* (L.) Moench) is an important biofuel crop that produces both food (grain) and biofuel (from stalk juice). The objective of this investigation was to assess the effect of different crushing treatments on juice extraction and sugar quality traits of sweet sorghum cultivars grown in different seasons. Three sweet sorghum cultivars along with three stalk crushing treatments namely (i) stalk only crushed (leaf, sheath and panicle removed), (ii) stalk plus sheath crushed (leaf and panicle removed), and (iii) whole plant crushed (but only panicle removed) were assessed in split–split-plot design during 2009 rainy (*Kharif*) and 2009 post-rainy (*Rabi*) seasons. The percent juice extraction and juice sugar quality traits were significant ($P \leq 0.05$) in different crop seasons, but were non-significant among cultivars and crushing treatments. Sweet sorghum cultivars grown during rainy season had significantly higher total soluble sugars (TSS), sucrose and purity per cent than in post-rainy season. Experimental variety SPSSV 30 showed significant superiority by 25 % in TSS and sucrose content than check namely CSH 22SS. Effect of crushing treatments on juice extraction and sugar quality traits were non-significant except juice brix. It is recommended that the complete sweet sorghum stalks after removing the panicle can be crushed without the need for removing leaf and sheath both in large research trial samples, and bulk harvested stalks at biofuel processing facility. This will reduce processing time at the sugar mill and helps avoiding rapid deterioration of stalk sugars in the ambient field condition, as removal of leaf and sheath in sweet sorghum is highly cumbersome unlike sugarcane, where it is relatively easy.

Keywords Sweet sorghum · Stalk crushing treatments · Juice quality · Sugar mill · Total soluble sugars

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Introduction

Sweet sorghum (*Sorghum bicolor* (L.) Moench) is the bioenergy crop which accumulates large amounts of fermentable sugars in its stalks, similar to sugarcane, and is grown for syrup in USA on small scale and bioethanol production in India and elsewhere (Srinivasa Rao et al. 2009; Han et al. 2012; Whitfield et al. 2012). Production and use of renewable sources of energy is accorded the high priority to ensure India's energy security (MNRE 2009). In India, sugarcane molasses which is the by-product of sugar processing is the primary feedstock for ethanol production, while its reduced availability, variable and high cost (Shinoj et al. 2011) necessitated the search for alternative feedstock's such as sweet sorghum (Prasad et al. 2007).

Sweet sorghum is cultivated in a wide range of environments in Africa, China, USA, India, Mexico, etc., and is well adapted in countries located 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). Ethanol from sweet sorghum can be produced utilizing the same infrastructure and equipment as that utilized in converting sugarcane into alcohol (Schaffert 1992). Therefore, researchers, policy makers and producers both in tropical and temperate countries around the world are promoting sweet sorghum as alternative bioenergy feedstock for ethanol production (Hunsigi et al. 2010; Rao et al. 2008; Erickson et al. 2011; Ratnavathi et al. 2011). Coble et al. (1984) reported that leaf removal from stalk prior to fermentation yielded slightly more ethanol than solids removal before fermentation.

In general, sweet sorghum juice volume and ethanol yields are a function of % juice extraction, efficiency of crushing and crushing treatments used. Prior to the sweet sorghum stalks milling both at sugar mill and research station, the juice is analyzed for sugar quality parameters (Rao et al. 2008). In this process, the stalks are first harvested and transported from field to processing facility/laboratory for immediate sugar quality analysis. It is the general practice especially in tropical climates such as India that the sweet sorghum panicles (panicle is the grain bearing part of plant comprises the branched cluster of flowers in which branches are racemes, and is attached to the last internode of the plant namely peduncle) and leaves are separated immediately after field harvest. The separation of panicle is relatively easy, but removal of leaf and its sheath is cumbersome and time consuming, since leaf sheath clasp stem tightly (Lingle 2010). Past experiences indicated that it will take much longer time to remove the leaf and sheath of sweet sorghum compared to sugarcane (Dayakar Rao et al. 2004; Rao et al. 2008). Information on whether sweet sorghum stalks when milled along with leaf plus sheath decreases the juice extraction per cent and sugar quality traits is not available. The objective of this investigation was to assess the effect of different crushing treatments on juice extraction and sugar quality traits in sweet sorghum cultivars grown in rainy and post-rainy seasons.

Materials and Methods

Plant Material and Experimental Design

The experimental design was split–split-plot with three replications, and two growing seasons *Kharif* 2009 (rainy), and *Rabi* 2009 (post-rainy) were assigned to main-plots, the three cultivars (SSV 74, SPSSV 30 and CSH 22SS) to sub-plots, while three crushing treatments [(i) stalk crushed (leaf, sheath and panicle removed), (ii) stalk plus sheath crushed (leaf and panicle removed) and, (iii) whole plant crushed (panicle only removed)] to sub–sub-plots. The plots were arranged in a randomized complete block design. Each genotype was planted in 6 rows of 5 m length (plot size: 5.0×3.6 m = 18 m^2) with a plant spacing of 60 cm between the rows and 15 cm within the row. The pedigree details of experimental materials are listed in Table 1.

Experimental Site and Environmental Conditions

Sweet sorghum was planted during rainy and post-rainy seasons of 2009 at an experimental farm located at Directorate of Sorghum Research (Formerly National Research Centre for Sorghum), Hyderabad, India (17°19′N; 78°28′E, Altitude: 524.6 amsl). The soil at the experimental site was a clay loam (profile depth ~1.0 m).

Crop Husbandry

The seeds were hand-planted at 5 cm soil depth during second week of June 2009 and first week of October 2009 in 3 replications. A seeding rate of 10 kg^{-1} was adopted. Atrazine (@ 1 kg ha^{-1}) was applied one-day after sowing (pre-emergence) to contain the initial weed flora. The crop was grown under dryland with naturally occuring rainfall condition in rainy season (June to September), while three supplemental irrigations were given to the post-rainy (October to January) season crop. At 20-days after emergence (DAE), the seedlings were thinned to single 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 the remaining N was side-dressed at 35 DAE i.e., at panicle initiation stage. Furadan 3G (@ 20 kg ha^{-1}) was applied in furrows at planting to control the shoot fly (*Atherigona soccata* R). Need based minimal plant

Table 1 Pedigree details of sweet sorghum cultivars tested in 2009 rainy, and post-rainy seasons

Name	Pedigree details	Remarks
SPSSV 30	Selection from Urja—a temperate source for high stalk sugar content	Promising sweet sorghum source for high stalk sugars and sucrose retention beyond physiological maturity in rainy and post-rainy seasons. Produce high yields in post-rainy season
SSV 74	Selection from IS 23558 (PAB74)—Zera-zera landrace, Ethiopia	Promising sweet sorghum variety with high stalk yield, and adapted to rainy and post-rainy seasons
CSH 22SS	ICSA 38 × SSV 84	First commercial sweet sorghum hybrid developed at Directorate of Sorghum Research, Hyderabad, India. Released for commercial cultivation in 2005. The hybrid is high yielding (46.5 Mg ha^{-1})

protection measures were followed to control the major insect pests of sorghum.

Data Collection

Juice Extraction

At physiological maturity of the crop, ten competitive plants from central four rows of each plot were sampled for juice extraction and subsequent sugar analysis. Juice extraction was done from all three crushing treatments as per the experimental design described above. In all treatments, the stalk juice was extracted with a power operated three-roller sugarcane machine miller without imbibition water and was weighed immediately. The extracted juice was filtered immediately with standard Whatman filter paper to remove large solids. One hundred mililiters of fresh sweet sorghum juice was transferred to standard glass test tubes and was analyzed for juice °Brix, reducing sugars, sucrose content and total soluble sugars.

Juice °Brix, Reducing Sugars, Sucrose, Total Soluble Sugars, and Purity %

Juice °Brix of the extracted juice was determined using a digital hand-held refractometer (Digital hand-held pocket refractometer PAL-1, Atago, Tokyo, Japan). TSS 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 (RS) content was calculated in terms of glucose equivalents by comparing the absorbance with a standard curve of glucose. Sucrose content (Pol per cent) was directly measured using NIR Saccharimeter 880D (Optical Activity Limited, Cambridgeshire, UK) without using lead acetate clarification. Purity is the percentage of sucrose present in the total solids content in the juice, and it was computed with the formula i.e., purity percentage = (Sucrose %/Juice °Brix) × 100.

The data were analyzed according to the Fisher's method of analysis of variance (ANOVA) (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).

Results and Discussion

Environmental Conditions

Total rainfall received during rainy and post-rainy seasons, standard meteorological week 24 (second week of June) to 52 (last week of December), was 626 mm. Weekly mean minimum and maximum temperatures recorded during the crop growing periods in both rainy and post-rainy were ranged from 12.9 to 25.0 °C, and 28.5 to 37.1 °C, respectively. There was a declining trend in mean minimum temperatures especially from mid-October onwards coinciding post-rainy crop growing period.

Juice Extraction

Average juice extraction (%) was significant ($P \leq 0.05$) in rainy and post-rainy seasons, but non-significant among cultivars and crushing treatments (Table 2). Maximum percentage of extraction was recorded in stalks plus sheath crushing method (44.38 %), followed by whole plant (40.83 %) and stalk alone (40.42 %). Cv SPSSV 30 (42.1 %) produced marginally higher juice extraction.

Juice °Brix, Reducing Sugars (RS), Sucrose, Total Soluble Sugars (TSS), and Purity %

Effect of different seasons on juice quality traits were significant (Table 2). Cultivars grown during Rainy season accumulated 11.4, 15.0, and 24.0 % more TSS, sucrose %, and purity %, respectively than in post-rainy season. Significant differences between the seasons for sugar quality traits indicated that there are negative genotypes by season interaction for quality traits. This interaction is mainly due to the photoperiod sensitive nature of the sweet sorghum cultivars (Rao et al. 2008). The cultivars when grown during post-rainy season showed reduction in stalk yield by 25–30 %, and sugar quality traits (Rao et al. 2013). The yield of any crop at any given location is due to the effects of photoperiod, and temperature and their interaction (Craufurd and Wheeler 2009). Significant difference between the seasons (rainy and post-rainy) for juice quality traits in sweet sorghum cultivars was also reported (Sanjana Reddy et al. 2011; Srinivasa Rao et al. 2009).

Cultivar effect on juice quality traits was significant ($P \leq 0.05$) except for juice extraction and purity percent. The reducing sugars recorded among the cultivars were relatively low especially in genotype SPSSV 30, and the same cultivar showed significant superiority by 25 % in TSS and sucrose content than check cultivar CSH 22SS. The lower RS content in the juice is desirable, where in low RS is indicative of less contamination or deterioration of juice sugars, and hence increases the efficiency of fermenting sugars to ethanol. Accumulation of low reducing sugars, and high sucrose content in these cultivars indicative that there has been considerable genetic improvement and selection occurred in sweet sorghum for desirable juice sugar composition in the tropical sweet sorghums (Srinivasa Rao et al. 2009).

Effect of crushing treatments on juice quality traits were non-significant except for juice brix (Table 2). The juice

Table 2 Effect of sweet sorghum stalk crushing treatments on juice extraction, and sugar quality traits during 2009 rainy and post-rainy seasons

Treatments	Juice extraction (%)	Juice °Brix (%)	Total soluble sugars (%)	Reducing sugars (%)	Sucrose %	Purity %
Season (S)						
Rainy 2009	39.50	17.60	15.70	0.68	14.20	80.59
Post-rainy 2009	44.20	19.10	14.10	1.25	12.30	64.98
LSD ($P = 0.05$)	3.30	0.72	1.09	0.19	1.10	4.96
Cultivar (C)						
SSV 74	41.72	17.78	15.36	1.16	13.49	75.64
SPSSV 30	42.06	20.73	15.81	0.45	14.59	72.02
CSH 22SS	41.85	16.48	13.50	1.29	11.68	70.70
LSD ($P = 0.05$)	NS	0.89	1.33	0.23	1.35	NS
Crushing method (T)						
T1: stalk only crushed (leaf, sheath and panicle removed)	40.42	19.03	15.75	0.89	14.17	75.24
T2: stalk plus sheath crushed (leaf and panicle removed)	44.38	17.82	14.48	0.92	12.88	73.05
T3: whole plant crushed (but panicle removed)	40.83	18.15	14.44	1.09	12.71	70.06
LSD ($P = 0.05$)	NS	0.03	NS	NS	NS	NS
LSD (0.05) S × C × T	Sign	Sign	NS	Sign	NS	Sign

Sign significant at 0.05 probability level, *NS* non-significant

brix was high when only the stalk was crushed (19.03 %) followed by stalk plus sheath was crushed (17.82 %). Although variation in effects of sweet sorghum processing and harvesting methods on yield and quality were documented earlier (Coble et al. 1984; Webster et al. 2004; Lingle et al. 2012), the current findings on effect of crushing treatments on sugar quality traits in tropically adapted sweet sorghum cultivars are first in the literature. Non-significant differences among the stalk crushing treatments on juice sugar quality traits clearly indicated that crushing complete stalk after removing the panicle is as similar to crushing stripped stalk (leaf and sheath removed) treatment. The sugars in the sweet sorghum stalks begin deterioration once the stalk is harvested in the field (Lingle 2010). There is a need to process the large number samples (germplasm, and segregating breeding populations) immediately (≤2–3 h) after field harvest in research station trials to estimate the cultivar difference in extraction % and sugar quality. Similarly, at sugar mill also, bulk quantities of sweet sorghum stalks are to be processed within 12–24 h after harvest. Any delay in stalk crushing at the mill leads to rapid sugar losses, increase the inversion of sucrose to reducing sugars, and lower extraction percent. In both the above situations, crushing of sweet sorghum stalks without removing leaf and sheath reduces the processing time and helps avoiding rapid deterioration of stalk sugars in the ambient field condition, as removal of leaf and sheath is highly cumbersome and time consuming process in sweet sorghum unlike sugarcane, where the removal of leaf along with sheath (de-trashing) is relatively very easy. It was concluded that the complete sweet sorghum stalks after removing the panicle can be crushed without the need for removing the leaf and sheath.

Acknowledgments The authors are highly grateful to the financial assistance received from NAIP- ICAR, for the funded project entitled "Value chain model for bio-ethanol production from sweet sorghum in rainfed areas through collective action and partnership" for the conduct of this experiment.

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