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SHORT COMMUNICATION

Influence of Nitrogen Levels and Planting Geometry on Sweet Sorghum (*Sorghum bicolor*) Juice Sugar Quality Traits Under Semi-arid Tropical Environment

Sushil Kumar[1] · S. S. Rao[2] · M. Yakadri[3]

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Abstract Sweet sorghum (*Sorghum bicolor* (L.) Moench) is a potential bioenergy crop that produces both food (from grain) and biofuel (from stalk juice). The present investigation undertaken to assess the effect of different plant density and nitrogen levels on juice extraction and sugar quality traits of sweet sorghum grown in postrainy season of 2008–2009. Three planting geometries as main treatments (30 × 15, 45 × 15 and 60 × 15 cm) and four levels of nitrogen (0, 30, 60 and 90 kg ha^{-1}) application levels as sub-plot treatments were assessed in split-plot design. It is found that the combination of relatively lower nitrogen application level (60 kg ha^{-1}) with maximum population density (spacing 45 × 15 cm) are needed for higher sugar and ethanol yields in the farmer fields.

Keywords Sweet sorghum · Nitrogen level · Planting geometry · Bio-ethanol · Juice brix · Total soluble sugars

Sweet sorghum (*Sorghum bicolor* (L.) Moench) has the potential to yield food, feed, fibre and biofuel and accumulates fermentable sugars (10–20 %) in its stalks as similar to sugarcane [1, 2]. In view of increasing demands for alternate energy in India around the world, production and utilization of biofuels from renewable biomass sources are important to overcome the depletion of fossil fuels, as it reduces the dependence on imported oil, and mitigate climate change by green house gases (GHG) emissions [3]. The Government of India's policy mandated blending of ethanol (5–10 %) with gasoline has necessitated the searching alternative feedstocks other than sugarcane molasses [4]. Requirement of ethanol in the country is estimated to be around 0.64 billion liters annum^{-1} at the 5 % level of doping in petrol. Currently, molasses is the sole feedstock to produce alcohol. The price of molasses is highly variable (Rs 3000 and 6000 ton^{-1}) with its inadequate supply and cost of ethanol production from molasses also varies accordingly [5]. Researchers and policy makers are exploring alternative feedstock for ethanol production.

Sweet sorghum has been projected as the major source for biofuel production in India [6, 7], and around the world [8, 9].

The crop has an advantage of producing both food (from grains) and bioethanol (from stem sap) in rainfed condition, and thus does not compromise food security [7].

Nitrogen is one of the major nutrients which influence leaf area, biomass and yield of sorghum [10]. Maintaining optimum crop geometry in terms of inter and intra row spacing is pre-requisite for better utilization of water, nutrients and solar energy for realizing higher stalk yield and juice sugar quality traits in sweet sorghum [11, 12]. Sweet sorghum cultivars grown during rainy (*kharif*) season produce large leaf area, biomass and stalk yield due to longer day length and optimal temperatures well distributed rainfall. The adaptation of sweet sorghum to postrainy (*rabi*) season is not adequately understood in terms of its response to nitrogen fertility and planting geometry

✉ Sushil Kumar
sushilangrau@gmail.com

✉ S. S. Rao
ssrao@millets.res.in

1 ICAR-Central Arid Zone Research Institute, Regional Research Station, Bhuj, Gujarat 370 105, India

2 ICAR-Indian Institute of Millets Research, Rajendranagar, Hyderabad, Telangana 500 030, India

3 Department of Agronomy, ANGRAU, Rajendranagar, Hyderabad, Telangana 500 030, India

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on juice quality traits. The information on influence of nitrogen levels and plant spacing on juice sugar quality traits of sweet sorghum grown in postrainy (*rabi*) season is inadequately comprehensive. The present study was undertaken to assess the effect of nitrogen levels and planting geometry on sweet sorghum juice sugar quality traits and bioethanol yield. There is a need to identify the sweet sorghum genotypes that can be grown across rainy (*kharif*) and postrainy (*rabi*) seasons so as to make available the sweet sorghum feedstock to the biorefinery. A number of sweet sorghum genotypes were identified for general cultivation at all India level primarily for rainy season conditions. However, information on agronomic and physiological basis of adaptation of sweet sorghum under variable planting density and nitrogen levels in postrainy season is lacking. The quality of the sweet sorghum juice varies with genotypes, growth stage and environment in which it is grown. The juice sugar quality traits are also influenced by plant population and nitrogen levels across the seasons and latitudes [13–15]. Keeping the above points in view, the present investigation was carried out with two major objectives: (1) to assess the influence of plant population and nitrogen levels on juice sugar quality traits, and (2) to find out the best plant spacing and nitrogen level for improved crop management for realizing higher sugar and bioethanol yield.

The experimental design was split-plot and replicated thrice. The treatments comprised of three planting geometry (30 × 15, 45 × 15, and 60 × 15 cm) as main- plots and four nitrogen levels (0, 30, 60, and 90 kg N ha^{-1}) as sub-plots. Sweet sorghum cultivar 'SPSSV 30' seeds were directly hand dibbled as per the treatment of row spacing. The pedigree detail of the genotypes is furnished in Table 1. A uniform distance of 15 cm between plants was maintained after final thinning at 5-leaf stage (20 days after sowing (DAS) of crop. The gross plot size adopted was 3.6 m × 3 m (10.8 m^2). The crop was irrigated four times at fortnightly interval and the soil moisture was maintained near field capacity. The experiment was planted during post-rainy (*rabi*) season of 2008–2009 at experimental farm located at Acharya N.G. Ranga Agricultural University, Rajendranagar, Hyderabad (17°19′N latitude, 78°28′E longitude, and 542.3 m altitude). The soil was sandy loam (profile depth ~0.70 m) in texture with available N 282; P 26.5; K 245.4 kg ha^{-1}; Organic carbon 0.6 % and pH of 7.3. The seeds were hand-planted at 5 cm soil depth during second week of October 2008 in three replications as per the treatment of row spacing. Herbicide Atrazine (@ 1 kg a.i. ha^{-1}) was applied 1-day after sowing (pre-emergence) to control the initial weed flora. The crop was given four supplemental irrigations at fortnightly interval and the soil moisture was maintained near field capacity. At 20-days after emergence (DAE), the seedlings were thinned to single plant. Hand-weeding and intercultivations were done twice between 15 and 35 DAE. The recommended doses of phosphorus (60 kg P_2O_5 ha^{-1}) and potassium (40 kg K_2O ha^{-1}) were applied, while four nitrogen levels were given according to the treatments. The N, P and K were supplied through Urea, Single Super Phosphate and Muriate of Potash, respectively. Half of the nitrogen and full dose of phosphorus and potassium were incorporated at the time of sowing as basal and the remaining dose of nitrogen was top-dressed at about panicle initiation stage of crop (30 DAS). 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.

At crop physiological maturity, ten competitive plants from central four rows of each plot were sampled to extract stalk juice and subsequent juice sugar analysis. In all treatments, 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 Whatman filter paper (# 1 and 12.5 cm diameter) immediately to remove large solids. 100 mL of fresh sweet sorghum juice was transferred to standard glass test tubes and subsequently analyzed for juice sugar quality parameters. Juice Brix of the extracted juice was determined using a digital hand-held refractometer (Digital hand-held pocket refractometer PAL-1, Atago, Tokyo, Japan). Total soluble sugars were estimated by phenol sulfuric acid method using glucose as standard [16]. Reducing sugars in the fresh stalk juice were estimated by using the 3,5-dinitrosalicylic acid (DNSA)

Table 1 Pedigree details of sweet sorghum cultivar tested, post rainy seasons, 2008–2009

Name	Pedigree details	Remarks
SPSSV 30	Selection from Cv. Urja—a temperate sweet sorghum line from USA possessing very high stalk sugar concentration (high sucrose, low reducing sugars). Staygreen and drought tolerant genotype adapted to both rainy and postrainy seasons	Time to flowering is 70–75 days and fresh stalk yield is 25–30.1 Mg ha^{-1}. Promising sweet sorghum source for high stalk sugars and sucrose retention beyond physiological maturity in both rainy and post-rainy Seasons. Produce high yields in post-rainy season

reagent method [17]. Reducing sugar content was calculated in terms of glucose equivalents by comparing the absorbance with a standard curve of glucose. Sucrose content (Pol percent) was directly measured using NIR Saccharimeter 880D (Optical Activity Limited, Cambridgeshire, UK) without using lead acetate clarification. Computed ethanol yields were calculated as per the procedure reported by Smith and Buxton [18]. The data were analyzed using analysis variance (ANOVA) following the procedure for split-plot design as outlined by Gomez and Gomez [19]. Least significant difference (LSD) values were calculated at 0.05 probability level, wherever 'F' test was significant. The data analysis was performed using WINDOSTAT statistical software [20]. Total rainfall, weekly mean minimum and maximum temperatures recorded during the crop growing period (standard meteorological week 38–5) was 73.0 mm, 12.0–22.7, and 28.6–34.6 °C, respectively (Fig. 1).

Significant differences ($P = \leq 0.05$) were found in juice extraction due to variation in plant density, but the differences due to N levels including interaction were non-significant (Table 2). Interestingly lower plant density (60 × 15 cm spacing) produced 16.0 % more juice extraction than higher density (30 × 15 cm). High juice extraction might be due to the increased stem size, water content and stem. The present results are in conformity with the findings of those reported by Subramanian et al. [21]. The data on brix, reducing sugar, sucrose content and total soluble sugars are presented in Table 2. Significant effects ($P = \leq 0.05$) of nitrogen levels on juice brix were observed, while plant spacing effects were non-significant, but interaction effects too significant (Table 2). With increased nitrogen levels juice brix values showed a decreasing trend up to 90 kg h^{-1}. The increase in juice brix at 0 level N was 19 % more than at 90 kg. There was non-significant difference in juice brix from 0 to 60 kg ha^{-1} N levels. Decrease in brix content with increased nitrogen levels has been reported by Choudhari [22], while accumulation of higher reducing sugars (glucose content) in the juice with increased nitrogen application has been reported by Bapat et al. [23]. Significant effects ($P = \leq 0.05$) of nitrogen level were found on sucrose content. In the present study, lower plant population resulted in higher sucrose (10.8 %) content and the sucrose content showed a decreasing trend with increased nitrogen levels (Table 2). While the plant spacing effects including interaction on brix value were statistically non-significant. On the other hand the reducing sugars was neither significantly influenced by the plant spacing nor the nitrogen application. There was 44.2 % increase in sucrose content at 0 kg N level (control) compared to 90 kg N level (Table 2). Earlier studies also showed the decrease in fermentable sugars or sucrose content in sweet sorghum successively with increase in nitrogen levels [24–26]. Reduction in fermentable sugars was due to vigorous vegetative growth, leaf area and canopy development at higher nitrogen application. In the present study, it was observed that the sucrose content reached the maximum at lower nitrogen

Fig. 1 Weekly total rainfall (mm), mean minimum and maximum temperature (°C) recorded at Agricultural Research Station, Rajendranagar, (17°27′N, 78°28′E, Altitude: 522.3 m amsl) Hyderabad weather station (approximately 200 m from the study site) from September 2008 second week to January 2009 last week

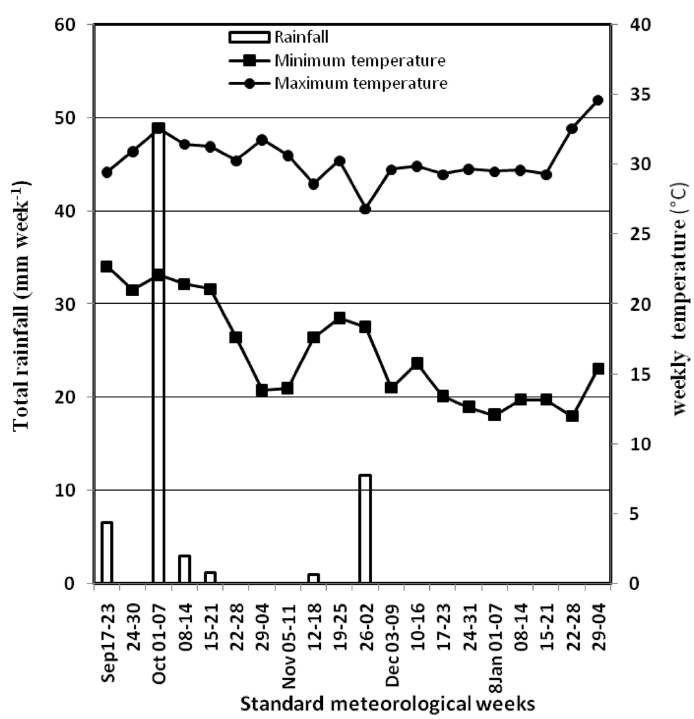

Table 2 Effect of nitrogen levels and plant geometry on juice quality traits of sweet sorghum at physiological maturity stage, postrainy season, 2008–2009, Hyderabad

Treatment	Juice brix (%)	Reducing sugar (%)	Sucrose content (%)	Total soluble sugars (%)	Juice extraction (%)	Computed ethanol yields (L ha^{-1})
Plant spacing (cm)						
30 × 15	20.56	7.36	9.87	18.13	40.02	880-2
45 × 15	19.17	6.17	9.90	16.91	43.74	586.0
60 × 15	19.89	5.88	10.78	17.54	46.49	557.1
SEd±	0.64	0.64	0.83	0.57	1.68	101.8
LSD ($P = 0.05$)	NS	NS	NS	NS	4.66	NS
Nitrogen levels (kg ha^{-1})						
0	21.06	5.92	11.71	18.57	39.85	695.0
30	20.51	6.44	10.73	18.07	42.91	639.4
60	20.28	6.84	10.13	17.90	45.72	734.1
90	17.64	6.68	8.12	15.56	45.18	629.2
SEd±	0.93	0.63	0.96	0.82	3.75	153.8
LSD ($P = 0.05$)	1.96	NS	2.02	1.72	NS	NS
Interaction						
SEd±	1.61	1.10	1.66	1.42	6.50	256.8
LSD ($P = 0.05$)	3.40	NS	NS	2.98	NS	NS

levels (control treatment). Several workers too showed non-significant differences in sweet sorghum quality traits as influenced by plant density or plant spacing [25, 27, 28]. Significant effects ($P \leq 0.05$) of nitrogen levels including interaction on total soluble sugars (TSS) were observed, while plant spacing effects were non-significant (Table 2). The TSS value recorded at physiological maturity was 19.3 % higher, at 0 kg N level than at 90 kg. The TSS in the juice decreased with increased level of nitrogen (18.57, 18.07, 17.90 and 15.56 % at 0, 30, 60 and 90 kg N ha^{-1}, respectively). The reduction in TSS at very high level of nitrogen may be due to more leaf area, profuse vegetative growth and succulent nature of the plants which had a dilution effect on soluble sugars. The decrease in TSS with increased nitrogen application levels was also reported by Meli [24] and Han et al. [26] in sweet sorghum. TSS content has showed a declining trend with increasing nitrogen levels from 0 to 90 kg N ha^{-1}. Computed ethanol yields recorded were not significantly different due to variation in plant density and nitrogen levels including interaction (Table 2). The computed ethanol yields ranged from 557 to 880 L ha^{-1} across plant densities and N levels. Among population levels, lower plant spacing (30 × 15 cm) produced numerically 58.0 % higher computer ethanol yields than higher plant spacing (60 × 15 cm). As regards nitrogen levels, computed ethanol yield was numerically 17 % higher at 60 kg N than at 90 kg N $ha^{-1.}$ The present results are in conformity with those of Lueschen et al. [25] who reported that neither N fertilizers nor seeding rate significantly affected ethanol yield in sweet sorghum grown in temperate climate.

Based on the above results it can be concluded that the lower dose of nitrogen application (60 kg ha^{-1}) with maximum population density (spacing 45 × 15 cm) has maintained higher juice sugar quality parameters i.e., brix, TSS, reducing sugars and sucrose content. Combination of relatively lower nitrogen application level along with less than recommended plant population is suggested for realizing higher sugar and ethanol yields in the farmer fields.

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