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Evaluating the Potential of Juice from Some Sweet Sorghum Varieties Grown In Kenya to Crystallize

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Abstract

Sweet sorghum (Sorghum bicolor (L) Moench) is a crop analogous to sugarcane with similar accumulation of sugars in its juicy stems. An earlier research study on agronomic trials carried out by Jomo Kenyatta University of Agriculture and Technology established that some of the imported varieties of Sweet Sorghum had sufficiently high amounts of sugar content in their Juice. The present study was undertaken with the objective of determining the potential of some of these sweet sorghum varieties to produce crystal sugar. This was with the long term goal of trying to find alternative uses for sweet sorghum. The sweet sorghum varieties were planted at the University research farm, and stalks of sixteen varieties were crushed using electrical roller mill to produce SS juice which was then subjected to a number of analyses including, total and specific sugar determination and apparent purity. The total sugars in degree Brix varied from 15.05^0 to 21.50^0, sucrose concentration ranged from 6.05g/l to72.77g/l, glucose 2.65g/l to 16.41g/l and fructose 2.66g/l to 17.16g/l whereas apparent purity(AP) ranged from 33.89% to 83.91%.The variation could have been brought about by varietal differences. The juice of variety RIO had the highest sucrose purity of 83.91% which was further clarified by liming and double carbonation method. The resulting juice was concentrated into syrup by evaporation. Supersaturation for crystallization was attained by cooling, followed by seeding. According to the present study, the following sweet sorghum cultivars; Rio, CMSXS636, IESV91018LT, IESV93042SH and SPV1411 could have potential in crystal raw sugar production because they have AP greater than 75% and a relatively higher sucrose concentration. The Rio sweet sorghum variety with the highest sucrose purity of 83.91% and sucrose concentration of 40.86g/l was selected and subjected to crystal sugar production processes. The Rio juice subjected to crystallization process failed to produce crystals probably due to the presence of dextran, aconitic acid and starch.

Key words: Brix, Sucrose, apparent purity, Clarification, Crystal Sugar,

1. Introduction

The demand for renewable energy has led to increased research on the potentiality of converting alternative biomass into energy sources (De Vries, 2010). Sweet sorghum (Sorghum bicolor (L.)Moench) has been considered as a particularly important energy plant, due to its high-yields, drought tolerance, relatively low input requirements and ability to grow under a wide range of environmental conditions (Gnansounou et al, 2008). There are numerous published reports on intensive research efforts progress in various countries such as the USA, China, India, Indonesia, Iran, Philippines and Kenya in assessing the agro-industrial potential of sweet sorghums. (Reddy et al. 2008; Ranola et al., 2007; Tsuchihashi and Goto, 2008; Bennett and Anex, 2009; Pillay and Da Silva, 2009; Zhang et al., 2010; Olweny et al., 2013; Owino et al., 2013). The Sweet sorghum (SS) crop offers great potential as a food and an industrial crop. It is a multifunctional crop that can be cultivated for simultaneous production of grain for food and utilization of juice from stalk in production of value-added products like syrup and ethanol. The leaves and stalks can be used for fodder, and bagasse for animal feed or fiber production.

Although the juice, grain and bagasse from sorghum provide opportunities for many uses, most applications around the world are for syrup and forage. An average yield of 1900L (500 gallons) of syrup per hectare can be achieved, although yields of 800-1200L (200-300gallons) per hectare can result if weather conditions are poor (Gnansounou et al., 2005). In forage applications, chickens can be fed with seed heads and ruminant livestock can use the grains, leaves and stalks. The organic by-product from sweet sorghum syrup processing is often fed to livestock, left on the field or composted (Gnansounou et al., 2005).

In general, the technology considered for juice extraction involves a series of tandem roller mills with countercurrent juice flow to leach the solubles. On this basis, the sugar extraction (i.e., the proportion of initial sugars present in the juice after extraction) reaches 87%. Because of the relatively high fibre content in sweet sorghum, it is unlikely that the yield will be as high as from sugarcane (Woods, 2000).

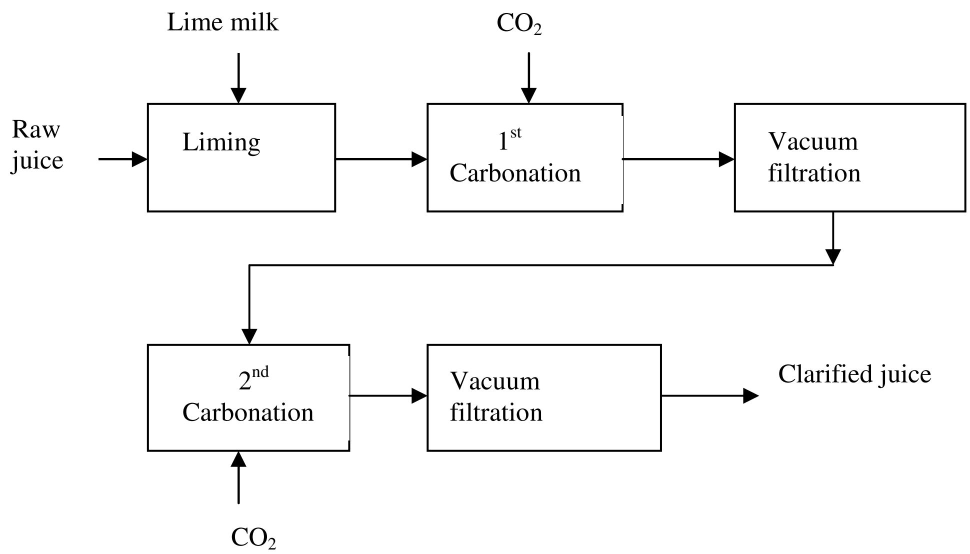

Figure 1: Juice clarification process

The first stage in SS juice purification is the addition of lime milk (liming) (**Figure 1**) followed by saturation with carbonation gas (mainly carbon dioxide) to precipitate the lime milk in a clarifier and capture the impurities in the raw juice (Gnansounou et al., 2005). The settled solids (mainly calcium carbonate and non-sugars) from the clarifier are filtered in membrane presses and sent to the spent lime storage area, while the clear portion is again saturated in a second carbonation station. The purified juice obtained after the consequent filtration is called thin juice and is thickened in a multi-effect evaporator into thick juice. The thin juice that has been diluted with water during extraction and purification enters the evaporation station with an average sugar content of 15% while the thick juice leaving the evaporators contain approximately 70% sugars.

White sugar in its crystalline form is eventually obtained from the thick juice by crystallization in vacuum pans at reduced temperature and pressure (Gnansounou et al., 2005). The mixture of crystals (sucrose only) and the mother liquor (green syrup) are separated in centrifuges, where the sugar is washed with hot water. The wet sugar is dried in a drum drier, screened and finally stored in silos after cooling, while the syrup from the centrifuge is passed through an additional boiling stage to extract most of the remaining sugars (that is to say, glucose, fructose and some of the sucrose left). The syrup left over is known as molasses.

There has been increased interest in the production of sweet sorghum in Kenya and the suitable areas for production in the Western, Central, Eastern and Coastal regions of Kenya are estimated at 46.4% of the total Kenya surface area (Ndegwa et al., 2011).As one of the value addition pathway to support the SS value chain in Kenya, this study was carried out with the objective of investigating the potential of juice from some of the SS varieties to crystallize into raw sugar. This would be beneficial in supplementing the production of sugar from sugar cane and be one of the interventions in mitigating against the persistent shortfall in sugar production in the country (Anyanzwa, 2014).

2. Materials and Methods

2.1Plant materials and juice extraction

The selected 16 sweet sorghum varieties were evaluated during the short rainy season of September –December 2012 and the long rains of April- July 2013 at the JKUAT experimental farm. The type of soils at JKUAT area is rhodicferralsols with pH of 6.2 with an annual rainfall of 856mm and a mean temperature of 25-27°C. The experimental design consisted of a randomized complete block design (RCBD) with three replications and each variety was sown in a plot size of 4 rows, 5 m long and 3 m wide (15m²), the spacing was 75cm by 30 cm and cultural practices such as weeding and disease control were done to obtain optimum stalk and sugar yields.

At specific periods, harvesting was done manually, where sweet sorghum plants were selected randomly from the middle rows, their leaves, heads, and pinnacles were stripped and weighed individually. The SS juice was extracted using electrical stalk juice crushers, filtered, clarified and held at -20 °C in a freezer until further analyses.

2.2.1 Clarification of Rio juice

This was carried out according the method of Klug, 1993 with modifications. Approximately 2L of SS juice was heated to 50^0C and lime milk added till pH was 11and carbon dioxide bubbled to drop the pH to 10. It was allowed to settle for 1hr then filtered under vacuum to give a clear juice. The juice was reheated to 50^0C and carbon dioxide bubbled through once more to lower the pH to 7.1. The temperature was then raised to 90^0C for 5min and allowed to cool to 60^0C and 0.2044g (0.0097% weight of feed) of calcium chloride and 0.2561g (0.0122% weight of feed) of amylase were added and allowed to react for 1hr and then vacuum filtered to get a clear thin juice. Calcium chloride was added to remove aconitic acid whereas amylase enzyme hydrolyzed starch to glucose.

2.2.2 Concentration of Rio juice

Approximately 1.3L of clarified juice was concentrated into syrup using a rotary vacuum evaporator.

2.2.3 Crystallization of Rio syrup

The seed was refined sucrose which was ground and passed through a 93µm sieve. Approximately 75mlof syrup in a 100ml beaker with a magnetic stirrer was cooled using ice cold water and when the temperature dropped to 18^0C, the seed in ethanol as a carrier was introduced into the syrup.

2.3Analytical methods

2.3.1 Analysis of juice and syrup

Total Sugars in terms of °Brix was measured using a digital refractometer (Model PAL-1, Atago Co. Ltd., Tokyo, Japan).

The specific sugars: The SS juice was filtered through filter paper number 1 and further microfiltered using a 0.45μm syringe. The sugars were analyzed using a high performance liquid chromatography (HPLC) (Model LC-10AS, Shimadzu Corp., Kyoto, Japan) fitted with aminopropylsilyl column and a refractive index (RI) detector. The mobile phase was acetonitrile / water at ratio of 80:20 (v/v) at a flow rate of 1 ml/min, and the column and detector temperature was maintained at 35±1°C.

2.4 Data Analysis

The data was analyzed using statistical software Genstat version14.1, and the means were separated using Duncan's Multiple Range Test (DMRT) to determine whether there was significance difference in total and specific sugars, and apparent purity among the varieties.

3. Results and discussion

3.1 The total sugar content, glucose, fructose and sucrose concentration in SS juice

The total sugar content in degrees Brix of the sweet sorghum varieties is shown in **Table 1**. Madhura had the lowest Brix of 15.05^0while Dale had the highest Brix of 21.50^0 after 16 weeks of planting in the field. The results are similar to what was observed by Reddy et al (2005) of 16- 23^0Brix and slightly higher than that observed by Woods (2000) of 11.0-18.5^0Brix.This variation could be attributed to stalk variety, different soils and climatic conditions. All the varieties except Madhura, Wiley, Brandes and IESV93042SH had a Brix higher than that of sugarcane of 16.8^0(Woods, 2000).Madhura had the lowest sucrose concentration of 6.05g/l whereas variety IESV91018LT had the highest sucrose concentration of 72.77g/l. These values far exceed those observed by Reddy et al (2005).These differences could also be attributed to different soils and climatic conditions. Those observed by Woods (2000) ranged from 6.3 – 12.8g/l and for sugarcane the sucrose concentration was 14.1g/l. Variety CMSXS636 had the lowest glucose concentration of 2.653g/l whereas Wiley had the highest glucose concentration of 16.415g/l. To the best of our knowledge, there is no literature quantifying glucose and fructose concentrations in sweet sorghum varieties, as they are lumped together as reducing sugars, hence there is no basis for comparison. According to the different positions of sugar contained in the stalks, it can be divided into saccharin-type SS and syrup-type SS (Li Dajue, 1995). Saccharin-type SS, which mainly contains sucrose, can be used for refining crystal sugar. Syrup-type SS, which mainly contains glucose, can be used for producing syrup. Also, syrup-type SS is a material of quality for making drinking wine and alcohol. Variety CMSXS636 had the lowest fructose concentration of 2.664g/l while Wiley had the highest fructose concentration of 17.139g/l.

3.2 Sucrose purity/Apparent purity (AP)

In **Table 2** are tabulated values for sucrose purity ([Pol/Brix]*100) for the sixteen sweet sorghum cultivars. Wiley had the minimum value of 33.89% whereas 6 varieties namely, CMSXS633, SPV1411, IESV91018LT, IESV93042SH, CMSXS636 and Rio had values above 75% of, 75.42%, 76.99%, 77.68%, 78.08%, 83.08% and 83.91%, respectively. Similar report was given earlier by Woods (2000) where the AP for the sweet sorghum varieties considered varied from 48.2% - 69.7% whereas that of sugarcane juice was 83.6%.

3.3 Crystallization process

After characterization of the sweet sorghum cultivars, the variety with the highest apparent purity of 83.91%, Rio, (**Table 2**) was chosen for crystal sugar production. Sucrose purity is used to calculate the ease with which sucrose can be extracted and crystallized and 75% is required as the minimum (Woods, 2001).

Table 1: Total sugar content in ^{0}Brix, glucose, fructose and sucrose in g/l

Variety	Brix(^{0})	Glucose, g/l	Fructose, g/l	Sucrose, g/l
Madhura	15.05a^z	3.02b	3.13b	6.05a
Wiley	16.20ab	16.41l	17.14k	17.20d
Brandes	16.40ab	8.03h	7.87f	15.99c
IESV93042SH	16.75abc	3.11b	3.17b	22.33g
CMSXS633	17.00bc	3.12b	3.14b	19.20e
Rema	17.00bc	3.79c	7.30e	25.11h
Ramanda	17.70bcd	6.91g	10.00g	38.07k
Theis	17.90bcd	10.30j	11.40h	38.19k
IESV91018LT	18.00bcd	8.39i	12.53j	72.77m
CMSXS636	18.50cd	2.65a	2.66a	26.10i
IESV92008DL	19.00de	7.01g	16.95k	38.37k
IESV92038/2SH	19.00de	5.62f	5.90d	20.67f
SPV1411	19.00de	4.98e	3.16b	27.21j
CMSXS644	20.50ef	3.76c	4.11c	9.62b
Rio	20.70ef	4.62d	3.21b	40.86l
Dale	21.50f	12.47k	11.99i	21.24f

^{z}means within columns followed by the same letter(s) were not significantly different (P≤0.05)

Table 2: Apparent purity/ Sucrose purity in percentage

Variety	Wiley	Dale	Madhura	Brandes	CMSXS644	IESV92008DL	Theis	IESV92038/2SH
Apparent purity, %	33.89a^z	46.48b	49.60c	50.13c	54.97d	61.55e	63.79f	64.21f

Ramanda	Rema	CMSXS633	SPV1411	IESV91018LT	IESV93042SH	CMSXS636	Rio
69.24g	69.35g	75.42h	76.99i	77.68i	78.08i	83.08j	83.91j

^{z}means within columns followed by the same letter(s) were not significantly different (P≤0.05)

3.3.1 Extracted Rio juice

From **Table 3**, it can be deduced that 1000kg (1 metric ton) of Rio stalk after 17 weeks in the farm yielded 312L of thin unclarified juice of 18.8^0Brix and 642kg of bagasse. The Brix of the juice was similar to that recorded by Gnansounou et al.(2005) of 17.5^0.The minimum Brix required for crystal sugar production is 12%(Woods, 2001) hence the RIO juice was suitable for crystal sugar production. From **figure 2**, the extracted juice had approximately 133g/l of sucrose, 7g/l of glucose and 6g/l of fructose and apparent purity of 91% (**Figure 3**).This was considered appropriate for saccharine-type juice for crystal sugar production as it had higher sucrose concentration relative to the reducing sugars.

Table 3: Characteristics of extracted Rio juice from the sugarcane presser

Variety	Age in days	Weight of stalks(kg)	Volume of juice expressed(L)	Weight of bagasse produced on wet basis, kg	Brix(^{0}) of juice	pH of juice
Rio	122	12.5±0.71	3.9±0.14	8.025±0.25	18.8±0.28	4.75±0.07

Values are presented as Mean±SD, n=2

3.3.2 Rio syrup

The Rio syrup after evaporation had a Brix of 68.05^0(**Table 4**). Thereafter 1000lts of clarified juice was fed to the vacuum rotary evaporator estimated to produce approximately 58.8lL of syrup. From **figure 2**, the syrup had 600g/l of sucrose, 19g/l of glucose, 14g/l of fructose and apparent purity of 95% (**Figure 3**).

Table 4: Characteristics of Rio syrup after evaporation

Sorghum variety	Volume of clarified juice (feed), L	Volume of syrup, ml	Mass of syrup, g	BRIX(^{0})
Rio	1.25±0.07	73.5±2.12	92.15±1.63	68.05±0.21

Values are presented as Mean±SD, n=2

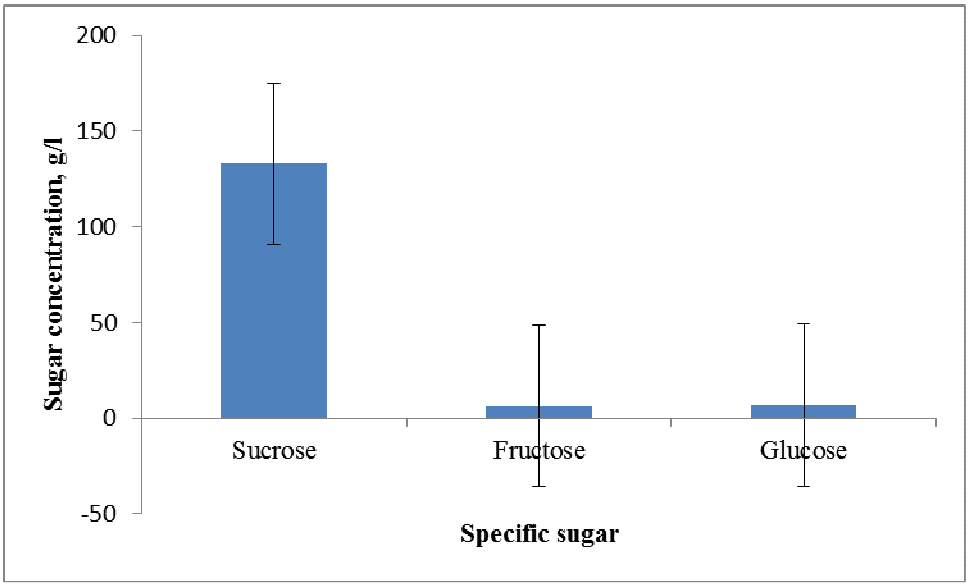

Figure 2: Specific sugar concentrations in Rio juice after extraction prior to clarification

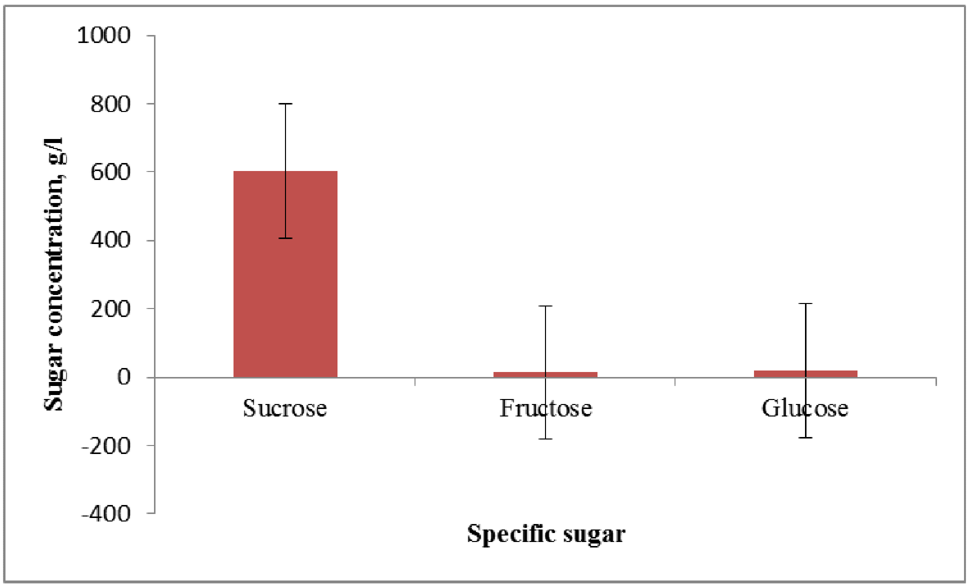

Figure 3: Specific sugars present in RIO syrup before crystallization

3.3.3 Rio syrup crystallization

The Rio syrup failed to crystallize into crystal raw sugar. The sweet sorghum juice is not commonly used for crystallized sugar production because of the presence of significant amounts of inverted sugars(glucose and fructose) and antiquality compounds such as aconitic acid that makes crystallization difficult and expensive (Wang,2014). The sweet sorghum cultivar chosen for crystal sugar production must have a high content of sucrose in the stalks and low levels of starch and aconitic acid which impede sorghum sugar crystallization (Kulp, 2000). During clarification, amylase enzyme was used to minimize the concentration of starch in the juice, but this enzyme converts starch to glucose thus increasing the concentration of glucose in the juice which is counterproductive. The concentration of glucose in the Rio syrup was 19g/l compared to 7g/l in the unclarified Rio thin juice. On the other hand, fructose concentration in the syrup and juice was 13.8g/l and 6g/l respectively. Therefore the residual concentration of invert sugars in the Rio syrup was relatively high and could have hindered crystallization. Calcium chloride was used during clarification to eliminate aconitic acid but the concentration of the aconitic acid was never determined to find out if it was completely removed from the sample. The other probable reason for not getting crystal sugar is because of the presence and concentration of dextran (Abdel-Rahman, 2007). The presence of dextran in the sugar factories leads to a falsely high polarization, increased viscosity, slowing of filtration, lower evaporation rates, elongated crystals (needle grain), longer wash and separation cycles in centrifuges and increase of sugar loss to molasses (Imrie &Tilbury, 1972; Jolly & Prakash, 1987; Kim & Day, 2004; McGinnis, 1982; Singleton, 2002 and Singletone et al, 2001). However, the most damaging effects of elevated dextran concentrations in a technical sucrose solution are foreseen in the crystallization process. Dextrans slow down the crystallization rate or even inhibit crystallization (i.e., they have a high melassigenic effect). It is estimated that for every 300ppm dextran in syrup there is a 1% increase in molasses purity (the % ratio of sucrose) in total solids in a sugar solution (Atkins &McCowage, 1984; Cerutti de Guglielmone, Diez, Cardenas, & Oliver, 2000; Clarke, Edye et al, 1997 and Godshall et al, 1994).

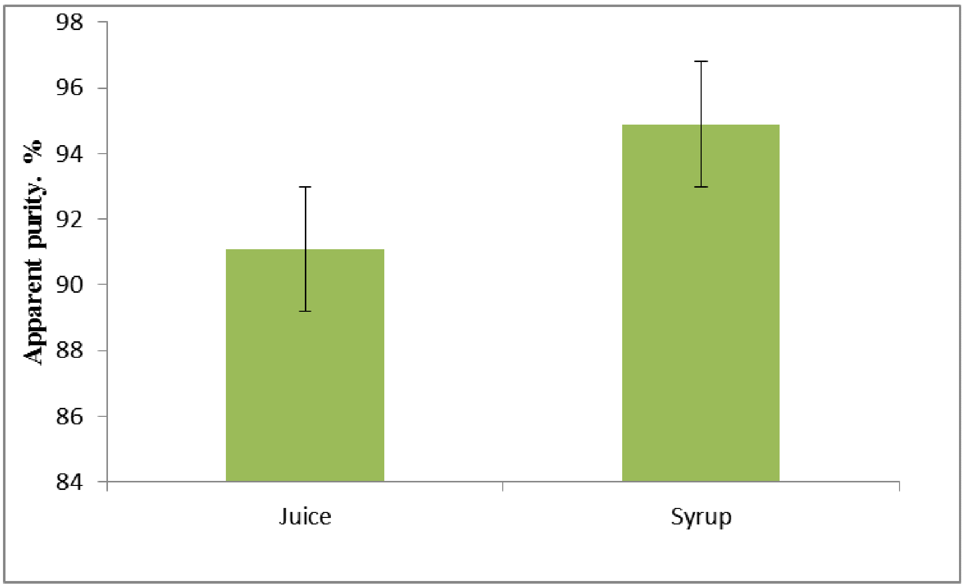

Figure 3: Apparent purity of clarified Rio juice and Rio syrup before crystallization

Conclusion

Due to the lower purity(ratio of the %wt. of sucrose to the %wt. of soluble) of the sugar extracted from sweet sorghum(about 75 apparent purity, AP) compared to that of sugar cane or sugar beet(80-85 AP), it may require further technological input to produce white sugar from sweet sorghum. Thus, the more likely markets for sorghum sugar can be syrup for local foodstuffs or as raw material for the food industry.

According to the study, the following sweet sorghum cultivars namely; Rio, CMSXS636, IESV91018LT, IESV93042SH and SPV1411 could have the potential to be used in raw sugar production. If starch, dextran and aconitic acid can be removed, crystal sugar can be obtained from the sweet sorghum juice especially from the variety RIO.

Acknowledgements

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