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RESEARCH ARTICLE

Physico-Chemical Properties and Antioxidant Potential of Syrup Prepared from 'Madhura' Sweet Sorghum (*Sorghum bicolor* L. Moench) Cultivar Grown at Different Locations in Kenya

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Abstract The study was undertaken with the objective of producing sweet sorghum syrup, analyze its physical, chemical and antioxidant properties, and quantify the influence of environment on the properties of the syrup. The color coordinate values of Chroma and Hue angle were indicative of the dark brown coloration of the syrups and were most influenced by location compared to L* values. The density and the moisture content showed no significant difference while apparent viscosity and total acidity was significantly different between the syrup compared from two locations. The sweet sorghum syrups from the two locations had fructose levels of 12 and 2 %, sucrose at 66 and 88 % while and glucose levels were 17 and 6 %, respectively. Calcium was the macro-element with the highest concentration ranging between 108.0 and −272.33 mg/100 g of syrup and was significantly different ($p \leq 0.05$) between the locations. For micro-elements, magnesium had highest (124 and 118 mg/100 g).The sweet sorghum syrups exhibited high level of total phenolic content and total flavonoid content at 261.31 mg Gallic acid equivalents and 197.50 mg quercitin acid equivalent per 100 g syrup respectively. Since the radical scavenging activity was greater than 50 % even at low syrup concentrations, indicates that the sweet sorghum syrups are potent free radical-scavengers. This study shows that the sweet sorghum syrup is comparable to sugarcane syrup. Because of its superior antioxidant properties the syrup may find application in the food industry.

Keywords Sweet sorghum syrup · Physicochemical antioxidant · Color · Minerals · Phenolics · Flavonoid · Radical scavengers

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Introduction

Sweet sorghums (SS) (*Sorghum bicolor* L. Moench) are sorghum varieties that accumulate high levels of sugars like sucrose, glucose and fructose in the parenchyma juicy stems and produce high biomass (Rao et al. 2013). They are much larger, typically averaging between 2 and 3 m, with thicker stems than the grain varieties, but with much smaller seedheads. The 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 or feed 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 paper pulp manufacture (Whitfield et al. 2012).

Sweet sorghum have a C4 photosynthetic pathway that enables it to yield higher levels of biomass and sugars relative to inputs used compared to other sugar producing crops like sugarcane (Almodares and Hadi 2009). Therefore the SS is considered as a crop with low input cost and is highly tolerant to poor soil, and low nutrient conditions (Calviño and Messing 2012). Despite the fact that water

availability do affect total biomass production, sweet sorghum uses less water per unit biomass produced than many other C4 plants and tolerate drought conditions relatively well (Curt et al. 1995; Kalyanasundaram et al. 2008). The SS crop can be harvested within a period of three to 4 months and therefore it is a crop that can be grown on marginal or lower potential arable lands of Kenya.

There has been no production of SS in Kenya though it is estimated that SS has suitability area for production in the Western, Central, Eastern and Coastal regions of Kenya estimated at 46.4 % of the total Kenya surface area, and can play a key role in ensuring food security (Ndegwa et al. 2011).The major interest in sweet sorghum both for food and fermentation is due to the large amounts of sugar in its juice—generally comprising anywhere from 20 to 50 % of the whole plant dry weight and ranges between 16° and 23° Brix (Whitfield et al. 2012). The nutritional profile of sweet sorghum juice has been reported to contain essential amino acids, minerals etc. (Nimbkar et al. 2006), which provides a wide spectrum for value addition of the juice for applications in the food industry.

One of the value added products that can be derived from SS juice is the syrup, which has potential uses in the food industry. The syrup can be used as an ingredient in bakery products. It can also be used as stir fry base, in baked beans, and can be substituted in any recipe that calls for glucose syrup, maltose syrup, fructose syrup, corn syrup, molasses, maple syrup, honey. In the food Industry, manufacturers often prefer to use sugar in the form of syrup mostly due to the ease and efficiency of liquids and to the favoured process economics. Sugar syrups produce pleasant flavour and occasionally cooling sensations, enhance shelf life properties and may simultaneously provide energy, nutrients and bio active compounds. The production of syrup from sweet sorghum has a long history and it is reported that the introduction of Sweet sorghum in United States in the 1850s was primarily for syrup production (Undersander et al. 1990). The production of SS syrup in the US was at its peak following sugar shortages during World War II at about 136 million litres per year of syrup in 1946, but thereafter dropped significantly due to low sugar prices and inadequate production efficiency (Hunter and Anderson 1997).

Syrup products such as maple have been reported to contain phenolic compounds with antioxidant and antiradical activities (Thériault et al. 2006). Natural antioxidants protect the human body from free radicals, prevent oxidative stress and associated diseases (Brewer 2011; Shahidi 2004). These substances, present at minimal concentrations compared to those of an oxidizable substrate, but significantly delays or prevents oxidation of that substrate, including other type of molecules found in vivo. The consumption of foods containing antioxidants is now widely considered to be an effective strategy to reduce oxidative damage and exert a beneficial effect on human health. As a result, the food industry in the recent years has shifting focus to antioxidant products from natural sources as a replacements for synthetic antioxidants and also as nutraceuticals.

The advantage of using sweet sorghum syrup is that it is a low-cost and renewable biomaterial (Stuckel and Low 1996). The production of SS syrup would add value to sweet sorghum production and enhance the sweet sorghum value chain thereby providing additional livelihood opportunities to farmers who will be involved in its cultivation. As nothing has been previously been reported in the literature on SS syrups in Kenya, the objective of this study was to prepare SS syrup by adopting standard approaches for its production, characterize the syrup in terms of it physical, chemical and antioxidant properties. Since SS has the potential to be grown in a number of regions within the country, we also determined the influence of the SS cultivation location on the properties of the syrup and compared the SS syrup properties with those of a commercially produced sugarcane syrup.

Materials and Methods

Plant Material

"Madhura" SS hybrid variety was sourced from Nimbkar Agricultural Research Institute (NARI) Maharashtra, India. On-station and on-farm plots were set up at JKUAT experimental farm and at Rongo in Migori county. The type of soils at JKUAT area are rhodic ferralsols with pH of 6.2 with an annual rainfall is 856 mm and a mean temperature of 25–27 °C, whereas Rongo has humic acrisols with pH of 5.81 and annual rainfall of 1,250 mm and a mean temperature of 25–20 °C. The sweet sorghum crop was planted on April 7 and 15 2010 at JKUAT and in Rongo respectively, in a completely randomized block design (CRBD) with three replications. Each plot consisted of 4 rows, 5 m long and 3 m wide (15 m^2), the spacing was 75 cm by 30 cm and cultural practices such as weeding and disease control were done to assume optimum stalk and sugar yields. The stalks of Madhura varieties grown at both locations, were collected at the physiological grain maturity. The harvesting was done manually, where sweet sorghum plants were selected randomly from the middle rows, their leaves, heads, and peduncles were stripped and weighed individually. The SS juice was extracted using stalk juice crushers, filtered, clarified and held at −20 °C in a freezer until further analyses.

Preparation of Syrup

The initial mean °Brix of the clarified raw juice was 18 % (w/w). After filtration of sap, the juice was subjected to

slow heating in a stainless steel pan using a hotplate, with continuous agitation. During concentration, there was formation of foam due coagulation of suspended particles, which was continuously removed. The concentration of the sap was terminated when the total soluble solids content reached 74–76 °Brix. The syrup was then cooled to ambient conditions and the packaged in sterilized containers and stored at 4 °C until further analyses.

Syrup Physicochemical Characteristics

The color of the syrup was determined using a NF-333-Color spectrophotometer (Nippon Denshoku Industries, Japan). Results were expressed according to CIELAB color coordinates system, L*, a* and b*; where L* represents the perceived lightness, a* and b* indicate the change in hue from red to green and from yellow to blue, respectively. The Chroma (C*) value and hue-angle (h°) were calculated as; $C^* = (a^*2 + b^*2)1/2$, and $h^\circ = \tan - 1(b^*/a^*)$, respectively (CIE 1986).

Density was determined at 25 °C, by weighing the sample in a 25 ml pycnometer (Constenla et al. 1989).The pycnometer was filled with syrup and incubated at 25 °C for 1 h for equilibration before determination.

The apparent viscosity of the syrup was measured according to the procedure of (Al-Hooti et al. 2002) using a Brookfield viscometer (model HBT Brookfield Eng. Lab., USA) at 25 ± 1 °C using spindle No.2, RPM of 30 and in a 250-ml capacity glass beaker (60 mm diameter).

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

The specific sugars were extracted with aqueous ethanol by shaking at 50 °C for 30 min (After centrifugation, the supernatant was collected and concentrated using a rotary evaporator at 40 °C. The sugars were analyzed using a high performance liquid chromatograph (HPLC) (Model LC-10AS, Shimadzu Corp., Kyoto, Japan) fitted with amino-propylsilyl column and a refractive index (RI) detector. The mobile phase was acetonitrile/water at ratio of 75:25 (v/v) at a flow rate of 0.6 ml/min, and the column and detector temperature was maintained at 35 ± 1 °C.

The pH of the syrup was measured using a pH meter (Model 200, Denver Instruments USA).

Total acidity of SS juice was determined by titration with a standard alkali (0.1 N NaOH). The formula below was used to calculate the total acidity;

$$\%\ \text{acid}\ (\text{wt/wt}) = \frac{\text{N} \times \text{V} \times \text{Eq.wt} \times 100}{\text{W} \times 1,000}$$

where N is normality of NaOH W mass of sample (g),

V is volume of titrant (mls) 1,000 is the factor relating mg to g

Eq. wt is the equivalent weight of citric acid which is the predominant acid in the syrup

The moisture contents were determined by placing 2 g of syrup sample an oven at 105 ± 2 °C until constant weight was achieved according to AOAC 1999.

The ash content was determined by placing 2–3 g of syrup samples in a crucible in a muffle furnace and heating at 550 °C for 6 h according to AOAC 1999.

Minerals content was determined according to the AOAC methods (1999). Two grams of syrup samples were dried in the oven, ashed in muffle furnace and diluted with 1 % HCl. Mineral constituents (Ca, Mg, Mn, Zn, Cu and Fe) were determined using Atomic Absorption Spectrophotometry, while Atomic Emission Spectrophotometry was used to analyze Na and K respectively in using Atomic Spectrophotometer (Model AA 6200, Shimadzu, Kyoto, Japan).

Determination of Antioxidant Components in Syrup Samples

Determination of Total Phenolic Content

The samples were prepared by dissolving 10 g of syrup in 100 ml of (70 %) methanol at room temperature for 48 h in darkness. The extracts were filtered through a Whatman filter paper, concentrated to dryness using a rotary evaporator, then redissolved in 25 ml of methanol and kept frozen until analysis. Total phenolics content was estimated by a colorimetric assay based on the procedure previously done by (Escarpa and Gonzalez 2001) with slight modifications. A 100-µL aliquot of the extracted sample was added to 500 µL of 0.2 N Folin-Ciocalteu reagent and 6 ml of distilled water. After mixing the contents for 1 min, 4 ml of saturated Na_2CO_3 was added. Samples were left to stand at room temperature for 90 min and absorbance measurements taken at 725 nm using a UV–VIS 1601 Shimadzu spectrophotometer (Shimadzu, Kyoto, Japan). Gallic acid was used as a reference standard, and the results expressed as milligram Gallic acid equivalents (mg GAE) per 100 g of syrup.

Determination of Total Flavonoid Content

Alu-minium Chloride spectrophotometric method was used for the determination of total flavonoid according to (Chang et al. 2002) with slight modification. 2 ml of syrup methanol extracts was mixed with 0.1 ml of 10 % aluminum chloride (m/v), 0.1 of 1 mol/L potassium acetate and 2.8 ml distilled water. A volume of 10 % (m/v) aluminum chloride was substituted by the same amount volume of distilled water in blank. After incubation at room temperature for 30 min, the absorbance of the reaction mixture

was measured at 415 nm using a Shimadzu 1601 UV–Vis spectrophotometer (Shimadzu, Kyoto, Japan). Quercitin was used as reference for the calibration curve and the results were expressed as quercitin acid equivalents (mg QAE/100 g) per 100 g syrup.

Determination of DPPH Radical Scavenging Activity of the Syrup

The antioxidant activity of the syrup methanolic extracts was measured on the basis of the scavenging activities of the stable 2,2-diphenyl-2-picrylhydrazyl (DPPH) radical (Brand-Williams et al. 1995), with slight modifications according to (Sharma and Bhat 2009). In test tubes with 1 ml of syrup samples of various concentrations (0.05, 0.1, 0.5, 1.0, 2.0, 5.0 mg/ml in methanol) were added 3 ml of methanol, and 0.5 ml 1 mM methanol solution of DPPH. After 30 min of incubation period in the dark at room temperature, the absorbance was measured against a blank (methanol) at 517 nm using a UV–VIS 1601 Shimadzu spectrophotometer (Shimadzu, Kyoto, Japan.

Inhibition of free radical DPPH in percent (%) was calculated using the formula:

$$\text{Percentage inhibition } (\%) = \left[\left(A_{\text{control}} - A_{\text{sample}}\right)/A_{\text{control}}\right] \times 100$$

where, A_{control} is the absorbance of the control reaction (containing all reagents except test samples); and As_{ample} is the absorbance of the test samples. Synthetic antioxidant L-ascorbic acid was used as a positive control.

Statistical Analysis

Each experiment and each assay was conducted in triplicate and data expressed as standard error of mean. Fisher's protected *t* test least significant difference (LSD) at 5 % level of significance was used for comparison of means using Genstat statistical Program version 14.

Results and Discussion

The comparison between the color, density and apparent viscosity characteristics of sweet sorghum and sugarcane syrups is shown in Table 1. Between the sweet sorghum syrups, the* and b* ($p \leq 0.05$) were the most influenced by location compared to L* values. The sugarcane syrup had comparable values to the sweet sorghum syrup in all the color indices. The L* values, which represent the overall intensity of dark or light a color, were 22.87, 21.80 and 22.11, for the three syrups, typical of the darker coloration of the syrup. The values of a* (green–red spectrum) and b* (the blue–yellow spectrum) values approaching zero was also indicative of the dark brown coloration of the syrups and may have been due to the Millard reaction during heating treatment as well as from caramelization (Whistler and BeMiller 2008). In either case, brown colored products are formed, giving the characteristic appearance of these syrups. The Chroma values which represents the dominance of the hue, showed relatively low values of 1.8, 0.7 and 0.5. The Hue angle which specifically defines the dimension were also found low corresponding to low Chroma values, being in the dark brown color range. Dark colored syrups can be desirable, while brown Maillard reaction products are important contributors to the aroma and flavor of many foods such as milk chocolate or toffees. Colored syrups present a pleasant taste and aroma that is preferred by the consumers.

Density is used routinely in the industry as a measurement of the percentage of dissolved solids, which includes carbohydrates and minerals. The density values showed no significant difference ($p \leq 0.05$) in syrups analysed from

Table 1 Comparative physical properties of analyzed syrups

Syrup	Color properties					Density	Apparent viscosity
	L*	a*	b*	C*	H*	g/cm^3	cP[d]
SS (JKUAT)[a]	22.87 ± 2.65a	−0.28 ± 0.19c	1.82 ± 1.38b	1.8 ± 0.4b	−1.42 ± 0.5a	1.41 ± 0.4a	4,530 ± 370b
SS (Rongo)[b]	21.80 ± 2.96a	0.68 ± 0.37b	0.11 ± 0.87a	0.7 ± 0.3a	0.16 ± 0.07b	1.31 ± 0.6a	3,120 ± 500a
SC (Rongo)[c]	22.11 ± 3.56a	0.32 ± 0.57a	0.33 ± 0.68a	0.5 ± 0.3a	0.80 ± 1.17a	1.30 ± 0.6a	8,100 ± 200c
LSD $_{0.05}$	2.62	0.04	0.26	0.2	0.46	0.02	470

Data are expressed as mean of triplicate determinations ± standard error. Means followed by the same letter within each column are not statistically significant different from each other ($p \leq 0.05$)

*L** lightness, *a**and *b** colour coordinates, *C** chroma, *H** hue angle

[a] Syrup produced from 'Madhura' sweet sorghum grown at the JKUAT experimental farm

[b] Syrup produced from 'Madhura' sweet sorghum grown at Rongo field station

[c] Commercially produced sugarcane syrup from Rongo

[d] Centipoise

the two locations (Table 1). The variation in density could be attributed to the effects of carbohydrate concentration in solution, whereby higher sugars concentrations results in higher density (Wartman et al. 1984). Furthermore, the syrups showed great differences in viscosity (Table 1), which might have been due to principally varying solid contents and, to a lesser degree, to the different quality of the juice extracted from the stalks at the two locations. During the process of concentrating various juices in preparation of jaggery products, the viscosity of date-palm syrup was higher followed by sugarcane and palmyra-palm juice at any corresponding value of solids concentration (Jagannadha Rao et al. 2009). The viscosity of these syrups might have been attributed to the nature of sugars similar to the current study.

The °Brix of the syrup collected from two locations was 76 and 72°Brix and was significantly ($p \leq 0.05$) different between the location and also significantly higher than sugarcane syrup which had a °Brix 68 (Table 2). The levels of the three simple sugars indicated differences in geographical location and the source plant material. The sweet sorghum syrup from the crop grown at JKUAT had significantly higher levels of fructose (12 %) and glucose (17 %) as compared to the syrup from Rongo 2 and 6 %, respectively. The major sugar found in the syrup samples was sucrose followed by glucose and fructose respectively. These results contrasts with the relative percentages of sugars estimated in sweet sorghum syrup of CSH 22SS cultivar, which were reported as 20, 14 and 65 % for glucose, fructose and sucrose, respectively (Kumar et al. 2012). Similarly, sugarcane syrup/black treacle was reported to have 57, 20 and 20 % mg/g of fructose and glucose respectively (Amin et al. 1999). The moisture content of the syrup ranged from 23.12 to 24.67 %, which was significantly higher than that of sugar cane syrup (19.62 %).

The moisture content did not differ significantly at JKUAT and Rongo ($p \leq 0.05$) locations. Moisture content can vary depending on the environmental conditions such as climatic, soil and processing conditions, and is critical because it affects the flowbility, storage stability, processing behavior, quality and appearance of syrups (Nimbkar et al. 2006). The moisture levels of the sweet sorghum syrups was consistent with those of treacle which ranged from 22.46 to 25.77 % (Amin et al. 1999) and date syrup which had a moisture content of 20.40–23.90 % (Ganbi 2012). These moisture levels were however lower than those reported for 80 maple samples which ranged from 26.5 to 39.4 %. (Stuckel and Low 1996) and palm tree syrup of 35.3 % (Luis et al. 2012). The sweet sorghum and the sugarcane syrups were acidic in nature at pH values of 4.95, 5.39 and 5.04. The acidic nature of the syrup can be attributable to the presence of organic acids and can function synergistically with sugar to prevent spoilage. Total acidity (TA) showed significant difference among the syrup types ($p \leq 0.05$) but not for the location (Table 2). TA values were 3.9, 4.3 and 2.0 for sorghum syrup from JKUAT, sorghum syrup from Rongo, and sugar cane syrup from Rongo respectively. TA is influenced by presence of more hydrogen ions either attached to organic acids or in form of free ions (Sadler and Murphy 2010), and this may give these syrups their distinctive taste and flavor. The ash content showed significant ($p \leq 0.05$) difference among the syrup types, having values of 5.14, 5.16 and 1.47 % for sweet sorghum syrup from JKUAT, sorghum syrup from Rongo, and sugar cane syrup from Rongo respectively (Table 2). The results obtained were comparable with reported ash content of sweet sorghum as 3.69 and 4.17 % respectively (Nimbkar et al. 2006; Mazumdar et al. 2012). The variation of ash content could be attributed to genetic and climatic factors, composition of soil, cultural practices, and harvesting stage. For example higher mineral absorption efficiency for sweet sorghum may be the cause of high ash content as compared to sugar cane plant (Belitz et al. 2009).

The concentrations of the macro elements and trace elements analyzed from the SS and sugarcane syrup samples revealed that in all samples, calcium was the macroelement with the highest concentration ranging between 108 and 272.33 mg/100 g of syrup and was significantly

Table 2 Comparative chemical properties of the syrups

		% Dry weight basis						
Syrup	(°Brix)	Fructose	Glucose	Sucrose	MC	Ash	pH	Acidity
SS (JKUAT)	76.00 ± 0.07b	12 ± 1.12b	17 ± 0.22b	66 ± 2.4b	24.67 ± 0.03a	5.14 ± 0.58a	4.95 ± 0.00a	3.9 ± 0.86a
SS (Rongo)	72.00 ± 0.61a	2 ± 0.54a	6 ± 0.21a	88 ± 3.7a	23.12 ± 0.02a	5.16 ± 0.30a	5.39 ± 0.01a	4.3 ± 0.01a
SC (Rongo)	68.00 ± 2.35c	3 ± 0.10a	12 ± 1.6b	80 ± 4.6a	19.62 ± 0.07b	1.47 ± 0.01b	5.04 ± 0.01a	2.0 ± 0.33b
$LSD_{0.05}$	2.0	1.2	3.8	9.1	0.2	0.61	0.14	0.3

Data are expressed as mean ± standard error. Means followed by the same letter within each column are not significantly different from each other ($p \leq 0.05$). Acidity as % Citric acid of syrup

MC moisture content

Table 3 Mineral composition of the syrups

Syrup type	Mineral composition in mg/100 g syrup							
	Na	K	Ca	Mg	Mn	Zn	Cu	Fe
SS JKUAT	84.25 ± 0.03b	145.00 ± 0.04c	272.33 ± 1.93c	124.60 ± 1.37b	68.90 ± 1.55a	8.42 ± 0.36b	3.53 ± 0.29a	15.43 ± 0.26b
SS Rongo	153.13 ± 0.01c	133.20 ± 0.02b	190.87 ± 3.85b	118.50 ± 1.42b	87.93 ± 0.62b	11.62 ± 0.42c	5.86 ± 0.13b	19.74 ± 0.48a
SC Rongo	4.95 ± 0.03a	43.46 ± 0.01a	108.01 ± 0.78a	68.70 ± 1.04a	101.39 ± 1.5c	5.36 ± 1.20a	7.69 ± 0.13c	20.27 ± 0.16a
$LSD_{0.05}$	2.46	5.18	4.36	7.10	3.39	1.01	0.97	1.02

Data are expressed as mean of triplicate determinations ± standard error. Means followed by the same letter within each column are not significantly different from each other ($p \leq 0.05$)

different ($p \leq 0.05$) between the syrup type and the location (Table 3). In the JKUAT sample potassium was the second highest (with 145.00 mg/100 g) while syrup from Rongo had Sodium (with 153 mg/100 g) as the second highest macro element. As for micro-elements, magnesium presented the highest levels in the sweet sorghum syrups (124 and 118 mg/100 g) with lower levels of copper (3.5 and 5.8 mg/100 g). In the sugarcane syrup, manganese was found as the main micro element (101.4 mg/100 g) with low levels of zinc. This indicates that sweet sorghum syrup contains considerable amounts of macro and micro elements suggesting the important role of syrup as a mineral source in human nutrition. These results are comparable with the mineral element composition reported for 'Madhura' sweet sorghum syrup in India, which had the highest levels of potassium (1,810 mg/100 g followed by calcium (160 mg/100 g) and sodium (86 mg/100 g fresh sample) (Nimbkar et al. 2006).

Phenolic compounds such as, phenolic acids and flavonoids are considered to be major contributors to the antioxidant capacity of plants and have received much attention as potential natural antioxidant in terms of their ability to act as both efficient radical scavengers and metal chelator (Balasundram et al. 2006). In this study, there were significant differences in the level of total phenolics content (TPC) between the syrups and between the locations. The sweet sorghum syrup derived from crop grown at JKUAT exhibited the highest level of TPC at 261.31 mg Gallic acid equivalents (GAE) per 100 g of syrup. The order of TPC in the syrups was sweet sorghum-JKUAT > Sugarcane syrup Rongo > Sweet sorghum-Rongo. The quantitative role in the TPC may be explained by the total variation in growing conditions between JKUAT experimental farm and Rongo. Flavonoids are one of the most diverse and widespread group of natural compounds and are probably the most important natural phenolics (Agati et al. 2012). Significant differences in total flavonoid content (TFC) were observed among the syrups and between the locations (Table 4). The sweet sorghum syrup collected from JKUAT had the highest TFC (197.50 mg Quercitin acid equivalent (QAE) per 100 g of syrup), followed by sugar cane syrup-Rongo (115 mg QAE/100 g), while the sweet sorghum syrup from Rongo was the lowest

Table 4 The total phenolic, flavonoids and tanning contents in the syrups

Syrup type	Total phenolic content (mg GAE/100 g syrup)[a]	Total flavonoid content (mg QAE/100 g syrup)[b]
SS JKUAT	261.31 ± 3.3c	197.50 ± 5.2c
SS Rongo	184.70 ± 4.6a	75.62 ± 6.8a
SC Rongo	216.10 ± 6.2b	115.00 ± 5.14b
$LSD_{0.05}$	8.86	2.34

Data are expressed as mean ± standard error. Means followed by the same letter within each column are not significantly different from each other ($p \leq 0.05$)

[a] Data are expressed as mg Gallic acid equivalents (GAE) per 100 g of syrup

[b] Data are expressed as mg of Quercitin acid equivalent (QAE) per 100 g of syrup

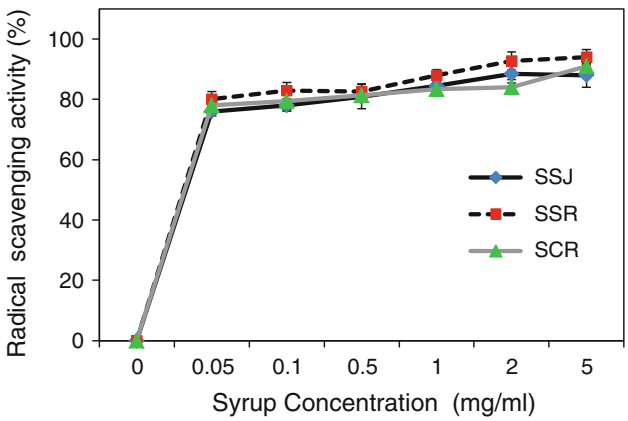

Fig. 1 DPPH radical scavenging activity at different concentration of the syrup samples

TFC at 75.62 mg QAE/100 g. Flavonoids have been described to possess-health promoting properties due to their peculiar chemical structures, as they are very reactive towards Reactive Oxygen Species (ROS) (Agati et al. 2012). The TPC and TFC were higher than those reported for honeys from South Africa (Serem and Bester 2012).

We investigated the free-radical scavenging activity (FRS) of syrup samples at different concentrations, using the DPPH assay and vitamin C (80 μg/ml) as the antioxidant standards. DPPH is a stable organic free radical and is widely used in assessment of antioxidant activity of various samples (Sharma and Bhat 2009). In the DPPH test, the antioxidants reduce the DPPH radical (diphenylpicrylhydrazyl, violet colour) to a yellow-coloured compound, diphenylpicrylhydrazine. The reduction capability of DPPH radical is determined by the decrease in absorbance at 517 nm induced by antioxidants, that can donate an electron or a hydrogen atom. The DPPH free radical scavenging capacity of the syrup samples is presented in Fig. 1 and indicates that the three syrup samples exhibited a potential free radical scavenging activity, capable of scavenging free radical in an amount-dependent manner as reported for date syrup (Abbès et al. 2013). Even at a dose of 0.05 mg/ml, the activity of the three samples ranged from 78 to 79 %, while at a dose 5 mg/ml, the scavenging effect of syrups with the DPPH radical was SSJ (93 %), SSR (96 %) and SCR (92 %). Since the scavenging activity was greater than 50 % even at low syrup concentrations, indicates that the sweet sorghum and sugarcane syrups are potent free radical-scavengers. Significant ($p < 0.05$) linear correlation was found between total phenolic content and DPPH radical scavenging activity ($R^2 = 0.9858$, data not shown). These findings suggest that total phenolic content may be important contributors to the DPPH radical scavenging capacity of both the sweet sorghum and sugarcane syrups.

This study revealed that sweet sorghum syrup can be produced cheaply, possesses physical and chemical attributes, and having significant high levels of antioxidant properties with therapeutic potential. There is need to quantify the specific phenolic compounds and confirm the antioxidant and anti-radical activities in living cells. There is also need to further investigate consumer insight, to understand the marketability of the SS syrup and identify other suitable varieties of sweet sorghum for food grade syrup production.

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