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Comparison of Physicochemical Characterization of Grain Flour from Different Sweet and Grain Sorghum Varieties

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Abstract: Worldwide interest about using sweet sorghum (*sorghum bicolor* L. Moench) as bio-fuel stock is booming and a little has been focused to it is grain flour composition, whereas sorghum is important for the economy of semiarid regions since it thrives and produces both grain and forage. Eight sweet sorghum and four grain sorghum were investigated for chemical composition and physico-chemical characterization. The result showed that amylose content for some sweet varieties was high (YT, 27.10%) as that of grain varieties (GL-1, 27.19%). Total phenolic content of most sweet varieties was high relative to the grain, whereas most of the grain varieties showed thick gel. Total starch showed significant variation among varieties with higher values obtained from sweet ones (80.20% GL-6 and 82.60% GL-13). For pasting properties all of sweet varieties clotted upper to the grain varieties in the RVA viscogram. Sweet varieties ranked lower for most of thermal properties than the grain varieties. Current result reflected that sweet varieties studied have prospective future for starch industries and generally characterized by low grain quality in respect to protein content. Among parameter studied protein content, pasting properties and thermal properties clearly exhibited different trends between sweet and grain varieties studied.

Key words: Sorghum, sweet sorghum, flour, amylose content, physico-chemical properties, grain quality.

1. Introduction

Sorghum (*Sorghum bicolor* L. Moench), the world's fourth major cereal in terms of production and fifth in acreage [1], is a staple food crop of millions of poor in semi-arid tropics (SAT) of the world. It is mostly grown as a subsistence dry land crop by resource limited farmers under traditional management conditions in SAT regions of the Africa, Asia and Latin America, which are frequently drought-prone and characterized by fragile environments [2]. The area planted to sorghum worldwide had increased by 66% over the past 50 years, while yield had increased by 244% [3].

Sorghum is classified to grain and sweet types according to application. The grain sorghum used as a principal food in tropical areas and often used as raw materials for alcoholic beverages, while the sweet type is used as a material for sweetener syrup. Sweet sorghum defined as any of the many varieties of the sorghum grass whose stalks have a high sugar content, it thrives better under drier and warmer conditions than many other crops and is grown primarily for forage, silage, and syrup production due to the high biomass and sugar content [4, 5].

Like other cereals, sorghum is rich in starch, a major storage form for carbohydrates, which makes up about 60%-80% of normal kernels and has excellent potential for industrial applications [6, 7]. Starch is composed almost entirely of the polysaccharides amylose and amylopectin. The physical arrangement of amylose and amylopectin and the interaction between starch molecules and other food components

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determine the physico-chemical and functional properties of starch and further affect the flour properties. These properties affect the quality of starch-based products and are essential to determine potential applications of starch [8]. Udachan et al. [2] mentioned that one way of using surplus sorghum is by way of producing starch and starch based sweeteners, the process is likely to be economical as sorghum is available on large scale with low cost. The sorghum starch is now considered excellent potential for global industrial applications as reported by Singh et al. [9]. Gelatinization process is very important in food processing and has been extensively studied in food science for decades [10-13], particularly with higher water content (1:2) [14]. Differential scanning calorimetric (DSC) is known as the most used technique to study thermal properties of the flour.

The second major component of sorghum grains is protein. Jambunathan and Subramanian [15] noticed in sorghum the variability of protein content is large (4.4% to 21.1%) besides the genetic factors, probably because the crop is grown under diverse agro-climatic conditions that affect the grain composition [16, 17].

The general definition of a phenolic compound is any compound containing a benzene ring with one or more hydroxyl group. All plant-based foods have phenols, which affect their appearance, taste, odor, and oxidative stability [18]. In general, the tannin sorghums had the highest levels of phenols and antioxidant activity [19].

Therefore, the present study was pursued to characterize physico-chemical and functional properties that affect the end use of the flour from twelve sorghum varieties. Among varieties invested, three were from Sudan, which are known as grain sorghum and used mainly for food; other eight sweet land races and a grain variety were from China, and they have other uses rather than food.

2. Materials and Methods

2.1 Materials

Twelve sorghum varieties from China and Sudan were used in this study (Table 1). Among them, eight are sweet type while four are grain type, and all were planted in the summer of 2013 in the experimental farm of Yangzhou University (32° N, 119° E) in Yangzhou, Jiangsu province, China, and the mature grains were harvested for following characterizations.

2.2 Methods

2.2.1 Flour Preparation and Amylose Content

Flour was prepared from decorticated sorghum grains by dry milling method [20]. Amylose content

Table 1 Different sweet and grain sorghum varieties used in current study.

Sample symbol	Origin name	Type	Place	Resource
WAH	Wad ahmed	Grain	Sudan	ACSP*
ARG	Arfa gadamak	Grain	Sudan	ACSP
TAT	Tabbat	Grain	Sudan	ACSP
GL-1	Bi nian gao liang	Grain	China	ICSCAAS **
GL-4	Huang nian	Sweet	China	ICSCAAS
GL-6	Beijing nian	Sweet	China	ICSCAAS
GL-13	Tian xuan 33	Sweet	China	ICSCAAS
GL-14	Tian xuan 184	Sweet	China	ICSCAAS
ZS	Zao shu	Sweet	China	Yancheng***
YT	Yan tian	Sweet	China	Yancheng
T-1	Tian nong1	Sweet	China	Yancheng
ST	St008	Sweet	China	Yancheng

* ACSP: Arab Company for Seed Production, Khartoum, Sudan.
** ICSCAAS, Institute of Crop Science, China Academy of Agricultural Sciences, Beijing, China.
*** Institute of Agricultural Sciences in coastal area of Jiangsu province, Yancheng, Jiangsu, 22400, China.

of flour was estimated by using the iodine blue value method as mentioned in Mohammadkhani et al. [21]. The sample (50 mg, dry weight basis, done in triplicate) was dissolved in 0.5 mL of anhydrous ethanol and 4.5 mL of 1N NaOH, in 50 mL vials. The contents of the vials were vigorously agitated and then heated in a boiling water bath for 20 min (with intermittent shaking). The vials were then cooled to ambient temperature. Distilled water was added up to volume, mixed gently and 5 mL was pipetted from each sample to opposite 100 mL volumetric flask containing distilled water. Sodium acetate (1.0 mL, 1N) and iodine solution (0.04%, 750 ul) were added respectively. Volumetric flask was shaken gently after the distilled water was added up to volume. After 15 min OD was measured at 620 nm (Ultrospec 2000, Pharmacia Biotech. Cambridge, England).

2.2.2 Crude Protein Content

Samples' protein content was measured according to AOAC [22], using Automatic kjeldahl instrument procedures (FOSS, Kejltec^{TM} 8400, Analyzer Unit, 2013, Sweden). For 1.0 g of sample two Teca Tuo catalytic film (equivalent to 7.0 g K_2SO_4 and 0.8 g Cu $SO_4.5H_2O$) and 12 mL of concentrated sulfuric acid were added. Then, the digestion was held at 420 °C for 1 h.

The vials were connected to instrument after being cooled for 15-20 min. The results (done in triplicate) were recorded (Crude protein (N% × 6.25)/10 and expressed in percentage.

2.2.3 Total Phenolic Content

Prussian blue method was used to estimate total phenolic content of the flour according to Gupta and Verma [23]. Sample prepared as follows, 250 mg of flour was extracted with 10 ml of anhydrous methanol and left at room temperature for overnight. Then, filtered with what man filter paper and make the volume up to 25 mL with anhydrous methanol. 0.1 mL of aliquot was taken and diluted within 60 mL of distilled water and 3.0 mL of 0.5 M FeCl3 in 0.1 N HCl and 3.0 mL of 0.008 M $K_3Fe(CN)_6$ were added respectively. Color was developed immediately after 10-15 min. The optical density of the above solution was measured at 720 nm. Phenolic content was calculated by using the following formula (Factor value in tannic acid (in mg/ mL) = 0.225).

2.2.4 Total Starch Content

Total starch content was determined following the reagent kit from Megazyme International, Ireland 2011, Ltd. A sample size of 100 mg (sieved and weighed accurately) was dissolved in 0.2 mL of ethanol (80% v/v) in a test tube and stirred on a vortex mixer. Immediately 3.0 mL of thermo stable α - amylase was added and incubated in boiling water bath for 6.0 min with vigorous stirring after 2, 4 and 6 min. Then, tubes were placed in 50 °C and 0.1 mL of amyloglucosidase was immediately added and stirred in vortex mixer and incubated at 50 °C for 30 min. After the incubation period, samples were then diluted to 100 mL with distilled water and 0.1 mL of the homogenized sample was added to 3.0 mL of the glucose determination reagent (GOPOD) and incubated for 20 min at 50 °C. The absorbance was immediately red at 510 nm against a reagent blank.

2.2.5 Pasting Properties of the Flour

The pasting properties were analyzed by using a Rapid Visco-Analyzer (RVA Tec Master, Newport Scientific, 1998, Australia). Approximately 25 mL distilled water was transferred into a canister and then 3.0 g of sample was added (corrected to compensate for 14% moisture basis). The sample was heated to 50 °C and stirred for 10 sec for thorough dispersion. The time temperature profile was: held for 1 min at 50 °C, then heated to 95 °C in 7.3 min, held at 95 °C for 5 min, cooled to 50 °C in 7.7 min and finally held at 50 °C for 4 min. The rotating speed of the paddle was 160 rpm according to Sang et al. [24].

2.2.6 Gel Consistency of the Flour

Gel consistency was measured by modifying a procedure described in Cagampang et al. [25]. The modified procedure consisted of combining 100 mg of refined flour with 0.2 mL of Thymol blue indicator

(0.025%) in 12 cm × 13.35 mm culture tubes and oscillated in Vortex Genie 2 (Scientific industries, INC, USA). Then, 2.0 ml of KOH (0.2 N) was added and the tubes oscillated again. Firstly the mixture was cooked in a vigorously boiling water bath (101 °C) for 8 min. After cooking, the tubes were allowed to cool in room temperature for 5 min. The mixture was then placed in ice water in an upright position to cool for 20 min. After cooling, the tubes were placed horizontally over ruled logarithmic paper for 1hr at room temperature (25 °C ± 2 °C) and the gel front migration were red to the nearest millimeter. The experiment was done in triplicate.

2.2.7 Thermal Properties of the Flour

DSC has proven to be an extremely valuable tool to quantify the gelatinization process and has been widely used to study the thermal behaviors of different samples [26-29]. Thermal properties of samples were determined by using a differential scanning calorimeter (DSC 200F3, Netzsch company, Germany) for investigating thermal properties of the flour. The samples (5.0 mg) with excess water (1:2) were heated at 10 °C/min from 20 °C to 120 °C. Thermal transitions of samples for gelatinization were characterized by To (onset temperature), Tp (peak temperature), Tc (conclusion temperature), and ΔH (J/g) (enthalpy of gelatinization). The enthalpy calculations were based on dry flour weight. The samples were analyzed twice, and the data were calculated with software package (DSC 200F3, Netzsch Company, Germany) [30].

2.2.8 Statistical Analysis

Data were analyzed using Analysis of Variance (ANOVA) procedures of the SPSS version 16.0. Variances were considered at a significant level of 95% ($P < 0.05$). Means were compared using Duncan's multiple range test (DMRT). Cluster analysis was done for the RVA and DSC data to investigate the grouping of the varieties using SPSS version 16.0 and cluster analysis was done using Euclidean distance and Ward's clustering algorithm. Correlations between different parameters were pursued using SPSS version 16.0.

3. Results and Discussions

3.1 Diversity of Flour Compositions among Different Varieties

Starch and protein are among the many important ingredients used in food manufacture. The total starch content showed range from 40.40% to (82.60%) as in Table 2, which was quite different among varieties and seems significantly lower in grain-type varieties than sweet varieties (Fig. 1a). The amylose content (AC) of flour was diverse among 12 sorghum varieties. The grain variety GL-1 showed highest AC (27.19%) followed by YT a sweet variety (27.01%), whereas sweet varieties GL-4 and GL-6 showed the lowest AC (6.07% and 5.18%, respectively). Fig. 1b shows no significant difference ($P < 0.05$) was noticed between sweet and grain varieties for AC. The crude protein content was shown in Table 2, and its range was from 7.60% (GL-14) to 15.14% (GL-1). Grain varieties showed range from 9.76% to 15.14% with three of four had values over 14.00% which exhibited significant differences ($P < 0.05$) from the fourth one (TAT, 9.76%). For sweet varieties the range was from 7.60% (GL-14) to 12.05% (GL-4) with three of eight had values lower than 10.00% and significant differences (P < 0.05) were observed between individuals. Grain varieties showed protein content almost higher than that of sweet varieties as shown in Fig. 1c.

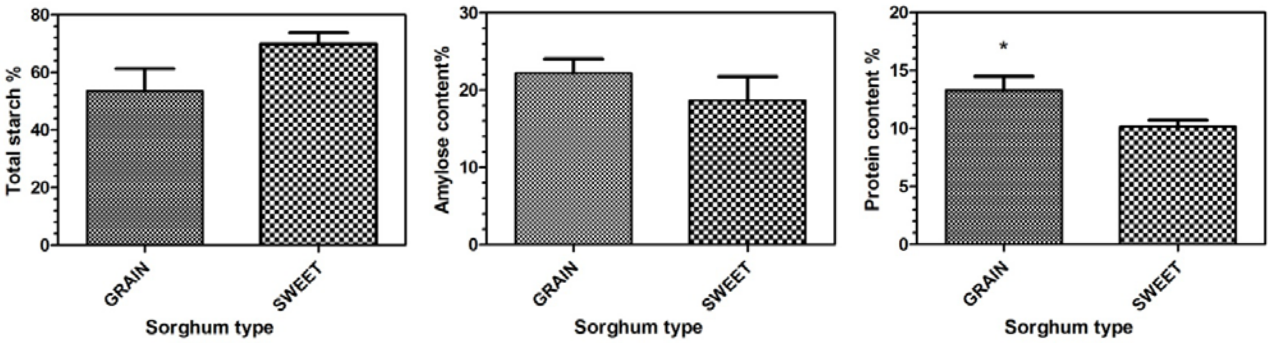
Total phenolic content was from 0.18% to 0.30% (Table 2). Varieties described as grain type had phenolic content ranged from 0.18% to 0.28% with two of four had values 0.25% which were significantly different from the higher and lower values. For those described as sweet the range was from 0.18% to 0.30% with seven of eight varieties had values over 0.20% and two of eight had values above 0.25%. Grain varieties exhibited values slightly lower from that of sweet varieties.

Table 2 Main composition of flour and gel consistency for different sweet and grain sorghum varieties.

Sample number	Amylose content (%)	Crude protein content (%)	Total phenolic content (%)	Total starch content (%)	GC (mm)
Grain					
GL-1	27.19 ± 0.36^{a}	15.14 ± 0.02^{a}	0.18 ±±0.003^{e}	52.50 ± 0.40^{f}	25.5 ± 0.05^{h}
WAH	20.45 ± 0.16^{d}	14.03 ± 0.10^{a}	0.28 ± 0.005^{ab}	45.70 ± 0.55^{g}	52.5 ± 0.25^{e}
ARG	18.68 ± 0.16^{e}	14.25 ± 0.11^{a}	0.25 ± 0.003^{bc}	75.60 ± 0.55^{bcd}	31.5 ± 0.05^{g}
TAT	22.49 ± 0.64^{c}	9.76 ± 0.02^{de}	0.25 ± 0.002^{bc}	40.40 ± 1.35^{h}	85.5 ± 0.05^{c}
Sweet					
GL-4	6.07 ± 0.28^{g}	12.05 ± 0.04^{b}	0.30 ± 0.001^{a}	59.40 ± 0.75^{e}	96.0 ± 0.1^{b}
GL-6	5.18 ± 0.32^{g}	11.68 ± 0.02^{bc}	0.18 ± 0.003^{e}	80.20 ± 1.47^{ab}	104.5 ± 0.05^{a}
GL-13	25.00 ± 0.77^{b}	10.37 ± 0.06^{cd}	0.24 ± 0.002^{cd}	82.60 ± 0.51^{a}	55.0 ± 0.0^{e}
GL-14	23.68 ± 0.20^{bc}	7.60 ± 0.94^{f}	0.21 ± 0.004^{de}	50.90 ± 0.63^{f}	44.5 ± 0.05^{f}
ZS	24.00 ± 0.08^{bc}	10.23 ± 0.01^{cde}	0.24 ± 0.004^{cd}	77.50 ± 0.67^{bc}	29.5 ± 0.05^{gh}
YT	27.01 ± 0.53^{a}	8.71 ± 0.04^{ef}	0.23 ± 0.001^{cd}	61.70 ± 0.75^{e}	41.5 ± 0.05^{f}
T-1	22.74 ± 0.16^{c}	9.25 ± 0.06$^{d}{}_{e}$	0.30 ± 0.004^{a}	72.70 ± 0.67^{d}	39.5 ± 0.05^{f}
ST	15.87 ± 0.06^{f}	11.46 ± 0.04^{bc}	0.25 ± 0.002^{bc}	74.00 ± 0.99^{cd}	62.0 ± 0.20^{d}
SEM	2.13	0.67	0.01	4.19	7.64

-All data represent the mean of two or three determinations.

-Means with the same subscript in each column are not significantly different (P < 0.05).



(a) (b) (c)

Fig. 1 Comparison (a) total starch (b) amylose content (c) protein content between sweet and grain sorghum varieties.* Significant (P < 0.05) was noticed.

Gel consistency values showed range from 25.5 mm to 104.5 mm (Table 2). The range for grain varieties was from 25.5 mm to 85.5 mm, whereas for sweet varieties was from 29.5 mm to 104.5 mm. GL-1 variety had high AC, which ranked second top among grain varieties for GC value. GL-4 and GL-6 varieties had the lowest AC among all varieties, showed highest GC values. GL-13 showed high AC and also ranked third top among all varieties studied. The values and the ranges of GC for sweet varieties were mostly higher than grain varieties.

As reported previously amylose content could play a major role to swelling, pasting properties and gel firmness of starch [31]. The results for AC, in current study almost revealed accordance with that reported in Wonga et al. [32] who summarized from their study with 18 sorghum lines that AC was from 5.70%-31.90%, whereas for current study was from 5.18% to 27.19%. For PC almost similar observations for range have been noticed in Lasztity [33] and Normella et al. [34], they reported that sorghum grain has protein content varying from 6.0% to 18.0%, with an average of 11.0%; Wonga et al. [32] reported that from 10.0% to 15.0%; Hill et al. [35] mentioned that protein content had range from 10.0% to 19.3%, which a little higher than the current study (7.6%-15.14%) as they used 55 different accessions almost from worldwide. For starch content similar observations (with a little difference) have been reported by other scientists: Singh et al. [9] reported that sorghum starch content approximately 70.0%; Elkhalifa et al. [7] concluded from their study that sorghum starch making up about 60.0%-80.0% of the kernels; Jambunathan et al. [15] reported the starch content of sorghum ranged from 56.0% to 73.0%; Hill et al. [35]; Subramanian et al. [36]; Shinde [37] noticed total starch from 59.0% to 72.5% with a average of 65.7%; Kigozi et al. [38] reported that from 53.7%-76.2% and Wong et al. [32] reported that from 47.9%-80.9%, which relatively closed to the range in current study (40.4%-82.6%). Singh et al. [39] mentioned that sorghum grain starch depending upon cultivar, region and climatic conditions. Therefore, the current results are in accordance with that reported previously and discrepancies appeared maybe due to different region and different varieties used. Grain varieties starch content about one out of four showed value over the average 68.6% (summarized from all previous studies), whereas sweet varieties five out of eight varieties showed value over the average. Previous study was done by Bhoyar and Thakare [5] who noticed that starch content for sweet sorghum ranged from 64.0% to 72.5%, a little different from current study, which the range for sweet varieties was from 50.9% to 82.6%. These clarified the existence of wide diversity among sweet varieties. For GC previous observations have been reported in Chandrashekar and Kirleis [14] who mentioned that the range was from 40-110 mm; Elkhalifa and Bernhardt [40] reported that from 55 mm to 145 mm; Murty et al. [41] found from 24 non waxy cultivars that average gel spread was from 56.0 mm to 73.0 mm and mentioned that waxy grain samples gels spread beyond 100.0 mm. For current study was from 25.0 mm to 104.0 mm. Differences clarified that gel spread absolutely depending on cultivars.

3.2 Difference of Pasting and Thermal Properties among Varieties

3.2.1 Viscosity of the Flour

The viscosity of sorghum flours were obtained and calculated from the pasting curve, using Thermo cline for Window version 1.1 software for the Rapid Visco Analyzer. As shown in Fig. 2, sweet varieties clotted in three groups (GL-4 and GL-6; GL-13, GL-14 and YT; ST, ZS and T-1), whereas grain varieties clotted

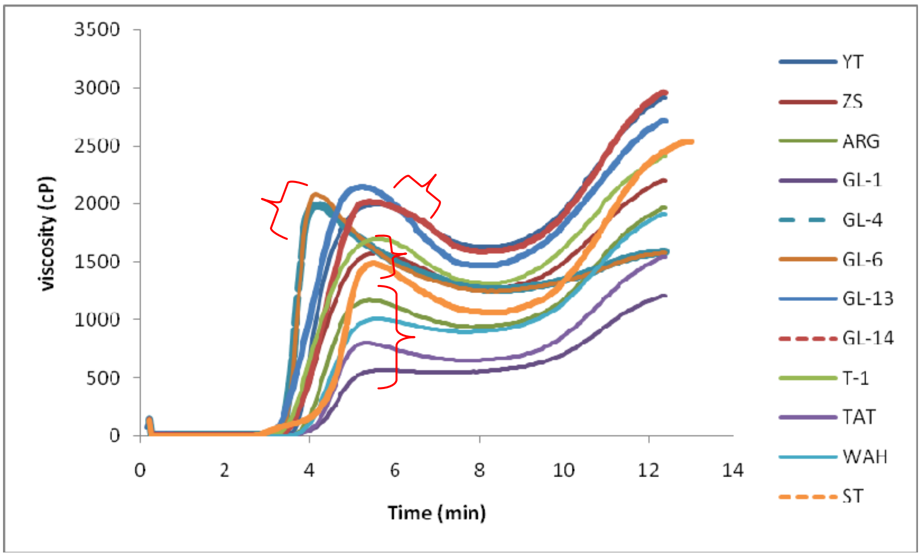


Fig. 2 RVA profile (viscogram) for different sweet and grain sorghum flour.
cP: centipoises.

in one group and ranked lower in the viscogram for most of the RVA parameters. Table 3 shows that peak viscosity (PV) showed range from 569.0 centipoise (cP) (GL-1) to 2,143.0 cP (GL-13). Grain varieties range was from 569.0 cP to 1,168.0 cP for GL-1 and ARG, respectively, whereas sweet varieties ranged from 1,484.0 cP to 2,143.0 cP for ST and GL-13 respectively, which exhibited higher values than grain varieties as noticed in Fig. 3a. PV is related to the degree of swelling of granule during heating and the starch with higher swelling capacity causes the higher PV as reported previously by Ragaee and Abdel-Aal [42]. Therefore, we concluded that sweet varieties had higher swelling capacity as they showed higher PV than grain one (Figs. 2 and 3a).

Grain varieties showed Breakdown (BD) range from 23.0 for GL-1 to 227.0 for ARG, whereas sweet varieties range was from 307.0 (ZS) to 837.0 (GL-6). BD is the measure of the vulnerability or susceptibility of the cooked sample to disintegration. Higher BD in viscosity indicates the lower of the ability of the sample to withstand heating and shear stress during cooking. Obviously, sweet varieties showed BD higher from grain ones (Fig. 3b) which indicated decreasing in their ability to withstand shear conditions.

Peak temperature (PT) exhibited range from 76.5 °C to 89.4 °C for GL-13 and GL-1, respectively. The lowest value for PT among grain varieties (83.7 °C for ARG) ranked higher than seven of eight of sweet varieties. Fig. 3c shows that grain varieties PT are significantly higher from sweet varieties. Peak time (Pt) for all varieties showed range from 4.1 min to 5.8 min for GL-6 and GL-1, respectively (Table 3). The Pt means of sweet varieties (5.13 min) are slightly lower than grain varieties (5.53 min).

Set back (SB) showed range from 405.0 cP to 1475.0 cP for GL-4 and ST, respectively. SB for grain varieties ranged from 638.0 cP to 904.0 cP, whereas for sweet varieties ranged from 405.0 cP to 1475.0 cP. Three of eight of sweet varieties showed SB values are higher than the highest value of grain varieties (904.0 cP for WAH). SB is a measure of re-crystallization during cooling after gelatinization. Thus, high setback values shown from grain and some sweet varieties indicate their ability of re-crystallized after cooking and cooling which correlated with high AC noticed from them.

The range for final viscosity (FV) was from 1,207.0 cP to 2,963.0 cP and clearly sweet varieties showed significant difference ($P < 0.05$) from grain varieties (Fig. 3d). The ability to form viscous paste seems better

Table 3 RVA measurements of the flour from different sweet and grain sorghum varieties.

Sample	PV/cP	BD/cP	FV/cP	SB/cP	Pt/min	PT/°C
Grain						
GL-1	569.0	23.0	1,207.0	638.0	5.80	89.40
WAH	1,008.0	114.0	1,912.0	904.0	5.60	85.35
ARG	1,168.0	227.0	1,962.0	794.0	5.40	83.70
TAT	799.0	149.0	1,542.0	743.0	5.33	87.80
Sweet						
GL-4	1,988.0	727.0	1,583.0	-405.0	4.27	77.30
GL-6	2,085.0	837.0	1,574.0	-511.0	4.13	78.15
GL-13	2,143.0	676.0	2,716.0	573.0	5.20	76.55
GL-14	2,017.0	427.0	2,963.0	946.0	5.40	79.70
ZS	1,574.0	307.0	2,204.0	630.0	5.53	80.50
YT	1,995.0	365.0	2,913.0	918.0	5.53	81.25
T-1	1,698.0	383.0	2,405.0	707.0	5.60	78.95
ST	1,484.0	421.0	2,538.0	1,475.0	5.47	87.45

-PT: pasting temperature; PV: peak viscosity; FV: final viscosity; BD: breakdown viscosity; SB: setback viscosity; Pt: peak time; cP: centipoise.

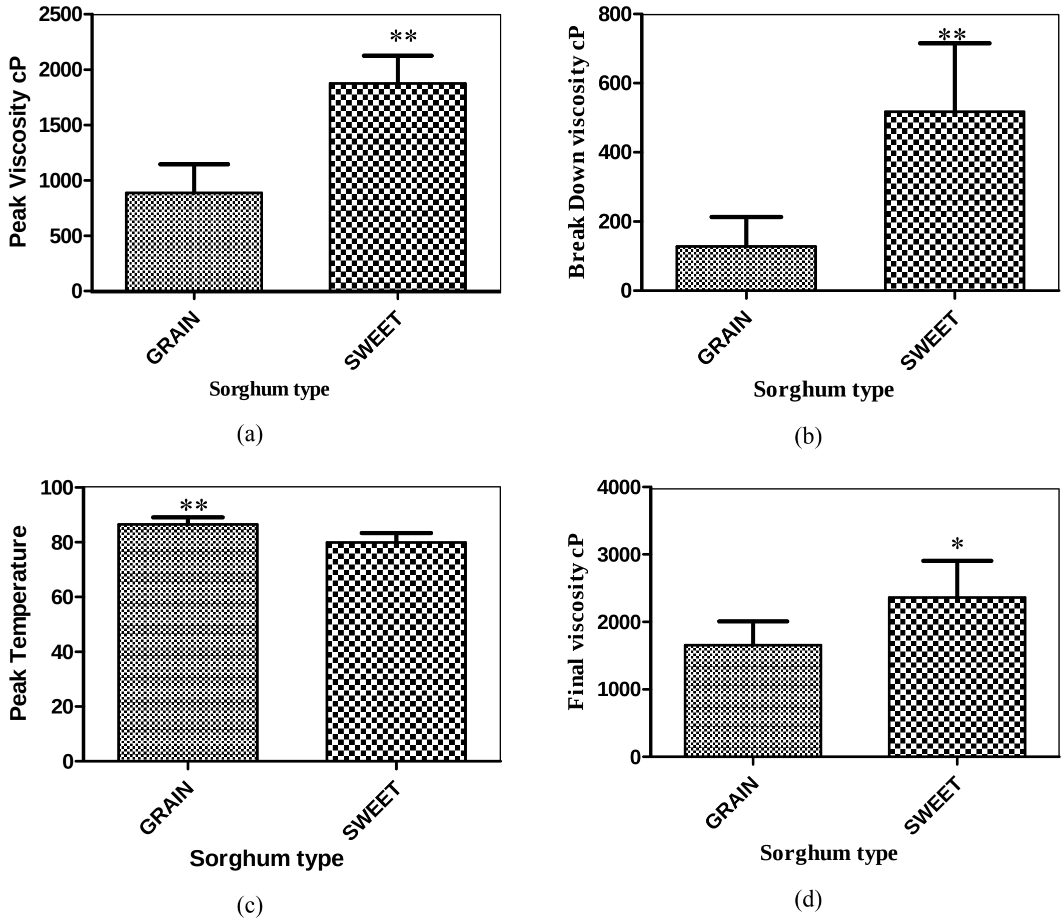


Fig. 3 Comparison (a) peak viscosity (b) break down viscosity (c) peak temperature (°C) (d) final viscosity between sweet and grain sorghum flour. * Significant difference (*P* < 0.05) was noticed. ** High significant difference (*P* < 0.01) was noticed.

Table 4 Comparison of the RVA measurements range between current study and other previous studies.

	PV/cP	FV/cP	BD/cP	SB/cP	PT/ºC	Pt/min
Current study	549-2,143	1,207-2,963	23-837	405-1,475	76.5-89.4	4.1-5.8
Kigozi et al. (2013)	1,331-2,976	2,495-4,172	82-715	1,245-2,342	75.13-90.6	5.57-6.13
Shewayrga et al. (2011)	175-1,001	452-2,037	-3-175	211-970	63.2-89.2	5.2-6.9
Hill et al. (2012) *RVU*	257-523	205-641	66.8-307	48-398	71.9-93.6	3.6-6.0

1 *RVU* (rapid visco unit) = 12 cP (centipoises).

from sweet varieties as FV indicates the ability of the material to form a viscous paste or gel after cooking and cooling.

Varietal differences for RVA measurements had been noticed with that of Shewayrga et al. [43]; Hill et al. [35]; Kigozi et al. [38] as shown in Table 4 and the differences noticed probably due to that they investigated different varieties as well as existence of wide diversity for sorghum flour viscoelasticity. Differences in pasting characteristics of sweet and grain samples can be attributed to the amylopectin molecular structure as well as existence of limited branching in amylose.

3.2.2 Thermal Properties of the Flour

The DSC properties of the flour were shown in Table 5. In general, the sweet varieties ranked lower for To, Tp and Tc compared to the most of grain varieties, whereas for ΔH showed higher values. Sweet varieties exhibited lowest AC (GL-4 and GL-6), showed To, Tp and Tc relatively high and the highest

ΔH noticed from them.

Quantifying gelatinization characteristics of food is very relevant in food processing because it allows simulation of the cooking process for improved functional properties [44, 45]. The current range for To (60.25 °C -75.0 °C) was a little higher than that of Udachan et al. [2] for their study in four sorghum cultivars (64 °C-68 °C). Ji et al. [46] mentioned that the To of gelatinization would be a measure of the perfection of starch crystallites, and the more perfect crystallites, the higher To. Thus, sweet varieties in current study relatively exhibited less perfect crystallites compared with grain varieties. The slightly lower values showed from some sweet varieties for To, Tp and Tc may due to lower values for AC. This finding in agreement with that of Hermansson and Svegmark [12] found that amylose tends to act as a restraint to gelatinization. On the other hand the relatively higher To of some sweet varieties with low AC showed from them, was comparable with that found in Gaffa et al. [47] who attributed that due to high amylopectin content, the branches prevent the degree of association for gel formation.

3.3 Correlations Analysis

Table 6 shows the correlations among 12 sorghum varieties studied for different parameters. The results showed that AC revealed negative correlation with

Table 5 Thermal properties of the flour from different sweet and grain sorghum varieties.

Sample	To (°C)	Tp (°C)	Tc (°C)	ΔH (J/g)
Grain				
GL-1	75 ± 0.0^{a}	79.45 ± 0.05^{a}	85.6 ± 0.0^{a}	6.27 ± 0.16^{ef}
WAH	72.75 ± 0.45^{c}	77.05 ± 0.15^{d}	84.45 ± 0.15^{bc}	7.78 ± 0.31^{cd}
ARG	73.65 ± 0.15^{b}	77.75 ± 0.15^{c}	84.25 ± 0.35^{bc}	7.54 ± 0.30^{cde}
TAT	73.45 ± 0.05^{bc}	77.5 ± 0.0^{cd}	85.1 ± 0.1^{ab}	7.98 ± 0.05^{cd}
Sweet				
GL-4	71.3 ± 0.0^{d}	77.2 ± 0.0^{cd}	83.9 ± 0.3^{c}	10.415 ± 0.2^{ab}
GL-6	72.7 ± 0.0^{c}	77.2 ± 0.0^{cd}	83.9 ± 0.1^{c}	10.66 ± 0.34^{ab}
GL-13	69.05 ± 0.05^{e}	73.55 ± 0.15^{f}	80.85 ± 0.15^{e}	7.001 ± 0.31^{de}
GL-14	71.4 ± 0.1^{d}	75.40 ± 0.1^{e}	81.65 ± 0.05^{d}	7.47 ± 0.15^{cde}
ZS	67.85 ± 0.05^{f}	73.0 ± 0.1^{f}	79.6 ± 0.0^{e}	7.56 ± 0.01^{cde}
YT	74.6 ± 0.0^{a}	78.65 ± 0.05^{b}	84.4 ± 0.2b^{c}	9.36 ± 0.11^{ab}
T-1	70.9 ± 0.0^{d}	75.25 ± 0.15^{e}	81.55 ± 0.15^{d}	8.47 ± 0.35^{bc}
ST	60.25 ± 0.15^{g}	68.5 ± 0.20^{g}	77.0 ± 0.10^{f}	5.40 ± 0.09^{f}

-All data represent the mean of two determinations.

-Means with the same subscript in each column are not significantly different ($P < 0.05$).

-To, Tp, Tc: Onset, peak and conclusion temperatures respectively; ΔH: Enthalpy of gelatinization.

Table 6 Correlations among different sweet and grain varieties for different parameters studied.

	AC	PC	TST	PHC	GC	PV	To	ΔH
AC	1.0							
PC	-0.221	1.0						
TST	-0.233	-0.037	1.0					
PHC	-0.244	0.092	-0.063	1.0				
GC	-0.797**	-0.076	-0.056	0.152	1.0			
PV	-0.320	-0.605*	0.531	-0.064	0.295	1.0		
To	0.157	0.174	-0.436	-0.296	-0.051	-0.366	1.0	
ΔH	-0.572	-0.182	0.034	0.003	0.587*	0.484	0.476	1.0

AC: Amylose content; GC: Gel consistency; To: Onset temperature; ΔH: enthalpy of gelatinization; PV: Peak viscosity; TST: total starch; PC: Protein content.

* Correlation is significant ($P < 0.05$). ** Correlation is high significant ($P < 0.01$).

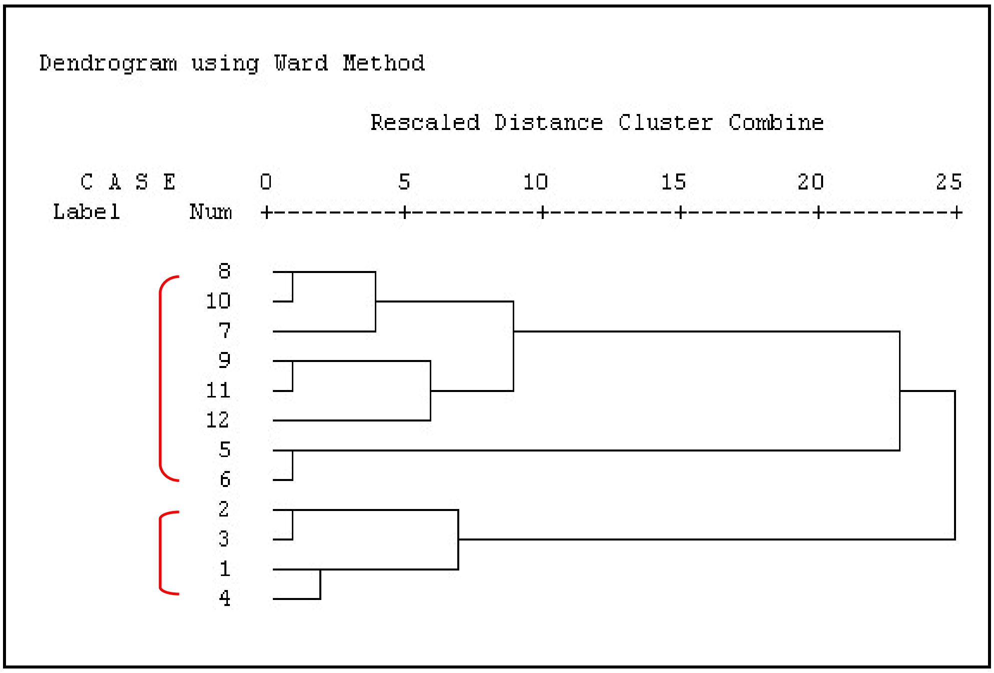


Fig. 4 Cluster diagrams of RVA and DSC measurements for different sweet and grain sorghum varieties for the flour. Sweet varieties: 5-12 (GL-4, GL-6, GL-13, GL-14, ZS, YT, T-1 and ST, respectively), Grain varieties: 1-4 (GL-1, WAH, ARG and TAT, respectively).

GC (-0.797). PV revealed negative correlation with AC and PC (-0.320 and -0.605, respectively). Similar trends had been observed by Shewayrga et al. [43] who noticed that most of the viscosity parameters positively correlated with starch content, but negatively correlated with protein content. ΔH correlated positively with GC (0.587). On the other hand negatively correlated with AC (-0.572). This is in relevant with that mentioned in Bao et al. [44] who notice that AC exhibited negative correlation with ΔH in their study for rice (-0.417**).

3.4 Cluster Analysis

The function of clustering programs is for summarizing data in grouping using various similarity and dissimilarity of measurements widening their uses for data analysis. In current study, the cluster analysis separated varieties, according to physico-chemical measurements like RVA and DSC, into two distinct main groups, and each group had sub-groups as shown in Fig. 4. All grain varieties located in the one of the two main groups, whereas sweet varieties located in the other one and divided into another two main groups. Clearly, it can be concluded that the possibility of those measurements to be used was as fingerprint for classification of sweet and grain sorghum varieties.

4. Conclusions

From the above mentioned data it can be concluded that grain varieties characterized by high protein content, a little bite lower phenolic content and intermediate starch content which make them better for edible purpose. On the other hand, sweet varieties characterized by low protein content, high phenolic content and higher starch content, which make them with prospective future for starch industries as sorghum is well known as low-cost production crop. The protein content has impact beside amylose content for affecting gel spreading. Some sweet varieties reflect grain varieties trends which indicate their ability to use for food and starch industries. All grain sorghum in current study showed higher AC, but sweet sorghum varied from relatively high and low AC which seems to have substantial role in the other physio-chemical and functional properties noticed from them. Pasting properties are a key to understanding the physical properties and potential utilization of sorghum.

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