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Physicochemical and functional properties determination of flour, unmodified starch and acid-modified starch of Philippine-grown sorghum (*Sorghum bicolor* L. Moench)

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Abstract

Three products were made from Philippine grown sorghum (*Sorghum bicolor* L. Moench) grains namely: flour, unmodified starch and acid-modified starch. The physicochemical and functional properties of the three products were studied using standard methods. Results showed that the chemical properties of Philippine made sorghum flour were within the limits set by Codex Standard 173-1989 for sorghum flour prodcution. The sorghum starch (unmodified and acid-modified) produced in this study also had higher amounts of ash, fat, protein and fiber content in comparison to rice, corn and cassava starches. In terms of color, the lightness of the Philippine sorghum flour and starch (86-92 L^*value) were comparable to rice and corn while cassava flour and starch products were the lightest. The functional properties of sorghum flour and starch showed desirable attributes with amylose content of 25.7–26.30%(db) for flour and 31.5–32.8%(db) for starch. Water absorption capacities of flour and starch were 145% and 96–103%, respectively.The swelling capacity (2–6%) and solubility (1–3%) were minimal. The pasting profile of the three products were significantly different from each other with unmodified sorghum starch having very high peak, trough and final viscosities while the acid-modified starch showed the least values and the sorghum flour being the middle of the two. The gelatinization temperature range of sorghum flour was found to be 63˚C – 77˚C while sorghum starch was in the range of 61˚C - 71˚C. The scanning electron microscopy (SEM) of sorghum flour and starch granules showed that acid-modification can affect the granule structure producing various cracks and disruptions that would have affected the pasting profile of the products. The present findings suggest that the three products have different potential applications and are suitable for making sauces, thickeners and pastries.

Introduction

Sorghum (*Sorghum bicolor* L. Moench) is a tropical plant belonging to the family Poaceae, and is considered to be one of the most important crop in Africa, Asia and Latin America (Dicko *et al*., 2006). It is grown in semi-arid tropical and sub-tropical regions. Certain varieties of sorghum contain “stay green” genes that make the plant perform photosynthesis permanently and adapt to drought prone areas which are too dry for other cereal crops (Lochte-Watson *et al*., 2000; Dicko *et al*., 2006; Belhadi *et al*., 2013 and Lazaro *et al*., 2014). Sorghum is a drought-tolerant cereal grain crop and only requires little input during growth. In the USA, sorghum is primarily used as animal fodder and ethanol production (Kulamarva *et al*., 2009). However, it is considered staple food for most food insecure people in the developing world, especially in the drier and more marginal areas in the sub-tropics (Elkhalifa *et al*., 2005; Kulamarva *et al*., 2009). Thus, it can be a vital crop to address food security (Taylor *et al*., 2006). Sorghum grain is one of the top 5 cultivated and consumed cereal grains of the world (Awika, 2011).

The Philippines rapidly increasing population and decreasing rural areas for food cultivation added with the natural disasters such as typhoons, floods and droughts have led to an increase interest in finding alternative food and carbohydrate source. According to the 2015 report of USDA by Corpuz and Albanese on grain and feed consumption, the country is a major importer of wheat, both foreign and locally milled with an annual demand of 4.0 million tons/year. The country also imports approximately 2 million tons of milled rice to augment the demand. Hence, the food and carbohydrate source production of the

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Philippines simply cannot keep up with the growing population. The production of the sorghum grains exceed the yield/hectare/year of rice since it can be planted in 3 cropping seasons as compared to rice's 2 cropping seasons. Sorghum is also suitable for human consumption and the grain can be processed into flour and starch (Reddy *et al*., 2011).

In 2005, improved varieties of sorghum grain were introduced by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in the Philippines in coordination with the Department of Science and Technology (DOST) and Department of Agriculture (DA). Five varieties were found suitable for planting in the country and were used to reinforce the Biofuels Act of 2006 (Philippine Republic Act 9367). Along with the increase in planting hectares of sorghum stalks for bioethanol a concurrent increase in sorghum grain production was observed. Only one out of five of the sorghum varieties introduced is currently commercialized for food and feed, the variety is called SPV-422.

Sorghum grain utilization into flour and starch will provide useful information for industry purpose and future Philippine product development. Sorghum has been studied in many food products like breads (Schober *et al*., 2005; Schober *et al*., 2007), tortilla chips (Rooney and Waniska, 2000), tortilla (Winger *et al.*, 2014), cookies (Ferreira *et al*., 2009), chicken nuggets (Devatkal *et a*l., 2011) and noodles (Liu *et al.*, 2012).

Besides the use of flour and unmodified starch, physical and chemical modification methods can be employed to explore other suitable uses of sorghum starch. Example of physical methods are heat-moisture treatment and annealing while chemical modification includes oxidation, acid thinning, hydroxypropylationand acetylation, dextrinization, enzyme treatment and etc (Okunlola and Akingbala, 2013).One of the simplest and cost effective way (cheap and does not require large capital outlay) of starch modification is acid-thinning. It has been employed in most types of cereal grains and raw materials with high amounts of starch. Studies on sorghum starch acid modification have also been explored in other countries especially in India where sorghum is a staple (Zhu, 2014). However, the Philippines lack the data on the crop since it has only been recently re-introduced in the country and published articles regarding the crop are limited.

One of the benefits of sorghum is that it can be recommended for celiac patients because it is gluten free and is distantly related to wheat, rye and barley (Taylor *et al.*, 2006). Celiac disease is an immunological response to gluten intolerance (Kulamarva *et al*., 2009). It is a syndrome characterized by the damage in the mucosa in the small intestine due to the ingestion of certain wheat proteins from wheat, rye and barley (Fasano and Catassi, 2001; Taylor *et al*., 2006). The treatment of celiac disease is total avoidance of gluten ingestion (Kasarda, 2001; Taylor *et al.*, 2006).

Sorghum grain utilization is based on starch and protein content, after bran removal. The bran is low-value, high fiber co-product which is discarded or used for animal feed. During flour production, bran may be removed by decortication processes (Lochte-Watson *et al*., 2000). Sorghum grains that are intended for human consumption must be dehulled to remove the seed coat. Dehulling is a crucial process because the seed coat contains high crude fiber and pigments as well as anti-nutritionals like tannins and phytic acid (Lazaro *et al*., 2014).

Studies on flour and starch obtained from Philippine grown sorghum grains may have varying functional properties when compared to sorghum varieties of other countries; hence, better understanding and knowledge on its proper use for Philippine consumption is needed. The study aimed to characterize Philippine made sorghum flour and sorghum starch (unmodified and acid-modified) in terms of chemical composition (moisture, ash, protein, fat, dietary fiber, amylose content and carbohydrate computation by difference), physical (color, water activity and starch granule structure) and functional properties (water absorption, pasting, gelatinization, swelling and solubility). The utilization of sorghum into food products will provide not only livelihood opportunities for the Filipinos but it will also address the country's food security concerns.

Materials and methods

Materials

Sweet sorghum grains (*Sorghum bicolor* L. Moench) of the SPV-422 variety introduced by the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) and grown in the Philippines were obtained from BAPAMIN Enterprises, Inc. in Batac, Ilocos Norte. The grains were processed into sorghum flour and starch (unmodified and acid-modified) in the Food Processing Facility of the Food and Nutrition Research Institute – Department of Science and Technology. All chemical reagents used were of analytical grade.

Production of sorghum flour

Sorghum flour was prepared by boiling the whole sorghum grains in water for 5 mins. The grains were drained and dried in a fluidized bed dryer (15 HP Fan Motor 3-Phase, Steam-heated, Australia) for 5 mins at 90°C. The dried grains were dehulled using grain dehuller equipment (6N-80, Q/20715618-42, Leshan San Yuan Electrical Machinery Factory, Sichuan, China) and milled in the Hammer Mill equipment (Dynamics Development Trade and General Services, Inc., Caloocan, Philippines). The milled flour was sifted in a Vibroscreen separator (Kason Vibroscreen Separator Serial No. 76487 Model K24-4-SS; Separation Engineers Pty. Ltd, Sydney Australia) using 60–mesh.

Production of sorghum starch

Sorghum starch was obtained using the modified alkaline steeping method of Sira and Amaiz (2004). Sorghum flour (60–Mesh) was steeped in 0.25% sodium hydroxide solution overnight (1 part sorghum flour: 2 parts soaking solution) at room temperature. The mixture was added with water at 1 part mixture: 2 parts water prior to extraction of starch using high speed grinder-separator (M-18, Patent #86719.152569, China). The process of extraction was repeated thrice. The homogenate was passed thru 100–Mesh (once) and 200–Mesh sieves (twice) prior to starch settling. The extracted starch was washed thrice at 1 part sorghum flour weight: 20 parts water. Finally, the starch was dried in a drying oven at 55°C for 20hrs or until 7–10% moisture content was reached. The obtained starch was ground and sieved using 100–Mesh starch.

Production of modified sorghum starch

Acid-modified starch was produced using the method of Wang and Wang (2001). The sorghum starch was soaked in 0.14M hydrochloric acid and heated at 50°C for 8hrs. The starch and soaking solution ratio was 1:2. After heating, the mixture was adjusted to pH 5.5 with 1M sodium hydroxide and washed thrice with 2 times water. After settling the starch was dried in a drying oven at 55°C for 20hrs or until 7–10% moisture content was reached.

Chemical analyses

Chemical analyses of sorghum flour and starch (unmodified and acid-modified) were determined using AOAC methods. The following analyses were performed: moisture content (AOAC 925.10), crude ash/minerals (AOAC 923.03), crude fat (AOAC 920.39) (Ether extraction/Soxhlet method), total dietary fiber (AOAC 9991.43) (modified) and total sugars (AOAC 968.28). Total carbohydrate was computed by difference and expressed as, Total Carbohydrate = {100 – (Moisture + Ash + Protein + Fat)}. All measurements were done in duplicates.

Physical analyses

Color analysis

The color of sorghum flour and starch (Mesh 60) were determined using a chromameter (Konica Minolta CR 400 Chroma meter; Tokyo, Japan) based on the Hunter system identifying 3 attributes: L (black = 0, white = 100), a (red = positive value, green = negative value) and b (yellow = positive value, blue = negative value).All measurements were done in triplicates.The illuminant was D65, while the observer was 2° [Closely matches CIE 1931 Standard Observer ($\bar{x}2\lambda$, $\bar{y}\lambda$, $\bar{z}\lambda$)].The color difference (ΔE), a measure of the distance in colour space between two colours, was determined by comparison to a white standard tile with colorimeter values of *L* = 94.5; a = -1.0 and b = 0.2, using the following relationship:

$$\Delta E \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2}$$

Water activity determination

Water activity was determined using Novasina LabMaster water activity meter (Novasina AG, CH-8853, Lachen, Switzerland). All measurements were done in triplicates.

Water absorption (WAC)

The water absorption capacity (WAC) was determined using the method of Sosulski *et al.* (1976). One gram of the flour and starch (unmodified and acid-modified) samples were mixed with 10 mL distilled water and let stand at room temperature for 30 mins, then centrifuged at 3,000 rpm for 30mins. Water absorption was measured as percent water bound per gram starch. All measurements were done in triplicates.

Swelling power and solubility

Swelling power (SP) and solubility were determined according to Li and Yeh (2001) and Adebooye and Singh (2008) with slight modifications. One gram of the flour and starch (unmodified and acid-modified) samples was weighed in centrifuge tubes and 10 mL distilled water was added. The tubes were heated at 55°C, 75°C and 95°C for 30 mins with occasional stirring. The supernatant was decanted carefully and sediment was weighed for swelling power (SP) determination. The clear supernatant was poured into pre-weighed petri plates and dried at 130°C for 2hr, cooled and then weighed. All measurements were done in triplicates and the swelling power and solubility were calculated using the following equations:

$$\text{Swelling power (\%)} = \left[\frac{\text{sediment weight}}{(\text{initial weight x } (100\% - \%\text{solubility}))}\right] \text{x } 100$$

$$\text{Solubility (\%)} = \left(\frac{\text{dry supernatant weight}}{\text{initial sample weight}}\right) \text{x } 100$$

Pasting property

The pasting property of sorghum flour and starch were evaluated using a Newport Rapid Visco-Analyzer 4 (Newport Scientific Pty. Ltd, Warriewood, Australia). A 3 gram sample was weighed in an RVA canister and tared in a balance. The canister was then added with water until 25 g was reached. The mixture was properly mixed to obtain a lump-free sample. The time-temperature profile was: holding for 1 min at 50°C, heating to 95°C in 5 mins, holding for 2.5 mins at 95°C and cooling to 50°C in 3.8 mins. The peak viscosity, setback, breakdown and final viscosity were recorded (AACC 61-02).

Scanning electron microscopy (SEM)

Dried and finely ground sorghum flour and starch (unmodified and acid-modified) were placed on aluminum specimen holders with carbon double-sided adhesive tapes. The flour and starches were coated with thin film of gold under vacuum using JEOL JFL-1200 fine coater. The coated samples were examined using JEOL JSM 5310 (JEOL Ltd., Japan) scanning electron microscope operated at 15 kV. The images were viewed at 1,000x magnification.

Gelatinization properties

The gelatinization temperature of sorghum flour and starch (unmodified and acid-modified) were determined according to the method of Capule and Trinidad (2016) with some modifications using a differential scanning calorimetry (DSC-Q100, TA Instruments Waters, USA) equipped with a TA Universal Analysis Software. Water (15 µL for flour and 30 µL for starches) was added using a microsyringe to starch (15.0 mg) in aluminum DSC pans, which were then sealed and allowed to equilibrate for 1hr. The sealed pans were then heated (20–120°C at 5°C/min) to gelatinize the samples with an empty pan used as a reference. The on-set of gelatinization (T_o), peak temperature (T_p), completion temperature (T_c) and gelatinization enthalpy (ΔH, J/g) were determined.

Gel consistency

Gel consistency was determined using the method of Cagampang *et al.* (1973). One hundred milligram samples were placed in a test tube. The samples were added with 0.2 mL of 0.025% thymol blue (25 mg/100mL ethanol) and mixed thoroughly followed by the addition of 2 mL 0.2N KOH. The test tubes were covered with glass marbles and were boiled for 8 mins. The samples were cooled down in an ice water bath for 20 mins and laid horizontally over a ruled paper graduated in millilitres and left undisturbed for 1hr. The length of the gel from the bottom of the tube to the gel front was measured and compared to a standard qualification.

Amylosec

Apparent amylose content (AC) was determined according to the pH 9.2 calorimetric method of Juliano *et al*. (2012).

Sorghum flour or starch sample (100mg) was wetted with 1.0 mL of 95% ethanol and swirled carefully to disperse clumps. Then ethanol-wetted flour/starch was dispersed in 1N NaOH (9.0 mL) in a 100 mL volumetric flask and let stand overnight. The solution was made up to 100 mL with distilled water and mixed. A 5 mL aliquot (0.09N NaOH) was placed in a 100 mL volumetric flask with approximately 50 mL of distilled water. Next, 1.0 mL of 0.9N NH_4Cl was added, followed by 2 mL of 0.15% iodine in 1.5% KI, and the solution was made up to volume with distilled water to obtain a stable deep-blue color with the least amount of interference from amylopectin (waxy starch produces a greenish tinge). Color was read at 620 nm within 20–60 mins, and its stability and pH were measured. AC was calculated from standard curves based on potato amylose V (Avebe) alone (0, 5, 15, 25, and 35 mg/100mL of 0.09N NaOH).

Statistical analysis

All results were analyzed for Analysis of Variance (ANOVA) and t-tests using SPSS Base 19.0 software (Stat-Packets statistical analysis software, SPSS Inc., Chicago, IL). Differences between means were compared by least significant differences (LSD) and differences at $p < 0.05$ were considered to be significant.

Results and Discussion

Chemical properties

Chemical analyses of sorghum flour and starch are presented in Table 1. The moisture content of produced sorghum flour and starch were well below the standards of 14% moisture content (CODEX 173-1989). The 14% moisture content is used as a baseline for flour and starch tests. To ensure profitability, the sorghum flour and starch produced must be close to 14% moisture. In wheat flour production, ash content

Table 1. Chemical properties of sorghum flour and starch (unmodified and acid-modified) (dry basis).

Parameter	Sample		
	Sorghum flour	Sorghum starch (unmodified)	Sorghum starch (modified)
Ash (%)	1.24 ± 0.07[a]	0.25 ± 0.03[b]	0.43 ± 0.04[c]
Fat (%)	4.27 ± 0.09[a]	1.18 ± 0.06[b]	1.58 ± 0.06[c]
Protein (%)	11.41 ± 0.04[a]	2.47 ± 0.01[b]	1.44 ± 0.01[c]
Total dietary fiber (%)	6.38 ± 0.05[a]	1.70 ± 0.21[b]	1.56 ± 0.18[b]
Total sugars (%)	3.80 ± 0.18[a]	2.18 ± 0.01[b]	2.02 ± 0.15[b]
Total carbohydrates	83.08 ± 0.19[a]	96.10 ± 0.10[a]	96.55 ± 0.09[a]
Amylose (%)	26.03 ± 0.34[a]	32.04 ± 0.56[b]	32.42 ± 0.42[b]

Values are means ± s.d.'s of duplicate determinations
[a, b, c]Different letters at the same row indicate significant difference at $p<0.05$.

Table 2. Physical properties of sorghum flour and starch (unmodified and acid-modified).

Parameter		Sample		
		Sorghum flour	Sorghum starch (unmodified)	Sorghum starch (modified)
Color	L*value	86.76 ± 0.92[a]	90.37 ± 0.04[b]	92.29 ± 0.04[c]
	a*value	-0.95 ± 0.07[a]	-0.94 ± 0.03[a]	-0.98 ± 0.01[a]
	b*value	11.44 ± 0.22[a]	6.26 ± 0.05[b]	4.76 ± 0.00[c]
	ΔE	11.74 ± 0.78[a]	5.6 ± 0.05[b]	3.29 ± 0.03[c]
Water activity		0.28 ± 0.03[a]	0.31 ± 0.01[b]	0.13 ± 0.00[c]
Gel consistency, mm		55.00 ± 0.00[a]	25.00 ± 0.00[b]	100.00 ± 0.00[c]
Water absorption capacity (WAC) (%)		145.29 ± 6.95[a]	103.44 ± 19.73[b]	96.25 ± 10.08[b]
Solubility (%)	55°C	2.91 ± 0.22[a]	0.94 ± 0.19[b]	1.33 ± 0.23[b]
	75°C	2.11 ± 0.03[a]	1.28 ± 0.48[a]	2.18 ± 0.75[a]
	95°C	2.36 ± 0.40[a]	0.59 ± 0.16[b]	1.96 ± 0.27[a]
Swelling Capacity	55°C	3.04 ± 0.40[a]	2.80 ± 0.12[b]	2.34 ± 0.08[c]
	75°C	5.68 ± 0.05[a]	5.86 ± 0.04[b]	4.92 ± 0.14[c]
	95°C	5.17 ± 0.05[a]	5.76 ± 0.33[b]	4.74 ± 0.03[c]

Values are means ± s.d.'s of triplicate determinations
[a, b, c]Different letters at the same row indicate significant difference at $p<0.05$.

is used an indicator of milling efficiency and bran contamination (since ash is primarily found in the bran) (Wheat Marketing Inc., USA, 2004). This can also be used for the production of sorghum flour since sorghum dehulling is a necessary step for sorghum flour production. Ash in flour can also affect the color of baked products imparting a darker shade to finished products. The ash, fat, and protein content of sorghum flour were within the codex standards (CODEX 173-1989) while the fiber content was above the set standard. Considerable amount of sugars were also present in sweet sorghum flour. The sorghum starch produced in this study has higher ash, fat, protein and fiber content in comparison to rice, corn and cassava starches; however, when compared to the amylose content, both unmodified and acid-modified sorghum starch exhibited high amylose content (Ashogbon and Akintayo, 2012; Ali *et al*., 2016). The high amylose content is important in retrogradation, gel and pasting properties. The higher the amylose content the easier for the starch to retrograde, form firmer gels and be less sticky in terms of texture (Sang *et al.*, 2008; Yu *et al.*, 2009).

Physical properties

The results of physical analyses of sorghum flour and starch (unmodified and acid-modified) are presented in Table 2. The color of flour and starch determines the eye appeal of the product while absorption capacities and swelling property reflect the carbohydrate quality and affects the viscosity and gelling properties of flour/starch (Oladunmoye *et al.*, 2014). The whiteness, L^* value, of sorghum flour was comparable to flour and starches from rice and corn cultivars grown in the Indian climate (Ali *et al.*, 2016) while cassava starches and flour were whiter than sorghum made flour and starch in general (Oduro-Yeboah *et al.*, 2010).

The color of sorghum starch isolated from SPV-422, a sorghum variety introduced in the Philippines, was comparable to starch isolated from white and pigmented sorghum landraces grown in hyper arid regions (Boudries *et al.*, 2014). Also, in terms of whiteness, the three products are significantly different. Sorghum flour had the least L^* value because of high amounts of colored impurities such as protein, sugars and especially fiber. On the other hand, the color of unmodified and acid-modified sorghum starch also significantly vary. This might be because of less protein present in acid-modified starch as evidenced by Table 1. The excess protein responsible for browning might have been removed thru washing of the acid-thinned starch. Even though the protein may have undergone maillard reaction during the process of acid-thinning, the resulting products of the reaction might not have adhered to the starch granules and were also removed during the washing process of the acid-thinned sorghum starch.

Water activity (a_w) is good measure of shelf-stability and food preservation. It is widely accepted that a certain critical water activity is needed by spoilage microorganisms to grow. In food samples, no microbial growth is observed below 0.62 (Barbosa-Cánovas *et al.* 2003). In Table 2, sorghum flour and starch water activity were way below 0.62; hence, microbial growth in sorghum is unlikely.

The scanning electron microscopy of sorghum flour and starch are shown in Figure 1. The sorghum flour was found to be aggregated and was irregularly shaped. Rough edges were also observed for each granule with some flaky material which might be the non-starch components. The average granule size is 10–32 µm. On the other hand, sorghum starches had an ordered structure and were well distributed with smooth to semi-smooth surface. It also showed minimal starch granule damage probably caused by physical grinding. The average granule size of the starch is 7.5–20 µm. The acid-modified sorghum starch granules were clustered. They were also smooth to slightly rough and a number of starch granules are damaged with some having the granules completely destroyed with an average size of 5–25 µm. According to Zhu (2014), the size of sorghum starch granules are very heterogeneous and may range from 4–35 µm.

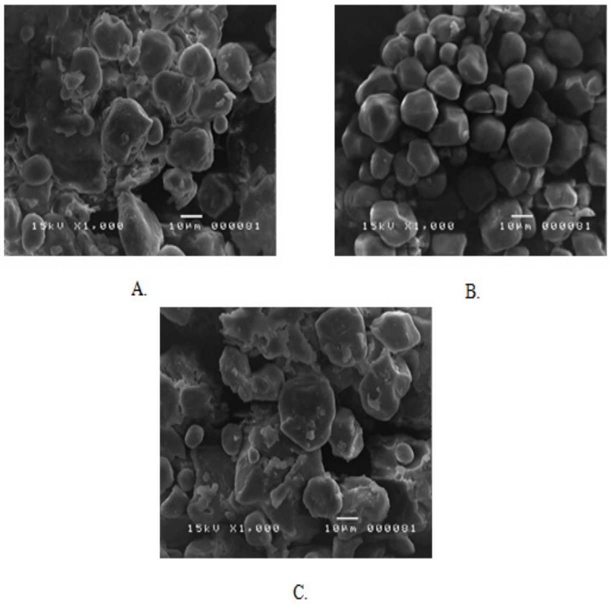

Figure 1. Scanning electron micrograph of Sorghum flour (A.) and starch (B. unmodified and C. acid-modified).

Functional properties

The gel consistency results of sorghum flour and starch samples were presented in Table 2. Gel consistency is designed to test the length of gelatinized samples in a test tube after cooling to room temperature (Cagampang *et al*., 1973). This would indicate if samples can form firm gel structures, properly retain water and the ability of the formed gels to resist flow. Results showed that sorghum flour can form medium gel consistency while unmodified sorghum starch form hard gels. The modified sorghum starch, on the other hand, would form soft gels and were not resist to flow.

In Table 2, water absorption results showed that sorghum flour absorbed more water compared to sorghum starch. The solubility of sorghum flour and starch samples exposed to varying temperatures (55°C, 75°C and 95°C) was very minimal (1–3%).On the other hand, the swelling power of sorghum flour and starch increased as it was subjected to higher temperatures. However, it peaked off at 75°C and then started to decline. The swelling capacities of sorghum flour and starch (unmodified and acid-modified) were different in all levels of heating (55–95°C). This data coincides with the data on gel consistency indicating that the three samples have varying gel strength and their ability to hold water and maintain the structure were different. In summary, sorghum flour has high water absorption, low values of starch solubility and swelling capacity with medium grade gel consistency due to the fibrous material present in the flour. This suggests that sorghum flour may be used in soup-based food products because sorghum flour has good amount of fiber and the resulting soup will not be too thick. Unmodified sorghum starch, on the other hand, can form hard gels, properly hold water and has the highest swelling capacity among the three samples due to the purity and ordered structure of the starch granules. Unmodified sorghum starch can be used as a part substitute or an ingredient for confectionary gums, jelly-based products and thickener. Acid-modified sorghum starch can form soft gels, absorb less water than the two samples and has very low swelling capacity because of the disrupted structure of the acid-modified starch granules. It is recommended that modified starch can be used as creamers or for free-flowing food products used in pharmaceuticals like food tablets. See Figure 1 for the comparison of sorghum flour and starch granules. It is important to note that the sorghum flour and starch obtained from SPV-422 variety grown in the Philippines are very insoluble to water and has a lower swelling capability in comparison to other sorghum varieties (Udachan *et al.*, 2012).

The pasting property measured using a rapid viscoanalyzer (RVA) is one of the most widely

Table 3. Pasting properties of sorghum flour and starch (unmodified and acid-modified).

Sample (Sorghum)	Pasting parameter (RVU)						
	Peak Viscosity	Trough Viscosity	Breakdown	Final Viscosity	Setback	Peak Time (mins.)	Pasting Temperature (ºC)
Flour	61.58ª ± 1.23	61.14ª ± 1.47	0.44ª ± 0.29	119.61ª ± 1.55	58.47ª ± 1.48	6.49ª ± 0.50	78.33ª ± 0.06
Unmodified starch	263.89ᵇ ± 4.14	178.86ᵇ ± 1.04	85.03ᵇ ± 4.72	304.44ᵇ ± 7.81	125.58ᵇ ± 8.17	5.31ᵇ ± 0.03	73.50ᵇ ± 0.44
Acid-modified starch	38.69ᶜ ± 1.78	10.64ᶜ ± 0.99	28.06ᶜ ± 2.77	23.42ᶜ ± 0.44	12.78ᶜ ± 0.55	5.13ᶜ ± 0.01	75.80ᶜ ± 0.56

Values are means of triplicate determinations.
[a, b, c]Different letters at the same column indicate significant difference at p<0.05.

Table 4. DSC transition parameters of sorghum flour and starch.

Sample (Sorghum)	T_o (ºC)	T_p(ºC)	T_c (ºC)	T_c-T_o (ºC)	ΔH (J/g)
Flour	63.39 ± 0.52ª	68.68 ± 0.38ª	77.06 ± 0.40ª	13.67 ± 0.80ª	7.33 ± 0.63ª
Unmodified starch	61.54 ± 0.22ᵇ	65.50 ± 0.12ᵇ	71.03 ± 0.27ᵇ	9.49 ± 0.49ᵇ	11.68 ± 1.43ᵇ
Acid-modified starch	61.96 ± 0.20ᵇ	65.48 ± 0.10ᵇ	70.49 ± 0.45ᵇ	8.53 ± 0.39ᶜ	9.82 ± 0.54ᵇ

T_o= on-set temperature
T_p= peak temperature
T_c= conclusion temperature
T_c – T_o = range of gelatinization temperature
Values are means ± s.d.'s of triplicate determinations
[a, b, c]Different letters at the same column indicate significant difference at p<0.05.

accepted rheological analyses for flour and starches. In sorghum starch, pasting behavior was related to the swelling and solubility properties of the starch granule (Zhu, 2014). In Table 3, unmodified sorghum starch showed very high peak, trough and final viscosity as well as lower pasting temperature in comparison to sorghum flour and acid-modified sorghum starch. This is in line with the comprehensive review of Zhu (2014), that alkaline (NaOH) steeped sorghum starch tend to have higher peak viscosity and lower pasting temperature in comparison to other types of sorghum starch extraction. The results in Table 3 also showed that acid-modified starch was more susceptible to shear-thinning in comparison to sorghum flour and unmodified sorghum starch. This was apparent in lower pasting viscosity and other parameters; however, the pasting temperature was quite high indicating that it needed a higher temperature to form pastes. The pasting temperature of sorghum flour and starch was comparable to other sorghum varieties (Zhu, 2014). High peak viscosity (PV) values, indicates high swelling capacity of flour and starch while trough viscosity indicates the water holding strength/capacity. Unmodified sorghum starch has high peak viscosity and trough values; hence, it can hold high amounts of water for extended periods and is excellent in food applications that need high moisture content.The setback phase is associated with the cooling process during formation of pastes and causes the re-association of starch molecules resulting to increased gel structure formation. In the case of sorghum flour and unmodified sorghum starch, it was apparent that both can form stronger gels in comparison to modified sorghum starch. In terms of peak time, acid-modified starch reached the fastest peak viscosity at 5 minutes followed closely by unmodified starch while sorghum flour would need longer time to reach peak viscosity at 6.5 minutes.

The gelatinization parameters of sorghum variety SPV-422 flour in comparison to starch (unmodified and acid-modified) were significantly different. The gelatinization range of flour was approximately 63–77ºC while starch (unmodified and acid-modified) was approximately 61–71ºC (Table 4). When compared to other sorghum starch of different sorghum varieties, the ranges of gelatinization temperature obtained in this study weresomewhat similar to Udachan *et al*. (2012) at 64-68ºC and Zhu (2014) at 60-85ºC. Moroever, sorghum flour was also within the range stated above. The gelatinization temperature range of SPV-422 is on the low side when compared to other sorghum starches because of high amylose content. Amylose affects the thermal properties of the starch. The higher the amylose content of the sorghum variety, the lower is the gelatinization temperature range (Zhu, 2014). The gelatinization temperature range of sorghum flour (13ºC-14ºC)and starch (9ºC-12ºC) was high because of high amounts of sugar. The presence of sugar extends the gelatinization range and decreases ease of gelatinization (Kim and Walker, 1992) probably because it binds the water to the sugar and not the starch, lessening available water for immediate starch gelatinization.

Conclusion

A number of studies have been published on the characterization and functional properties of sorghum flour and starch in different countries but very limited data is available for Philippine grown sorghum. The study addressed the possible use of sorghum flour and starch (unmodified and acid-modified) in different food applications by examining its chemical, physical characteristics and functional properties. The chemical characteristics of flour and starch (unmodified and acid-modified) produced from the SPV-422 variety (provided by ICRISAT) in the country were within the Codex Standards 173-1989 (i.e. ash = max 1.5%db, protein = min. 8.5%db and crude fat = max 4.7%db). Also, the color of sorghum flour (86 L^* value) and starch (90-92 L^* value) produced in this study were comparable to the color of rice and corn while cassava flour and starch products were whiter than those of sorghum. The produced sorghum flour and starch have very high amylose content (26% and 32-33% respectively). The high value is important in retrogradation, gel and pasting properties. Thus, sorghum can be used for food applications which needed firm and strong gel formations. Sorghum flour and unmodified starch produced in this study can be very viscous if added with water. They have high water absorption capacities (90-150%), low swelling (2-6%) and solubility (1-3%) except that sorghum flour contained more fiber than unmodified sorghum starch. It is advisable for sorghum flour to be used in soup-based products because the resulting mixture is moderately thick while unmodified starch is best for application in such products as confectionary gum, jellies and thickener. On the other hand, the acid-modified sorghum starch is best suited as creamers since it does not form strong and firm gels and the consistency of the product is not very viscous. This study recommendsstudying other functional properties such as freeze-thaw stability, paste clarity and interaction to oils. Functional properties in terms of bioactive compounds present and its impact on the nutritional value of sorghum-based products are also recommended for further study. Lastly, the study recommends the application of the produced sorghum flour and starch into different Philippine snack foods.

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