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# Characterization of flour made from Philippine-grown sorghum (*Sorghum bicolor* L. Moench) using different pre-processing treatments

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**Abstract**

Data on sorghum (*Sorghum bicolor* L. Moench) flour production process and utilization in the Philippines is very few. The crop is mostly unknown in the country and is now being developed as a key item to address food security. In line with this, the study aimed to characterize and determine the physicochemical, microbial and sensorial properties of sorghum flour prepared using different production and pre-process treatments. The produced flours were categorized as follows: a) undehulled sorghum flour (USF), b) untempered-dehulled sorghum flour (UDSF), c) tempered-dehulled sorghum flour (TDSF) and d) boiled-dehulled sorghum flour (BDSF). Chemical analyses showed that only BDSF have met the standard set by Codex Standard for Sorghum Flour (Codex 173-1989). Other flours failed to meet the minimum protein content of 8.5%. Color analysis of the flours revealed that TDSF has the lightest color ($L^*$value of 88.61), followed by UDSF, BDSF and USF, respectively. The color of the flour has an impact on sensory perception and was observed that the darker the flour, the more it becomes undesirable. Microbiological analyses showed that BDSF was the most desirable flour due to minimal microbial load.



## Introduction

Sorghum is one of the food choices of developing countries and the sub-tropics (Elkhalifa *et al.*, 2005; Kulamarva *et al*., 2009). Over the last few years, the Philippines have strong dependence on rice importation. The country has been burdened on finding an alternative and steady supply of carbohydrate source. One of the possible alternatives is sweet sorghum grains. The improved varieties of the plant were introduced by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) from India in 2005. The variety found suitable for planting in the Philippines was mainly used for bioethanol production. The study on sweet sorghum in the Philippines had generated interest since then because almost all of the plant parts can be utilized for food, feed and energy. The sorghum stalks are the main raw material used for bioethanol production while the sorghum grains are used as food and feeds since it is a rich source of carbohydrate. Also, the improved varieties exceed the yield/hectare/year (approximately 3-7 T $ha^{-1}$) of rice since it can be planted in 3 cropping seasons as compared to 2 cropping season of rice. Sorghum is suitable for human consumption and the grain can easily be processed into flour and starch (Reddy *et al.,* 2011).

Sorghum is the 5$^{th}$ most promising crop in the Philippines. It is a rich source of micronutrients (minerals and vitamins) and macronutrients (carbohydrates, proteins and fat). Sorghum has resistant starch which makes it interesting for obese and diabetic people. It is an alternative food for people who are allergic to gluten (Bogue and Sorenson, 2008) Sorghum also contains phenolic compounds like flavonoids which can inhibit tumor development (Huang, 1992; Kulamarva *et al*., 2009). Consumption of sorghum is also beneficial to diabetics because sorghum starch and sugars are released more slowly than other cereals (Kulamarva *et al*., 2009).

In sorghum flour production, bran removal by decortication processes similar to wheat flour production is important (Lochte-Watson *et al*., 2000). Removal of the bran or hulls is crucial to remove the anti-nutrients like tannins and phytic acid through dry abrasion principle (Lazaro *et al*., 2014). However, these technologies are not very efficient. It has low milling yield and high protein loss due to the softness of the endosperm (Dahir *et al*., 2015).

As a food ingredient, flour made from sorghum has been extensively used for pasta and noodles (Khan *et al*., 2013) as well as their use in flat breads and pita breads (Yousif *et al*., 2012). For a healthier lifestyle and to address celiac disease, sorghum can

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be applied in composite-based food products (i.e. sorghum-cowpea porridge, breads, intermediate moisture foods like cookies, brownies and cakes) and be labelled as gluten-free food products (Onyango *et al*., 2011; Apea-Bah *et al*., 2014).

In the Philippines, sorghum can still be considered as an underutilized crop. Utilization of flour made from sorghum grain will provide useful information for industry and future product development. Information on the production processes of sorghum flour in the Philippines is very few. Thus, the objective of this paper is to identify different production processes for the production of flour from sorghum. Specifically, the study aimed to determine different pre-processing methods that could affect the quality of the flour and determine the physicochemical, microbiological and sensory characteristics of the flour produced.

## Materials and Methods

*Materials*

Sweet sorghum grains (*Sorghum bicolor* L. Moench) SPV-422 variety was obtained from BAPAMIN Enterprises, Inc. in Batac, Ilocos Norte, Philippines. The grains were processed into flour in the Food Processing Facility of the Department of Science and Technology – Food and Nutrition Research Institute. All chemical reagents used were of analytical grade.

*Production of Sorghum Flour*

Four types of sorghum flour were produced in this study and the methods of production were described as follows:

*Undehulled Sorghum Flour (USF)*

Whole sorghum grains were milled using flour mill machine (Hammer Mill 1-Phase; Dynamics Development Trade & General Services Inc., Caloocan City, Philippines) and was sieved to 60 mesh sizes using vibroscreen separator (Kason Vibroscreen Separator Serial No. 76487 Model K24-4-SS; Separation Engineers Pty. Ltd, Sydney Australia), packed in plastic bags and stored at ambient temperature.

*Untempered-Dehulled Sorghum Flour (UDSF)*

Whole sorghum grains were dehulled using grain dehuller (Type: 6N-80 Standard: Q/20715618-42 Leshan San Yuan Electrical Machinery Factory, SiChuan China) and milled using flour mill machine. Then, flour was sieved to 60 mesh size using vibroscreen separator, packed in plastic bags and stored at ambient temperature.

*Tempered-Dehulled Sorghum Flour (TDSF)*

Whole sorghum grains were soaked in water for 15 mins, drained and then tempered for 21 hrs at room temperature. The tempered grains were dehulled using a grain dehuller and then dried in a forced-draft bed dryer (Serial No. 201510572Y; KNB Engineering Services, Caloocan City Philippines) at 60°C for 100 mins. The dried grits were milled into flour using a flour mill then sieved to 60 mesh size using vibroscreen separator, packed in plastic bags and stored at ambient temperature. Method of tempering was first optimized in a separate study.

*Boiled-Dehulled Sorghum Flour (BDSF)*

Whole sorghum grains were boiled for 5 mins and then drained. The boiled grains were dried using fluidized bed dryer (15HP Fan Motor 3-Phase Steam-heated; Australia) at 90°C for 5 mins. The dried grains were dehulled using a grain dehuller. The dried grits were milled into flour using flour mill, then sieved to 60 mesh size using vibroscreen separator, packed in plastic bags and stored at ambient temperature.

*Chemical analyses*

Chemical analyses of sorghum flour included moisture content (AOAC 925.10; air-oven method), crude ash/minerals (AOAC 923.03), crude fat (AOAC 920.39; Ether extraction/Soxhlet method), total dietary fiber (AOAC 9991.43; modified), total sugars (AOAC 968.28) and protein (AOAC 920.53; Automated Kjeldahl Method - Buchi). All analyses were done in duplicates.

*Amylose content*

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

*Physical analyses*

*Color analysis*

The color of sorghum flour were measured using a chromameter (Minolta 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). Analysis was 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 ($\Delta E$), 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 evaluated using Novasina LabMaster water activity meter (Novasina AG, CH-8853; Lachen, Switzerland). Analysis was done in triplicates.

*Microbiological analyses*

Microbiological analyses of sorghum flour included aerobic plate count (US FDA BAM-3, 2001), total coliform count (US FDA BAM-4, 2002), detection of *E. coli* (US FDA BAM-4, 2002), *Salmonella* sp. (US FDA BAM-, 2007), *Staphylococcus aureus* (US FDA BAM-12, 2001), *Bacillus cereus* (US FDA BAM-14, 2001), and molds and yeasts count (US FDA BAM-18, 2001). Microbiological analyses were performed right after the completion of each flour production process.

*Sensory evaluation*

Sensory evaluation of sorghum flour samples were conducted using 15 trained panelists, according to the Department of Science and Technology-Food and Nutrition Research Institute – Sensory Evaluation Laboratory Sensory Evaluation Procedures (SEP) Manual (2015). Samples were evaluated based on appearance, color, odor, texture and general acceptability. The attributes were measured using Quantitative Descriptive Analysis (QDA) Test. Evaluation was conducted in a controlled sensory evaluation room.

*Statistical analysis*

Results of the analyses were analyzed using Analysis of Variance (ANOVA) via 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 analyses*

The chemical analyses of different sorghum flour samples were summarized in Table 1. Results showed that most of the chemical components of the flour were within the Codex Standard for sorghum flour (Codex 173-1989). Preliminary trials were performed for each flour production method and the most effective processing steps were then followed in the study. Some of the pre-processing steps explored were the drying temperature, drying time, tempering time, boiling time and different equipment blade dehulling settings. These processing steps were improved to eventually deliver high material yield for sorghum flour production.

The moisture content of the flour samples has been limited to 14%. The ash content of UDSF and TDSF were less than the values of USF and BDSF. The BDSF ash content was higher than the other two dehulling processes probably because boiled sorghum whole grains exhibited pasting characteristics during the boiling process while the immediate fluidized bed drying made the sorghum hull adhere to the starch particles. This resulted to the partial dehulling of BDSF where only a part of the hull was removed by the dehuller; hence, ash content was significantly higher than the two dehulling processes (UDSF and TDSF) and was comparable to USF. Ash is primarily found in the bran which is removed in dehulling process. Ash content is used as an indicator of milling efficiency and bran contamination in wheat flour production (Wheat Marketing Inc., USA, 2004). The fat content for UDSF and TDSF were also lower than USF and BDSF but all values were within the CODEX 173-1989 standard. All flours have substantial amount of total dietary fiber and total sugars. However, it was noted that BDSF has the lowest total sugar content. This can be attributed to heat treatment resulting in Maillard reaction which affects the quantity of available sugar and the color of the flour produced (Dayakar *et al*., 2016).

Among sorghum flour production methods, only BDSF passed the standard set by Codex 173-1989 on the minimum 8.5% protein content. The higher protein content can be attributed to the effect of heat treatment. In a study by Capule and Trinidad (2016), the increase in protein may be due to the released residual protein embedded in the starch granules, after heat treatment. Moreover, higher protein content is beneficial as it results to higher water absorption which could affect the staling and firming of breads. The protein acts as humectant, decreasing available water for microbial growth but preserving the breads high moisture content (Salehifar *et al*., 2010).

The dehulling process has a significant effect in the chemical composition of sorghum flours. The removal of bran increases the protein content but reduces the protein quality due to the removal of the dietary fiber-rich pericarp and at least a part of the lysine-rich germ which is a primary essential acid found in sorghum. Dehulling, remarkably reduces the lipids, vitamin and mineral contents but improves the mineral bioavailablity due to elimination of phytic acid in the bran (Dahir *et al*., 2015).

Table 1. Chemical properties of different sorghum flour samples (dry basis).

| Components | Codex 173-1989 | Process Treatment | | | |
|---|---|---|---|---|---|
| | | Undehulled (USF) | Untempered-Dehulled (UDSF) | Tempered-Dehulled (TDSF) | Boiled-Dehulled (BDSF) |
| Ash (%) | 0.9 – 1.5% | 1.36 ± 0.05 [a] | 0.55 ± 0.02 [b] | 0.50 ± 0.02 [b] | 1.24 ± 0.07 [a] |
| Fat (%) | 2.2- 4.7% | 4.13 ± 0.24 [a] | 1.77 ± 0.05 [b] | 1.75 ± 0.04 [b] | 4.27 ± 0.09 [a] |
| Protein (%) | ≥8.5% | 7.94 ± 0.09 [b] | 7.04 ± 0.16 [d] | 7.26 ± 0.06 [c] | 11.41 ± 0.04 [a] |
| Total dietary fiber (%) | ≤1.8 %* | 7.27 ± 0.14 [a] | 4.44 ± 0.23 [c] | 3.55 ± 0.06 [c] | 6.38 ± 0.06 [b] |
| Total sugars (%) | - | 6.68 ± 0.12 [a] | 4.30 ± 0.15 [b] | 5.05 ± 0.66 [b] | 3.80 ± 0.18 [c] |
| Amylose (%) | - | 21.80 ± 0.24 [c] | 28.70 ± 0.20 [a] | 28.60 ± 0.25 [a] | 26.03 ± 0.34 [b] |

Values are means ± s.d.'s of duplicate determinations.
[a,b,c,d] Different letters at the same row indicate significant difference at $p<0.05$.
*Applicable for crude fiber values only (CODEX 173-1989).

Table 2. Physical properties of different sorghum flour samples.

| Parameters | Process Treatment | | | |
|---|---|---|---|---|
| | Undehulled (USF) | Untempered-Dehulled (UDSF) | Tempered-Dehulled (TDSF) | Boiled-Dehulled (BDSF) |
| Color, L | 82.85 ± 0.10 [d] | 85.12 ± 0.36 [b] | 88.61 ± 0.06 [a] | 83.99 ± 0.18 [c] |
| a | 0.51 ± 0.02 [b] | 0.14 ± 0.05 [c] | -0.71 ± 0.04 [a] | -0.76 ± 0.07 [a] |
| b | 11.49 ± 0.08 [b] | 11.24 ± 0.54 [b] | 10.41 ± 0.07 [c] | 12.98 ± 0.16 [a] |
| ΔE | 14.78 ± 0.05 [a] | 12.79 ± 0.60 [b] | 9.70 ± 0.07 [c] | 14.79 ± 0.21 [a] |
| Water activity | 0.398 ± 0.004 [b] | 0.442 ± 0.002 [b] | 0.291 ± 0.011 [c] | 0.490 ± 0.002 [a] |

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

The process of tempering or conditioning of sorghum grains before dehulling resulted to higher degree of separation of bran from the endosperm. The purpose of tempering was to increase the moisture content of the grains which made endosperm softer and more friable (Kebakile, 2008; Iva, 2011). This step made the bran tough and more resistant resulting in larger pieces facilitating easier separation (Duville, 2012). Tempering had already been used for centuries in traditional dehulling system. Utilization of this step in mechanical dehulling system resulted to reduced dehulling force (Lazaro *et al.*, 2014). Boiling whole sorghum grains accelerated the increase of moisture intake of the grains. Heat treatment of the sorghum grains can improve the flour characteristics. In the study of Meera *et al.* (2011), sorghum flour shelf-stability can be increased through exposure of grains to moist heat for 15 minutes which retards hydrolytic rancidity to 6-8 months of storage. Similarly, heat moisture treatment can improve the mouth-feel of the produced sorghum flour when used for food (Sun *et al.*, 2014).

BDSF have low amylose content in comparison to other dehulled sorghum flour (UDSF and TDSF) in the study due to amylose being leached by starch as temperature and heating period increases (Noranizan *et al.*, 2010; De la Hera *et al.*, 2013; Dayakar *et al.*, 2016). Nonetheless, the amylose content obtained was still comparable to the amylose content of rice cultivars studied by Oko *et al.* (2012). Moreover, undehulled sorghum flour (USF) contained lesser amylose content since other components (i.e. total dietary fiber and sugars) comprised the bulk of the percentage breakdown. In general amylose content of sorghum from different genotypes has a range of 20-30% (Zhu, 2014). In a study conducted by Winger *et al.* (2014) on flour characterization made from different hybrids of sorghum, the amylose content (%) of sorghum flour ranges from 20.2 to 27.3 (dry basis). The amylose content of UDSF (28.70%db) and TDSF (28.60%db) in this study are higher than Winger *et al.* (2014) while USF (21.80%db) and BDSF (26.2%db) have comparable values.

The amylose content affects gelatinization, gelation, solubility, resistant starch formation and textural properties (Wani *et al.*, 2012; Zhu, 2014).

Table 3. Microbiological analysis of different sorghum flour samples.

| Microbiological Counts | Philippine Standard* | Process Treatment | | | |
|---|---|---|---|---|---|
| | | Undehulled | Untempered-Dehulled | Tempered-Dehulled (TDSF) | Boiled-Dehulled (BDSF) |
| Aerobic plate count (CFU/g) | $<10^5$ | 9,600 | 940 | 120,000 | 380 |
| Coliform count (CFU/g) | $<10^2$ | <250 | 270 | 1700 | <10 |
| *E. coli* count (MPN/g) | - | <3.0 | <3.0 | <3.0 | <3.0 |
| Mold and yeast count (CFU/g) | $<10^4$ | <100 | <100 | 420 | <1000 |
| *Salmonella* sp. (CFU/g) | Negative | Negative | Negative | Negative | Negative |
| *Staphylococcus aureus* (CFU/g) | - | <10 | <10 | <10 | <10 |
| *Bacillus cereus* (CFU/g) | - | <100 | 100 | <100 | <100 |

[*] Food and Drug Administration Philippines; FDA Circular No. 2013-010.

Table 4. Sensory properties of different sorghum flour samples using Quantitative Descriptive Analysis.

| Sensory Attributes | Process Treatment | | | |
|---|---|---|---|---|
| | Undehulled (USF) | Untempered-Dehulled (UDSF) | Tempered-Dehulled (TDSF) | Boiled-Dehulled (BDSF) |
| Appearance | 8.86 ± 2.21 [bd] | 10.63 ± 1.68 [acd] | 11.71 ± 1.73 [ac] | 10.20 ± 1.86 [abd] |
| Color | 6.59 ± 3.38 [a] | 9.47 ± 2.20 [b] | 11.17 ± 2.09 [b] | 6.77 ± 2.86 [a] |
| Odor | 12.32 ± 2.33 [a] | 12.65 ± 2.09 [a] | 12.76 ± 2.13 [a] | 12.48 ± 2.32 [a] |
| Texture | 11.08 ± 2.35 [ab] | 12.05 ± 1.85 [a] | 12.31 ± 1.67 [a] | 9.38 ± 3.15 [b] |
| General Acceptability | 9.59 ± 1.64 [bd] | 11.13 ± 1.78 [acd] | 11.77 ± 1.70 [ac] | 10.21 ± 1.85 [abd] |

Scale: Appearance: (0) Not Appealing – (15) Very Appealing, Color: (0) Off-white – (15) White, Odor: (0) Strong off-odor – (15) No off –odor,Texture: (0) Coarse –(15) Fine, General Acceptability: (0) Dislike very much – (15) Like very much

[a,b,c,d] Different letters at the same row indicate significant difference at $p<0.05$.

In food product development, amylose content also affects the water absorption, lightness, fat absorption, cooking time and texture properties of cooked instant noodles (Taylor *et al*., 2006). In addition, it plays a critical role in the stabilization of crumb structure in bread making (Taylor *et al*., 2006; Winger *et al*., 2014). In pasting property, conflicting views have been observed. High amylose content will result in lesser breakdown viscosity while other studies also suggest that amylose does not significantly affect the pasting property of flour (Zhu, 2014).

*Physical analyses*

The physical analyses of different sorghum flour samples are summarized in Table 2. Color is an important factor in consumer acceptability of products made from sorghum, especially using colored sorghum varieties (Lazaro *et al*., 2014). The $L^*$values, degree of lightness, obtained from the flours were significantly different from each other. The $L^*$values imply that TDSF has the lightest color while USF has the least light color. This color difference may be attributed to the efficiency of bran removal and tempering. Bran contributes to the darker color of the flour and the more bran is removed, the lighter is the flour produced. Flour color is also correlated to ash content which is used as an indicator of bran and germ contamination in milling (Winger *et al*., 2014). In addition, heat treatment could also be a factor in lower $L^*$values of the flour. It was reported that the presence of oxygen, moisture and elevated temperatures combined contributed in the darkening during treatment and Maillard reactions are accelerated at high temperatures and pH (Chen *et al*., 2012; Dayakar *et al*., 2016). Hence, BDSF was darker compared to UDSF and TDSF. Besides the degree of lightness, the color manifested by the four types of sorghum flour was yellow. The degree of yellowish color was very light and this color represented the off-color perceived by trained sensory panelists. This was supported by a very low $a^*$value (-1 to 1 units) and minor b*value (10-13 units).

Water activity ($a_w$) is a 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 water activities were way below 0.62; hence, microbial growth in sorghum was unlikely.

*Microbiological analyses*

The microbiological analyses of different sorghum flour samples are presented in Table 3. It was reported that TDSF has high aerobic plate count (APC) which exceeded the standard maximum limit of $10^5$ cfu/g. High coliform count were also reported in USF, UDSF and TDSF which exceeded the maximum limit of $10^2$ cfu/g. Although there were molds and yeasts growth observed in all the flours, the values were less than the maximum limit of $10^4$ cfu/g. Other microbiological parameters like *Escherichia coli, Staphylococcus aureus* and *Bacillus cereus* are not part of the Philippine flour standard but are present in standards for cereals and cereal products. Nonetheless, the values obtained are within acceptable limits of the mentioned related products. The study used the standard of the Food and Drug Administration of the Philippines (2013) as baseline of flour microbial safety. The high microbiological count in TDSF can be attributed to tempering conditions (21 hours tempering at ambient temperature) used. These conditions favored the growth and proliferation of the microorganisms.

*Sensory evaluation*

The sensory evaluation of different sorghum flour samples is summarized in Table 4. It can be noted that in all sensory parameters, TDSF received the highest score. This was followed by UDSF, BDSF and USF, respectively. In all sensorial parameters, TDSF was not significantly different from UDSF. UDSF was not significantly different with BDSF in terms of appearance, odor and general acceptability. Furthermore, BDSF was not significantly different with USF in all sensorial parameters. The lower values of USF in appearance and color could be due to the presence of bran while for BDSF, it was the effect of heat treatment which caused Maillard reaction and color darkening of material for flour production. In general, the sensory attributes of all sorghum flour production methods were significantly different from each other except for odor.

## Conclusion

Four sorghum (SPV-422 variety) flour production processes were developed with different chemical and physical characteristics. Out of the four production processes, only boiled-dehulled sorghum flour (BDSF) met the chemical standards of Codex Standard 173-1989 for sorghum flour production. In terms of microbiological safety, only tempered-dehulled sorghum flour (TDSF) failed the standards of the Food and Drug Administration of the Philippines (2013). All flours produced from the SPV-422 variety have amylose content ranging from 21.8% (db) to 28.70% (db) which were in the normal range for different sorghum genotypes (Zhu, 2014). Based on sensory qualities and color measurements, tempered-dehulled sorghum flour (TDSF) was the most acceptable but due to high aerobic plate count, food safety of the flour was compromised. Over-all, the study have identified that the most suitable processing method for sorghum flour production is the method used for boiled-dehulled sorghum flour (BDSF). The flour may rank 3rd in terms of color perception and sensory analysis but it complies to the Codex 173-1989 chemical standards and the Food and Drug Administration of the Philippines (2013) microbiological standards for flours.

## Recommendation

Further studies should address the application of the developed sorghum flour production process (boiled-dehulled sorghum flour, BDSF) into food products for obese, adolescent and energy-protein deficient sector of the Philippine population.

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