



ORIGINAL ARTICLE

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Influence of Grain Size on the Agglomeration and Quality of Fine Couscous Derived from Decorticated White *Sorghum Bicolor* L.

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ABSTRACT

Aims: This study sought to estimate the effect of white *Sorghum bicolor* L. grain size and the decortication process on the production yield, physicochemical characteristics, cooking properties, color, and sensory quality of sorghum-based couscous.

Methods: White *Sorghum bicolor* L. grains originating from the same crop batch were initially separated into three distinct fractions based on their size. These fractionated grains were subsequently decorticated and milled to obtain sorghum semolina, which was then agglomerated to produce three respected homemade couscous samples. For comparative analysis, commercial ready-made durum semolina was employed to prepare a control couscous sample. All samples, including the control, were meticulously evaluated for their proximate composition (specifically protein, starch, and dietary fiber content), cooking properties, color indices, and overall sensory attributes.

Results: The three homemade couscous samples of sorghum were produced with a high yield, ranging from 88.42 to 90.27%, significantly surpassing the control yield of 82.30 %. The nutritional composition of the sorghum samples—namely the protein, starch and dietary fiber contents was both high and showed significant variations dependent on the initial grain size. The protein, starch, and dietary fiber contents in the sorghum couscous samples ranged from 11.45 to 14.67%, 60.18 to 75.51%, and 2.61–10.55%, respectively. Furthermore, the sorghum couscous exhibited a noticeably darker color compared to the control. Sorghum couscous samples A and B exhibited favorable cooking quality, although they required a prolonged cooking time. They also achieved moderate overall acceptability scores for appearance and color. Conversely, sorghum couscous C was characterized by poor cooking loss and received lower sensory attribute scores.

Conclusions: The findings definitively confirm the significant influence of grain size on both the semolina agglomeration process and the ultimate quality characteristics of the sorghum couscous. Moreover, the decortication process was associated with the production yield, particle size distribution, and color profile of the final sorghum couscous product.

Keywords: White *Sorghum bicolor*; Grain Size; Couscous; Physicochemical Properties; Nutrient Content; Food quality.

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1 INTRODUCTION

White sorghum (*Sorghum bicolor* L. Moench) is globally recognized as a significant functional grain. Its grains are valued as a dietary food for human consumption, primarily due to their naturally low tannin content (Pan *et al.*, 2019). Furthermore, the specific nutrient content of sorghum varies widely depending on the variety (Khalid *et al.*, 2022). Notably, sorghum's inherent low digestibility of both starch and protein positions it as a promising food source for individuals managing conditions such as obesity and diabetes (Xiong *et al.*, 2019).

To enhance its culinary utility, sorghum grains are traditionally decorticated prior to milling. This processing step has been shown to improve the grain's digestibility

(Hama *et al.*, 2011), as well as optimize the color and yield of derivative products such as sorghum couscous (Aboubacar *et al.*, 2006), or sorghum injera (Yetneberk *et al.*, 2005). White sorghum is predominantly utilized in semi-arid regions for preparing traditional foods, including couscous, which constitutes the main staple food across North Africa (Xiong *et al.*, 2019). Typically, couscous is manufactured by agglomerating semolina or flour derived from locally available grain crops, which can include barley (Messia *et al.*, 2019), sorghum (Anglani, 1998; Aboubacar *et al.*, 2006), millet (Hayes *et al.*, 2020), yam (Biao, 2017), or rice (Aydin, 2022). In the Northeast of Algeria specifically, a fermented variety known as “elm'ziyet” is prepared from the fermented semolina, which itself is extracted from a blend of fermented



durum wheat grains, *Sorghum bicolor* grains (or millet grains), and oak fruits (Chemache *et al.* 2018).

In related research, Mora-Ramirez *et al.* (2021) established that a larger grain diameter in wheat can positively influence the grain's chemical composition, flour extraction rates, and the subsequent quality of flour and final food products. For human consumption, sorghum grains with a corneous endosperm and large size are typically preferred (FAO, 1995), as an increase in grain size is commonly associated with an improvement in overall sorghum quality (Lee *et al.*, 2002).

The primary aim of the present study was to investigate the feasibility of producing couscous from white *Sorghum bicolor* based on the criteria of its initial grain diameter, focusing on the following specific aspects:

a) Analyzing the final couscous size distribution. b) Determining the cooking quality of the raw couscous. c) Quantifying the nutrient content (protein, starch, and dietary fiber) in the semolina and the raw couscous. d) Establishing the color indices of the semolina, raw, and cooked couscous. e) Performing a comprehensive sensory evaluation of the final couscous samples. f) Conducting a comparative analysis of the quality parameters between the different sorghum couscous samples and a commercial durum wheat couscous control sample.

2 MATERIAL AND METHODS

2.1 Materials

The plant material used was the domesticated cultivar of White *Sorghum bicolor* L. harvested from the In Salah region in southern Algeria. The grains were subjected to a dry-cleaning process to meticulously remove soil and extraneous matter. Subsequently, the cleaned grains were separated into three distinct (A, B, and C) based on their size and were stored in paper bags at a temperature ranged of 9°–18°C.

Commercial durum wheat semolina was procured from a local grocery store for use as a control.

Equipment: The sieves utilized for particle separation included those with apertures of 0.5, 1, 1.25 and 1.5mm (manufactured by DESCO, an ISO 9001:2000 certified Co.). Homemade materials employed for the couscous agglomeration and cooking stages included: sieves (approximately 1mm and 0.6mm), a large wooden bowl, and a traditional steamer (*couscoussier*).

2.2 Methods

2.3.1 Physical Properties of Sorghum Grains

The physical properties were determined using 100 grains sampled in triplicate from each of the three size divisions (A,

B and C). The parameters measured were: 100-grain weight, bulk density, and the primary grain dimensions, specifically length (L), width (W), and thickness (T). The endosperm texture and decortication yield were also determined.

Grain dimensions were measured using a digital vernier caliper (Total Tools. co., limited). These measurements were then used to calculate grain size D_m , sphericity Φ , and aspect ratio R_a of grains consistent with the methodology reported by Gierz *et al.* (2020).

Endosperm texture was qualitatively estimated following the method established by Taylor *et al.* (2008) classifying grains as: Corneous (100% corneous), Intermediate (100% corneous and intermediate) or Mixed (<10% and <90% floury or corneous or intermediate).

$$\text{Grain size: } D_m = \frac{(GMD+AMD+SMD)}{3}$$

$$GMD = \sqrt[3]{(L \times W \times T)} ; \quad AMD = \frac{(L+W+T)}{3} ; \\ SMD = L \times W + WT + TL$$

$$\text{Sphericity: } \Phi = \frac{\sqrt[3]{(L \times W \times T)}}{L}$$

$$\text{Aspect ratio: } Ra = \frac{\text{Longer diameter}}{\text{Shorter diameter}} \times 100 ; \text{ longer and shorter measure of L and W.}$$

2.3.2 Decortication and Milling Procedures

The white sorghum grains were initially soaked in warm water for a brief period. Decortication (hulling) was then performed using a metal grid with a fine mesh, which acted as a soft abrasive surface (Cruz *et al.*, 2020). For precise quantification of the decortication yield, 100 grains from each of the three size divisions (A, B, and C) were decorticated manually one at a time, in triplicate, to ensure the complete removal of the bran. The fully decorticated grains were carefully separated from the removed bran and subsequently dried. The decortication percentage was calculated as the mass percentage of decorticated grains obtained relative to the initial mass of the whole sorghum grains, adhering to the methodology reported by Yetneberk *et al.* (2005).

The decorticated sorghum grains were milled in a single pass using an electric grain mill (SAMAP F100, SAMAP Ecosysteme, France). The resulting milled product was subsequently sieved through a 0.8mm to separate the coarse particles (coarse semolina) and get suitable sorghum semolina (>800µm). This semolina was then packaged in paper bags and stored between 9°–18°C.

2.3.3 Couscous Preparation

Homemade couscous was prepared in three replicates from the refined sorghum semolina fractions (A, B, and C) and the semi-coarse durum wheat semolina (control). No oil, salt, or other additives were incorporated into the process.

A measured quantity of the fine sorghum semolina ($>0.800\mu\text{m}$) was dispersed in a large wooden bowl, slightly moistened with potable water, and rolled vigorously using the palms to facilitate the formation of fine couscous granules. Additional semolina was incorporated to adjust dryness, or extra water was added to achieve the moisture level required for a cohesive mixture. The mixture was then sieved twice: first through a domestic sieve ($\approx 1\text{mm}$) to standardize the diameter of the agglomerated semolina granules, and second through a smaller domestic sieve ($\approx 0.6\text{mm}$) to separate any non-agglomerated, uncooked semolina. The procedure was repeated in the moistened wooden bowl until the entire initial quantity of semolina had been processed.

The resulting uncooked couscous granules were refined by rolling them on the surface of a wooden bowl with the palm of the hands after incorporating an appropriate amount of the same type of cereal flour (sorghum or wheat). The granules were then steamed in a traditional *couscoussier* until steam was observed rising off the surface. The cooked couscous was immediately dispersed onto the flat plate for air-drying in a ventilated room for 24–48 hours.

To determine the couscous size distribution, the raw couscous was sieved using analytical sieves of 0.5, 1, 1.25 and 1.5mm, and then packaged in paper bags and stored at 9°–18°C.

2.3.4 Bulk Density and Yield Measurement

The bulk density of the whole grains, semolina, and raw couscous was determined using a graduated cylinder method (Yuksel *et al.*, 2017). Results were expressed as weight per unit volume (g/cm^3). The couscous yield was expressed as the mass ratio of the raw couscous weight obtained per unit mass of the initial semolina used (Aboubacar *et al.*, 2006).

2.3.5 Cooking Properties of Raw Couscous

The cooking properties of the raw couscous samples were assessed following the AACC International Approved Method 66-50.01 (AACC, 1999). A 10 g sample of raw couscous (sorghum or wheat) were cooked in 120 mL boiling distilled water. The Optimum Cooking Time (OCT) was determined as the point at which the white, opaque center of the cooked granules disappeared upon compression between two glass plates; this was checked at 30s intervals.

The following indices were calculated at the OCT:

- Weight Increase Index (WI): The increment in couscous weight during the optimal cooking time.
- Volume Increase (VI): The increment in couscous volume during the optimal cooking time.
- Cooking Loss (CL): The amount of solid matter leached into the cooking water.

$$WI = \frac{W_{\text{cooked couscous}}(g) - W_{\text{raw couscous}}(g)}{W_{\text{raw couscous}}(g)} \times 100$$

$$VI = \frac{V_{\text{cooked couscous}}(V) - V_{\text{raw couscous}}(V)}{V_{\text{raw couscous}}(V)} \times 100$$

$$CL = \frac{W_{\text{solid lost}}(g)}{W_{\text{raw couscous}}(g)} \times 100$$

2.3.6 Protein, Starch, and Dietary Fiber Contents

The contents of protein, starch, and dietary fiber in both the semolina and final couscous samples were determined at the CRAPC Expertise SPA laboratory in Bou-Ismaïl.

- *Protein content*: determined using the validated Kjeldahl method (ISO 20483:2013). This technique involves the mineralization of the sample in concentrated sulfuric acid, catalyzed by CuSO_4 and K_2SO_4 .
- *Starch content*: Determined according to the reference method specified in ISO 5554:1978.
- *Dietary fiber content*: Determined according to the Weende method (AOAC method 978.10). This method operates based on the solubilization (digestion) of non-cellulosic compounds using sulfuric acid and sodium hydroxide solutions.

2.3.7 Color Evaluation

The color of the semolina and couscous samples was assessed utilizing the CIE $L^* a^* b^*$ color space system. Measurements were performed using a tristimulus colorimeter (Konica Minolta Chroma Meter CR-410, Japan).

2.3.8 Sensory Evaluation

The sensory properties of both the raw and cooked couscous samples were evaluated using a nine-point hedonic scale (ranging from 1 = dislike extremely, to 9 = like extremely) (Rochmawati, 2019). The panel comprised twenty-eight untrained Panelists (14 males and 14 females) aged between 21 and 23 years. The author provided a description and explanation of the sensory attributes evaluated, which included appearance, color, flavor, odor, mouthfeel (mouthfulness), and overall acceptability (Suwonsichon, 2019).

The raw couscous samples were prepared by steaming without the addition of any flavorings: salt, oil or *Smen* (ghee). Samples (15 g portions of raw or cooked couscous) were placed in clear, coded containers. The testing was conducted over two separate sessions. In each session, four samples (raw or cooked couscous), water (provided during the cooked

couscous session) and a score card were presented to each panelist. For the cooked couscous session, panelists were instructed to clean their palate with water between samples.

2.3.9 Statistical Analysis

All measurements were performed in triplicate and initially recorded in Microsoft Office Excel. Statistical analyses were conducted using SPSS Statistics version 17.0.

The mean value $\pm$ standard deviation and the differences in paired measurements were expressed and evaluated using the Paired Sample *t*-test at the significant level of 95% ($p \leq 0.05$). Pearson correlation analysis was applied to examine the relationships between select physical and sensory properties of the couscous samples. Finally, a One-way Analysis of Variance (ANOVA) followed by a *Post-hoc* test was utilized to assess consumer acceptance data.

3 RESULTS AND DISCUSSION

3.1 Physical Properties of Sorghum Grains

The physical properties of the white sorghum grains from the same crop harvest are detailed in Table 1. The results indicate the existence of three distinct grain types, primarily differentiated by significant variations ($p < 0.05$) in their mean size (Dm), bulk density, and 100-grain weight.

The endosperm texture showed characteristic variation corresponding to grain size: the large grains were found to be corneous, the medium grains intermediate, and the short grains presented a mixed texture (7.5, 25.0, and 67.5 for the components, respectively). This textural heterogeneity may be

attributed to the environmental conditions experienced during the grain growth stages.

Regarding geometric parameters, the results for sphericity (Φ) and aspect ratio (R_a) showed a significant different ($p < 0.05$) between the large and short grain divisions, although the medium grains exhibited no significant difference ($p > 0.05$) in these parameters. The total manual decortication of 100 grains was measured as 93.72% ($p < 0.05$), 91.24% ($p > 0.05$), and 88.23% ($p < 0.05$) for sorghum grains A, B, and C, respectively, confirming an association between the decortication efficiency and the initial grain size.

3.2 Decortication and Milling of Sorghum Grains

To optimize the yield and improve the visual appeal of sorghum-based couscous (Yetneberk *et al.*, 2005), wet decortication of the white sorghum grains was performed. The extent achieved was 93.03%, 95.36% and 93.83% for sorghum grains A, B, and C, respectively.

The decorticated grains were milled in a single pass, resulting in a fine sorghum semolina yield ranging from 94.10 to 97.62%. The bulk density values exhibited significant differences ($p < 0.05$), 0.527 g/cm³ for semolina A, 0.501 g/cm³ for semolina B, and 0.471 g/cm³ for semolina C. This observed disparity is likely a function of the underlying structural differences and cell contents of the sorghum grain endosperm.

The protein, starch, and dietary fiber contents of the whole and decorticated sorghum semolina, along with the durum wheat control semolina, are presented in Table 2.

Table 1. Physical properties of sorghum grains, decortication and milling yield

Sorghum grain code		A	B	C
L (mm)		5.50 $\pm$ 0.03 ^b	5.08 $\pm$ 0.12 ^b	4.51 $\pm$ 0.02 ^b
W (mm)		5.01 $\pm$ 0.01 ^b	4.61 $\pm$ 0.03 ^c	4.02 $\pm$ 0.02 ^b
T (mm)		3.08 $\pm$ 0.02 ^b	2.87 $\pm$ 0.01 ^c	2.36 $\pm$ 0.01 ^b
D _m (whole grains, mm)		5.56 $\pm$ 0.02 ^a	5.12 $\pm$ 0.04 ^a	4.44 $\pm$ 0.02 ^a
Φ		0.799 $\pm$ 0.004 ^a	0.800 $\pm$ 0.014 ^c	0.775 $\pm$ 0.001 ^a
R _a (%)		1.09 $\pm$ 0.00 ^a	1.06 $\pm$ 0.05 ^c	1.12 $\pm$ 0.00 ^a
Bulk density (g/cm ³)		0.719 $\pm$ 0.009 ^a	0.687 $\pm$ 0.024 ^a	0.583 $\pm$ 0.008 ^a
100-grain weight (g)		5.81 $\pm$ 0.13 ^a	4.65 $\pm$ 0.14 ^a	2.63 $\pm$ 0.03 ^a
Endosperm texture (%)	Corneous	100	92.5	7.5
	Intermediate	0.0	7.5	25.0
	Floury	0.0	0.0	67.5
Decortication of 100grains (%)		93.72 $\pm$ 2.03 ^a	91.24 $\pm$ 0.8 ^c	88.23 $\pm$ 1.49 ^a
$\frac{\text{decorticated grains}}{\text{a unit of Whole grains}}$ (%) (ED %)		87.15 $\pm$ 1.03 ^a	86.99 $\pm$ 2.62 ^c	82.77 $\pm$ 0.99 ^a
		(93.03)	(95.36)	(93.83)
Milling yield (%)		94.10	95.21	97.62

Note: ED: Extent of decortication. Mean value $\pm$ SD, n=3, ($p < 0.01$). Values within the same row having the same letter are significantly different at $p < 0.05$

- **Protein content:** The protein content in decorticated sorghum semolina A, B, and C varied significantly ($p < 0.05$) according to grain size, ranging from a maximum of 15.6% in semolina A to a minimum of 10.16% in semolina C. The protein content of the whole sorghum semolina (12.30%) was distinct from that of sorghum semolina extracted from the decorticated grains and the control semolina (10.30%).
- **Starch and fiber content:** Starch ranged from 72.76% (semolina C) and 72.16% (semolina B) down to 70.15% (semolina A) and 70.18% (control). Conversely, the whole semolina displayed a lower starch content (62.12%) but a higher dietary fiber content (12.11%), which confirms that the sorghum bran is an excellent source of dietary fiber. The decorticated sorghum semolina samples and the control exhibited varied dietary fiber content, ranging from 4.15% (semolina A) to 2.18% (semolina B). Furthermore, a positive significant correlation ($p = 0.05$) was observed between dietary fiber and starch contents in the fine sorghum semolina samples (A, B, and C). These results collectively suggest that protein content is closely associated with grain size, unlike the starch and dietary fiber contents.

A strong positive linear correlation was established between the size of the initial sorghum grains and the yield of fine couscous ($r = 0.99$; $p = 0.05$). This is likely due to the higher protein (15.60%, and 12.76%) and starch (70.15% and 72.16%) content in semolina A and B, which effectively enhances the agglomeration yield.

The percentage of coarse couscous (1 < 1.5mm) decreased during in samples A and B. In contrast, sample C and the control displayed a higher proportion of coarse granules, which may be attributed to the lower protein content in semolina C (10.16%) and the presence of gluten protein in the durum wheat control, which typically facilitates the formation of coarser couscous. [Aboubacar et al. \(2006\)](#) reported that a greater decortication extent necessitates an increase water amount for the preparation of sorghum couscous with yields ranging from 4 to 42% for fine couscous (<1mm) and 53–85% for coarse couscous (1–2mm). During the agglomeration process, sorghum semolina required more water, consistent with the decrease in its protein content ([Table 2](#)). The combination of abundant water and manual heat promotes the reversible imbibition of water by starch granules through the amorphous regions, leading to swelling and pasting ([Elkhalifa et al., 2017](#)). This mechanism supports the agglomeration of sorghum semolina particles into cohesive couscous granules.

Table 2. Bulk density and chemical properties of semolina, and ingredients of agglomeration process

Semolina samples		WS	SS A	SS B	SS C	W SS
Bulk density (g/cm ³)		0.705 ± 0.007 ^a	0.527 ± 0.019 ^a	0.501 ± 0.010 ^a	0.471 ± 0.014 ^a	NM
Total protein (%)		10.30 ± 0.18 ^a	15.60 ± 0.31 ^a	12.76 ± 0.14 ^a	10.16 ± 0.15 ^a	12.30 ± 0.27 ^a
Total starch (%)		70.18 ± 1.14 ^a	70.15 ± 1.33 ^a	72.16 ± 1.12 ^a	72.76 ± 1.23 ^a	62.12 ± 1.10 ^a
Dietary fiber (%)		2.71 ± 0.16 ^a	4.15 ± 0.19 ^a	2.18 ± 0.16 ^a	3.45 ± 0.17 ^a	12.11 ± 0.21 ^a
Ingredients of agglomeration process	Semolina (g)	40 ± 0.01	40 ± 0.01	40 ± 0.01	40 ± 0.01	NP
	Water (ml)	15.4 ± 1.50	25.46 ± 1.00	25.6 ± 1.38	37.66 ± 3.78	NP

Note: WS: wheat semolina (the control semolina). SS: sorghum semolina. W SS: whole sorghum semolina. NM: no measurement. NP: no procedure. Mean value ± SD, n=3, ($p < 0.01$). Values within the same row having the same letter are significantly different at $p < 0.05$.

3.3 Characterization of Couscous

The homemade sorghum couscous visually represented in [Figure 1](#), was successfully produced as cohesive raw granules with a uniform shape and size. The yield was excellent and demonstrated a significant difference compared to the raw wheat couscous control.

As detailed in [Table 3](#), the yield of fine sorghum couscous (0.5 < 1mm) was exceptionally high 90.27% for sample A, 89.27% for sorghum couscous B, and 88.42% for sample C, all surpassing the fine wheat couscous control yield of 82.30%.

Furthermore, the bulk density of the fine sorghum couscous samples A, B, and C (0.684g/cm³, 0.684g/cm³, and 0.638g/cm³, respectively), was within the same range as the control (0.655g/cm³). The high extent of decortication was associated with a decrease of the dietary fiber content and a reduction in the proportion of coarse granules within the agglomerated sorghum semolina.

The protein, starch, and dietary fiber content of the sorghum and durum wheat couscous samples are presented in [Table 3](#). The protein and starch contents varied similarly across the samples, unlike the dietary fiber content. Comparing the couscous samples to their respective native semolina, a significant difference ($p < 0.05$) was observed for



Figure 1. Photographs of the Raw and Cooked Couscous: Sorghum and Wheat (control)

Table 3. Physicochemical properties of couscous samples and agglomeration yield

Couscous samples		WC	SC A	SC B	SC C
Agglomeration yield (%)		96.32 ± 0.88 ^b	96.16 ± 0.98 ^a	94.09 ± 1.12 ^a	88.96 ± 1.15 ^{a, b}
Couscous size distribution (%)	0.5<1mm	82.30 ± 2.41 ^a	90.27 ± 2.41 ^a	89.32 ± 4.58 ^c	88.42 ± 3.20 ^d
	1<1.5mm	16.59 ± 2.41 ^a	8.67 ± 1.99 ^a	9.94 ± 4.55 ^b	11.57 ± 3.20 ^d
	>1.5mm	1.09 ± 0.28 ^a	1.05 ± 0.42 ^{af}	0.72 ± 0.34 ^{cb}	0.58 ± 0.42 ^d
Bulk density (g/cm ³)		0.652 ± 0.002 ^a	0.653 ± 0.009 ^a	0.647 ± 0.006 ^a	0.658 ± 0.004 ^a
Total protein (%)		12.49 ± 0.19 ^a	14.40 ± 0.25 ^a	14.67 ± 0.11 ^a	11.45 ± 0.17 ^a
Total starch (%)		65.14 ± 1.22 ^a	73.11 ± 1.15 ^a	75.51 ± 0.88 ^a	60.18 ± 1.15 ^a
Dietary fiber (%)		10.13 ± 0.25 ^a	3.11 ± 0.10 ^a	2.61 ± 0.13 ^a	10.55 ± 0.31 ^a

Note: WC: wheat couscous (control couscous). SC: sorghum couscous. Mean value ± SD, n=3, ($p < 0.01$). Values within the same row having the same letter are significantly different at $p < 0.05$.

all three macronutrients. Protein content ranged from 14.67% (SC B) to 11.45% (SC C), while starch content ranged from 75.51% (SC B) to 60.18% (SC C). The protein (12.49%) and starch (65.14%) contents of the control were lower than those of SC B (14.67%, 75.51%) and SC A (14.40%, 73.11%), but higher than that of SC C (11.45%, 60.18%). Dietary fiber content ranged from 10.55% (SC C)

to 2.61% (SC B), with SC C exhibiting a notably higher content than SC A (3.11%) and SC B (2.61%). These findings indicate that the nutrient content is strongly associated with the initial grain size.

The cooking properties of the sorghum couscous samples and the control are clarified in Table 4. The Optimum

Table 4. Couscous cooking quality

Couscous samples	WC	SC A	SC B	SC C
Optimum Cooking Time (min)	5.0 ± 0.00 ^a	14.0 ± 0.00 ^a	15.0 ± 0.00 ^a	3.0 ± 0.00 ^a
Weight increase index (g/g)	3.43 ± 0.20 ^a	3.04 ± 0.11 ^a	3.21 ± 0.16 ^a	3.49 ± 0.38 ^a
Volume increase (v/v)	2.40 ± 0.00 ^a	2.08 ± 0.14 ^b	2.23 ± 0.15 ^c	2.39 ± 0.37 ^a
Cooking loss (%)	8.00 ± 0.00 ^a	8.94 ± 0.03 ^b	7.00 ± 0.00 ^c	12.21 ± 1.18 ^{ab}

Note: Mean value ± SD, n=3, ($p < 0.01$). Values within the same row having the same letter are not significantly different at $p < 0.05$

Cooking Time (OCT) ranged from 15 minutes for SC B to 3 minutes for SC C. This significant variability is primarily ascribed to the different nutrient compositions, suggesting that the higher content of protein and starch is associated with a longer cooking time ($r > 0.97$; $p < 0.00$).

The Weight Increase Index (WI) and Volume Increase (VI) are related to the amount of water imbibed by the starch and protein, causing swelling at 100°C during the OCT. The WI and VI values varied similarly across the sorghum couscous samples, exhibiting no significant difference ($p > 0.05$) with respect to cooking loss. WI (g/g) ranged from 3.49 (SC C) to 3.04 (SC A) and VI (v/v) ranged from 2.39 (SC C) to 2.08 (SC A). Swelling was more pronounced in samples with high dietary fiber content such as the control and SC C ($p = 0.084$), suggesting a positive association between high dietary fiber content and the extent of swelling.

Cooking Loss, which represents the solid matter lost during cooking in boiling water at the OCT, is a standard quality metric for pasta (Sissons *et al.*, 2021), typically acceptable at $\leq 12\%$. The CL values for SC B (7%), SC A (8.94%), and the control (8.00%) were all within the acceptable range. The significantly higher starch and protein content in SC B and SC A contributed to a reduction in the amount of solid loss compared to SC C. However, sorghum couscous C exhibited a high cooking loss of 12.21% despite its short OCT (3 minutes) classifying SC C as possessing undesirable cooking quality. Consequently, white sorghum grains with a Dm inferior to 4.44 mm are considered unsuitable for producing an edible couscous or pasta that requires cooking in boiling water. Nevertheless, the significant content of starch (72.76%), protein (10.16%), and dietary fiber (3.45%) in the semolina extracted from the short white

sorghum grains, along with the favorable WI and VI, highlights their potential for utilization in producing gluten-free flour and expanded food products such as pop sorghum (Kent *et al.*, 2021).

The color profile constitutes the primary quality parameter evaluated by consumers, and is crucial for monitoring chemical changes, often assessed using the CIE $L^* a^* b^*$ color space method widely adopted in the food industries (Pathare *et al.* 2013). In sorghum grains, color is influenced by the presence of natural pigments, namely carotenoids and anthocyanins (McDowell *et al.*, 2024). The color indices and scores for the semolina, raw couscous, and cooked couscous (sorghum and control) are summarized in Table 5.

The redness (a^*) of the sorghum semolina was not directly associated with the size of its native grains, unlike the yellowness (b^*). Semolina extracted from large grains exhibited higher a^* but lower b^* , while semolina from short grains displayed higher a^* and b^* . Conversely, the control semolina demonstrated low redness and high yellowness.

In a similar vein, when compared to the control semolina ($L^* = 77.66^\circ$ and color score = 6.949) the sorghum semolina samples exhibited higher brightness (L^*) and lower color scores. This is likely attributable to the significant differences in the endosperm structure and content between wheat and sorghum grains (Aboubacar *et al.*, 1999; Wang *et al.*, 2024). Sorghum semolina C displayed the highest brightness at ($L^* = 82.85\%$), surpassing SS A, SS B, and the control, resulting in a higher color score of 6.361. That observation is primarily ascribed to the mixed endosperm texture of the short sorghum grains (C) and the specific milling procedure utilized (Yogananda *et al.*, 2021). Generally, the hues of the sorghum

Table 5. Semolina and couscous (sorghum and wheat) color index and color score

Samples		Color index				Color score (1–10)
		L^*	$a^* (> 0)$	$b^* (> 0)$	$h^* (^\circ)$	
Semolina	WS	77.66 ± 0.24^a	0.76 ± 0.02^{ab}	30.66 ± 0.31^a	88.57 ± 0.04^a	6.949 ± 0.020^a
	SS A	79.91 ± 0.11^a	2.00 ± 0.02^{ab}	19.98 ± 0.14^a	84.28 ± 0.10^a	5.993 ± 0.020^a
	SS B	78.94 ± 0.17^a	1.87 ± 0.03^a	21.05 ± 0.15^a	84.93 ± 0.11^{ab}	6.052 ± 0.006^a
	SS C	82.85 ± 0.17^a	1.97 ± 0.03^a	22.19 ± 0.18^a	84.91 ± 0.04^{ab}	6.361 ± 0.009^a
	WSS	81.08 ± 0.10^a	2.17 ± 0.06^a	17.51 ± 0.07^a	82.92 ± 0.22^a	5.805 ± 0.012^a
Raw couscous	WC	69.97 ± 0.13^a	2.06 ± 0.04^a	33.62 ± 0.18^a	86.48 ± 0.09^a	6.860 ± 0.011^a
	SC A	65.97 ± 0.13^{ab}	5.10 ± 0.05^{ac}	23.66 ± 0.19^a	77.81 ± 0.20^{ac}	5.664 ± 0.022^a
	SC B	63.20 ± 0.11^a	4.89 ± 0.05^a	22.88 ± 0.22^a	77.92 ± 0.23^{ac}	5.448 ± 0.020^a
	SC C	66.53 ± 0.23^a	5.36 ± 0.12^a	23.57 ± 0.15^a	77.18 ± 0.34^{ac}	5.684 ± 0.009^a
Cooked couscous	WC	65.55 ± 0.11^a	1.24 ± 0.04^a	26.87 ± 0.78^a	87.57 ± 0.10^a	5.964 ± 0.084^a
	SC A	60.86 ± 0.12^{ab}	5.20 ± 0.22^{ac}	30.72 ± 0.30^a	80.38 ± 0.49^{ad}	6.115 ± 0.036^{ab}
	SC B	59.39 ± 1.25^a	6.58 ± 0.28^a	29.92 ± 0.17^a	77.58 ± 0.45^{ade}	5.962 ± 0.080^{ab}
	SC C	59.09 ± 0.70^a	6.22 ± 0.16^a	29.68 ± 0.24^a	78.14 ± 0.40^{ac}	5.922 ± 0.016^{ab}

Mean value $\pm$ SD, $n=3$, ($p < 0.001$). Values within the same column having the same letter are significantly different at $p < 0.05$. h : Hue angle ($^\circ$) = $\tan^{-1}(b^*/a^*)$

Color score = $\frac{(L^* + (b^* \times 2))}{20}$; score 10 was the best qualification (Martinez *et al.* 2007).

semolina samples were characterized as yellow-green and slightly darker than the durum wheat semolina control. Importantly, the decortication of sorghum grains led to a decrease in redness (a^*) by less than 2.17% compared to whole sorghum semolina, and an increase in yellowness (b^*) by more than 17.71%, consequently enhancing the brightness of the bran-free semolina.

Concerning the color of the sorghum couscous, the steaming process was found to increase both redness (a^*) and yellowness (b^*), while simultaneously reducing the brightness (L^*) of both cooked couscous samples and the control relative to their raw counterparts. As visually represented in Figure 1, raw sorghum couscous was darker than the cooked sorghum couscous, and both sorghum products were darker than the wheat control. The color scores of the cooked sorghum couscous and the control ranged from 6.115 (SCA) to 5.964 (Control), indicating a medium qualification of visual quality. The hues of the cooked couscous samples were inconsistent ($p > 0.05$) when compared to the raw couscous samples. In contrast, the hue of the raw and cooked wheat couscous control remained consistent, suggesting that panelists perceive minimal color change in wheat couscous compared to the substantial shifts observed in sorghum couscous.

3.4 Sensory Evaluation

The sensory acceptance of the couscous samples and the control, determined using a nine-point hedonic scale across attributes including appearance, color, odor, flavor, mouthfeel (mouthfulness), and overall acceptability, is presented in Table 6.

flavor, a rough and grainy texture, and a brown color. The perceived grainy and rough texture is often attributed to the protein-starch interaction prevalent in sorghum, which can impede protein digestion (Xiong *et al.*, 2019).

The control (durum wheat couscous) was rated significantly higher for its appearance, color, odor, and mouthfeel and overall acceptability, establishing it as the most preferred couscous, unlike the sorghum samples. While cooked sorghum couscous demonstrated sufficient quality and appeal to the panelists, when compared to the familiar wheat couscous (their habitual food), it was rated lower. In this context, the potential for improving the overall acceptability of sorghum couscous exists: incorporating flavor enhancers such as salt during cooking (Taylor *et al.*, 2007) and consuming it with traditional accompaniments such as vegetable sauce and buttermilk could significantly enhance its palatability.

4 CONCLUSION

The findings of this study conclusively demonstrate that white sorghum semolina can be efficiently and effectively agglomerated to produce a fine couscous product of desirable uniformity in size. The high extent of decortication of sorghum grains was positively associated with a high yield of fine couscous and resulted in a quantifiable decrease in the redness (a^*) of the final product. Large grains yielded semolina with the highest content of protein and dietary fiber, and their resulting agglomerated couscous exhibited the lowest percentage of coarse particles. Couscous produced from large

Table 6. Sensory attributes of sorghum couscous and control (raw and cooked)

Samples		LSD (0.05)	Appearance	Color	Odor	Flavor	Mouthfeel (mouthfulness)	Overall acceptability
Raw couscous	WC	0.220	7.64 ± 1.19 ^a	8.00 ± 1.15 ^a	7.07 ± 1.35 ^a	-	-	-
	SC A	0.116	6.07 ± 1.30 ^{ab}	5.50 ± 2.09 ^{ab}	6.54 ± 2.02 ^b	-	-	-
	SC B	0.610	5.64 ± 1.78 ^{ad}	5.21 ± 1.66 ^{ac}	5.61 ± 1.89 ^{ab}	-	-	-
	SC C	0.116	5.00 ± 2.27 ^a	4.61 ± 1.98 ^{ad}	5.75 ± 1.91 ^{ab}	-	-	-
Cooked couscous	WC	0.037	7.04 ± 1.40 ^{cb}	7.61 ± 0.87 ^c	7.71 ± 1.43 ^c	6.71 ± 1.78 ^c	6.61 ± 2.11 ^c	7.50 ± 1.79 ^c
	SC A	0.001	6.86 ± 1.35 ^{cc}	6.57 ± 1.33 ^{cb}	4.93 ± 2.47 ^{cb}	4.93 ± 1.90 ^{cd}	4.61 ± 2.20 ^{cb}	5.21 ± 2.04 ^{cb}
	SC B	0.001	6.71 ± 1.08 ^{cd}	6.07 ± 1.15 ^{cc}	5.29 ± 2.32 ^{cc}	4.43 ± 2.00 ^{cc}	4.21 ± 1.61 ^{cc}	4.89 ± 1.79 ^{cc}
	SC C	0.020	5.68 ± 1.56 ^c	4.32 ± 1.74 ^c	5.79 ± 1.91 ^{cd}	4.43 ± 2.15 ^{cd}	4.82 ± 2.19 ^{cd}	4.75 ± 2.25 ^{cd}

Note: Mean ± SD; one way ANOVA, LSD test: Values within the same column having or containing the letter ("a" or "c") are significantly different at $p < 0.05$. Values having second letter are not significantly different each other ($p > 0.05$).

Regarding the mean attribute scores, the panelists exhibited moderate acceptance of the color and appearance of couscous prepared from sorghum semolina A and B, with average preference scores close to 6 ("like slightly")—a slight but notable difference compared to the control ("like moderately"). Panelist comments frequently described the sorghum couscous samples as possessing a sweet and nutty

grains displayed acceptable cooking quality, high brightness and yellowness indices, and achieved satisfactorily sensory scores for its appearance, color, flavor and overall acceptability, particularly when compared to the wheat couscous control. Couscous produced from medium grains demonstrated the best cooking stability, indicated by the

lowest cooking loss, although this required a significantly longer optimum cooking time (15 minutes). The cooked couscous derived from short grains obtained the highest score for its odor attribute.

Generally, employment of larger, decorticated white sorghum grains yields the most promising avenue to produce high-quality, sorghum-based couscous with characteristics most similar to the conventional durum wheat product.

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