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Original Research Article

Effects of *Triticum aestivum* L. and *Triticum durum* Desf. Bran Processing on Fiber Content and Consumer Acceptance of Bran-Containing Cookies

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ABSTRACT

Triticum aestivum L. and *Triticum durum* Desf. bran is a by-product of milling with valuable dietary fiber content, yet its incorporation in food products often affects sensory acceptability. The present study aimed to determine how various processing techniques affect the amount of fiber in wheat bran and how these changes affect the overall quality, sensory qualities, and consumer acceptance of cookies made with bran. Untreated and cellulase-treated brans were incorporated into cookies to evaluate compositional changes and consumer acceptance. The results showed that soft wheat bran contained higher levels of cellulose (350 g/kg) and hemicellulose (270 g/kg) compared to durum wheat bran (300 g/kg and 230 g/kg, respectively), whereas durum bran had greater amounts of lignin (80 g/kg vs. 50 g/kg) and ash (120 g/kg vs. 90 g/kg). Enzymatic treatment reduced cellulose and hemicellulose contents to 324.5 g/kg and 150 g/kg in soft bran and to 280 g/kg and 125 g/kg in durum bran, respectively. Reducing sugar release increased more in treated durum bran (3.10 mg/g) than in soft bran (1.00 mg/g). Coarse bran retained more fibrous structures, while fine bran released more reducing sugars. No significant differences ($p \geq 0.05$) in water-holding or oil-holding capacity were observed across particle sizes. Sensory analysis slightly favoured cookies with coarse durum bran (taste: 15.7 ± 2.8; appearance: 14.6 ± 2.9), though not all differences were statistically significant. Demographic variables had a limited impact, though gender influenced appearance scores, and field of study affected taste ratings. The findings suggest that enzymatic treatment and optimal particle size can enhance the acceptability of bran-enriched products.

Keywords: Wheat, Bran, Cellulase, Dietary Fiber, Cookies, Sensory Evaluation

Introduction

Wheat (*Triticum aestivum* L. and *Triticum durum* Desf.) bran, a major byproduct of wheat grain milling, constitutes approximately 15–25% of the total grain.[1-4] It is an abundant source of dietary fiber (DF), vitamin B, minerals, and various bioactive compounds. Despite its nutritional value, wheat bran has traditionally been underutilized, often relegated to low-value applications. However, as a significant agro-industrial residue, it holds untapped potential for sustainable valorization. Due to its high dietary fiber content, wheat bran (WB) has applications in both animal and human nutrition.[5-7] Consuming fiber-rich foods is associated with numerous health benefits. Dietary fiber plays a crucial role in promoting health and preventing diseases, particularly in regulating blood sugar and cholesterol levels, managing body weight, and reducing the risk of colon cancer.[1] The dietary fiber in wheat bran is primarily insoluble (IDF), with a smaller portion being soluble (SDF). Soluble dietary fiber consists mainly of oligosaccharides, arabinoxylans, and inulins,[8,9] while IDF is predominantly composed of resistant starch, lignin, and structural polysaccharides, such as cellulose and hemicellulose.[8,10]Numerous studies have explored fiber enrichment by incorporating various cereal brans, such as wheat, rice, and oat brans, in human food.[11] The inclusion of wheat bran in bakery goods has encountered difficulties in consumer acceptance.

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Although wheat bran fiber contributes to the nutritional load of food, it often results in a denser, coarser texture and a darker color that many consumers find unappealing.[12,13] This challenge is particularly evident in cookies, where consumers tend to prefer those made with traditional white flour. The contrast between the health benefits of fiber and consumer preferences underscores the need to develop processes capable of overcoming this obstacle. This study was conducted to evaluate how different processing methods of wheat bran influence its fiber content and to assess the impact of these modifications on the quality, sensory attributes, and overall consumer acceptance of bran-containing cookies.

Materials and Methods

Source and preparation of wheat

Soft wheat (*Triticum aestivum* L.) and durum wheat (*Triticum durum* Desf.) grains were purchased in March 2024 from Minoterie Othmane, a commercial milling company located in the Zerhoune Area, Meknes Region, Morocco (coordinates: 34°03′15″ N, 5°31′38″ W; decimal: 34.054167, –5.527222; UTM: 30S 266736 3771044).[14] The botanical names were provided by the supplier. The grains were stored in a refrigerator at 4 °C until use, then washed, air-dried, milled, and sieved using a conventional grain milling machine. The resulting bran was used for the cookie formulations.

Processing of wheat bran samples

Wheat bran was fractionated by sieving through 0.8 mm, 1.2 mm, and 2 mm screens. Particles larger than 2 mm were classified as ground bran, with one portion ground through a 3 mm screen to obtain ground coarse bran (GC) and another ground at 0.5 mm to produce ground fine bran (GF). The 1.2–2 mm fraction was designated as sifted coarse bran and further ground at 3 mm to yield sifted coarse bran (SC). The 0.8–1.2 mm fraction was discarded, while particles ≤0.8 mm were categorized as sifted fine bran and ground at 0.5 mm to produce sifted fine bran (SF). Separation methods (grinding and sifting) were

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employed to account for wheat bran hardness at comparable particle sizes, with all grinding performed using a Retsch Cross Beater Mill SK 100–McCrone to ensure uniformity across samples.

Cellulase treatment of bran

To evaluate the efficiency of cellulase on different wheat bran types, four bran samples: GC, GF, SC, and SF, were treated with cellulase enzymatic hydrolysis.[15] This was achieved by incubating 9 Ug^{-1} dry matter (DM) of commercial cellulase from *Aspergillus niger* (Sigma-Aldrich) in 75 mL of an acetic acid–sodium acetate buffer (pH 4.2) for 120 minutes at 50 °C and 35 rpm. The control samples were subjected to the same conditions without the enzyme.[16-17] The amount of reducing sugars released from both treated and control samples was quantified using the 3,5-dinitrosalicylic acid (DNS) colorimetric method.[16] Enzyme activity was expressed in grams of glucose equivalent per kilogram of dry matter (g/kg DM). One unit (U) of endo-1,4-β-glucanase activity was defined as the amount of enzyme that releases 1 μmol of glucose per minute under the assay conditions (pH 4.2, 50 °C, 10 minutes).[16] The net enzyme efficiency for each bran type was determined by calculating the difference in reducing sugar release between treated and control samples as computed with Equation 1. Enzymatic treatment was applied to address the expected variation in the chemical composition of WB at the same particle size.

$$Enzyme\ efficiency\ (g/kg\ DM) = Treated\ sample - Control\ sample$$ …… Equation 1

Enzyme activity measurement

The cellulase enzyme activity was conducted by combining 0.5 milliliters of an enzyme solution (0.02 milligrams per liter of protein) with 0.5 milliliters of 0.05% (w/v) carboxymethyl cellulose (CMC), both prepared in a 0.05 M citrate buffer at pH 4.2. The reaction mixture was incubated at 50 °C for 10 minutes.[18] The quantity of reducing sugars released was expressed in grams per kilogram of dry matter (g/kg DM) and quantified using the dinitrosalicylic acid (DNS) colorimetric method. One unit (U) of endo-1,4-β-glucanase activity is equivalent to the release of 1 μmol of glucose per minute under the specified assay conditions (50°C, pH 4.2, 10-minute incubation), as outlined by standard protocols.[19]

Determination of the chemical composition of bran

The moisture content of the bran was determined using the oven-drying method (AOAC 925.10). The ash content was determined using the muffle furnace method (AOAC 942.05).[20,21] Water holding capacity (WHC) and oil holding capacity (OHC) were measured using the gravimetric method to assess the ability of bran to absorb and retain water and oil.[21] The capacities were calculated using Equation 2.

$$HC = \frac{Wheight\ of\ hydrated\ or\ oil\ saturated\ bran - Weight\ of\ dry\ bran}{Weight\ of\ dry\ bran}$$

…………………………………………………………… Equation 2

Where water holding capacity (WHC) is expressed as grams of water retained per gram of bran, oil holding capacity (OHC) is expressed as grams of oil retained per gram of bran.

Cookies formulation

The cookie formulation for the study was based on a traditional Moroccan recipe. It was adapted as follows: 400 g white flour (durum (control 1) or soft (control 2) wheat without bran), 125 g sugar, 150 mL vegetable oil, 8 g baking powder, 7.5 g vanilla sugar, and 225 g butter. Sixteen wheat bran samples (treated and untreated) were incorporated into the standard recipe at a ratio of 12 g per 100 g of white flour. The dough was rolled out to approximately 2 mm and then cut to make cookies, which were cooked in an electric oven at 180°C for approximately 30 min.[23]

Fiber analysis

Fibers were analyzed using the method described by Van Soest and coworkers.[24] Hemicellulose (HC) was calculated as the difference between neutral detergent fiber (NDF) and acid detergent fiber (ADF); acid detergent lignin (ADL) was considered equivalent to lignin (L); and cellulose (C) was determined as the difference between ADF and ADL.

Sensory evaluation

A sensory analysis was conducted with 124 participants from Fez and Meknes, Morocco, to evaluate the taste and appearance of a control cookie (100% white flour) and five additional cookie samples, which were randomly presented to each participant. Participants evaluated each cookie on a 0 - 20 scale in two stages: first for taste, with palate-cleansing water provided between samples, and then for appearance. This order (taste first, then appearance) was maintained to ensure that the taste and appearance of the cookie were evaluated independently, without influencing each other. Additionally, a standardized questionnaire collected information, including sex, age, culinary skills, health conditions, educational level, and study specialization (social sciences, technical sciences, or biological sciences). These data allowed for a deeper understanding of the participant's preferences and perceptions.

Statistical analysis

The statistical analysis was performed using R software (version 4.3.2, 2023-10-31 ucrt).[25] Data normality was assessed with the Shapiro–Wilk test, and homogeneity of variances was examined using Levene's test. When the assumptions of normality and homoscedasticity were satisfied, analysis of variance (ANOVA) was conducted to evaluate the effects of bran type, particle size, separation method, cellulase addition, and their interactions on the response variables, including cellulose, lignin, hemicellulose, WHC, OHC, resistant starch (RS), taste, and appearance. Post-hoc comparisons were carried out using Tukey's Honest Significant Difference (HSD) test to identify differences between groups. In addition, Welch's two-sample t-test was used to compare the means of "appearance" and "taste" within the same individual, while the Wilcoxon rank sum test was employed when the assumptions for ANOVA were not met. Finally, principal component analysis (PCA) was performed on the dataset, which consisted of 32 individuals and nine variables, to explore patterns and relationships among the measured traits.

Results and Discussion

Chemical composition of wheat bran

The chemical composition analysis of soft wheat bran and durum wheat bran on a dry weight basis is shown in Table 1. Soft wheat bran contained higher levels of cellulose (350 g/kg vs. 300 g/kg) and hemicellulose (270 g/kg vs. 230 g/kg), whereas durum wheat bran showed higher lignin (80 g/kg vs. 50 g/kg) and ash content (120 g/kg vs. 90 g/kg). These differences are consistent with previous studies that have highlighted variations in the composition of wheat bran depending on the wheat variety.[26,27] Several studies have shown that the fiber composition of wheat bran contributes to functional properties, such as WHC and OHC. These components are known to enhance the ability of bran to absorb and retain water and oil.[28]

Effect of cellulase treatment on composition and functional properties

The analysis revealed a statistically significant reduction in cellulose and hemicellulose content in treated samples of both bran types compared to untreated controls ($p < 0.05$), whereas lignin content remained unchanged ($p > 0.05$), as shown in Figure 1. Specifically, the cellulose content exhibited a significant decrease in the cellulase-treated samples (average cellulose decreased from 328.4 g/kg to 308.5 g/kg, with greater variability in treated samples) ($p < 0.0001$). This effect is more pronounced in durum wheat bran. The reduction in cellulose is attributed to the enzymatic action of cellulase, which breaks down cellulose, demonstrating the effectiveness of the enzyme used in this treatment.[16] Similarly, hemicellulose content declined from 166.0 g/kg to 143.7 g/kg, though with increased variability (higher standard deviation) among treated samples. This suggests divergent sample responses to the treatment, possibly due to structural differences in bran composition or uneven enzymatic accessibility.

Table 1: Physicochemical characteristics of wheat bran samples.

Parameter (unit)	Wheat bran separation method							
	Durum				Soft			
	Grinding		Sifting		Grinding		Sifting	
Size	Coarse	Fine	Coarse	Fine	Coarse	Fine	Coarse	Fine
Cellulose (g/Kg)	340.1^{c}	340.3^{a}	310.2^{b}	280.8^{a}	340.9^{c}	340.0^{c}	340.8^{c}	310.8^{b}
Hemicellulose (g/Kg)	150.8^{a}	140.9^{a}	160.5^{b}	180.4^{c}	150.8^{a}	190.8^{d}	105.2^{a}	180.1^{c}
Lignin (g/Kg)	30.7^{b}	30.8^{b}	30.8^{b}	30.9^{b}	50.3^{c}	40.9^{c}	30.1^{a}	30.8^{b}
RS (g/Kg)	35.9^{b}	36.9^{b}	33.4^{a}	36.9^{b}	44.3^{d}	41.5^{c}	44.0^{d}	45.5^{d}
OHC (g/Kg)	1.6^{b}	1.7^{b}	1.4^{a}	1.6^{b}	1.6^{b}	1.3^{a}	1.4^{a}	1.4^{a}
WHC (g/Kg)	2.4^{c}	2.2^{b}	1.8^{a}	2.9^{d}	2.5^{c}	1.9^{a}	3.2^{d}	2.1^{b}

RS: released sugar; OHC: oil holding capacity; WHC: water holding capacity; Values within the same row followed by different superscript letters (a, b, c, d) are significantly different ($p < 0.05$).

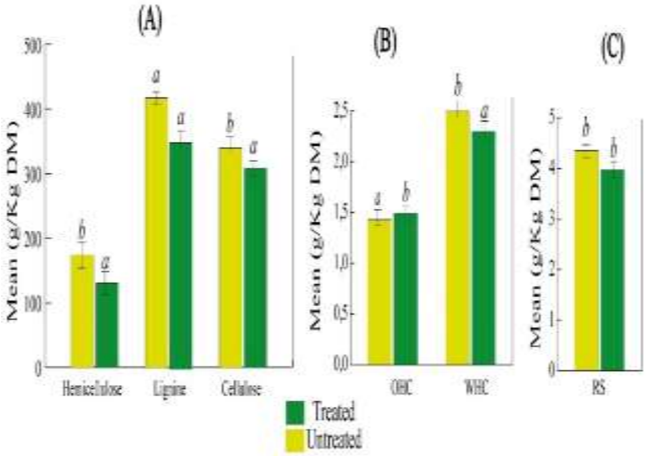

Figure 1: Effect of cellulase treatment on fiber composition (A); functional properties (B); and released sugars (C). WHC: water-holding capacity; OHC: oil-holding capacity; RS: reducing sugars.

The enzymatic treatment also had a significant impact on the functional properties of wheat bran (Figure 1). The WHC increased following cellulase treatment, attributable to the partial breakdown of cellulose and hemicellulose, which modified the bran's fiber matrix.[29-30]
As the rigid cellulose fibers are partially degraded, the bran structure becomes looser and more porous. This increases the available sites for water binding, leading to greater WHC. Additionally, the functional properties were found to be highly dependent on their physicochemical characteristics.[31] This increase in WHC is particularly beneficial for food applications, as it improves the hydration properties of bran, leading to better dough consistency and texture in baked goods.[32] In contrast, the OHC exhibited a modest but statistically significant decrease ($p = 0.048$). This reduction may result from the increased hydration of the fiber matrix (as evidenced by higher WHC), which likely diminishes its affinity for non-polar substances, such as oil. Furthermore, the cellulase treatment resulted in an increase in RS across both types of wheat bran, with the effect being more significant in durum wheat bran (Table 1). The RS increased by an average of 3.10 mg/g in durum wheat bran, while in soft wheat bran, the RS increase was comparatively lower, averaging 1.00 mg/g. As shown in the results, cellulase hydrolyzes cellulose and hemicellulose, releasing glucose, cellobiose, xylose, and arabinose as RS.[32,33]

Effect of particle size on composition and functional properties

Milling significantly altered fiber composition ($p = 0.045$) and sugar distribution ($p = 0.049$), while also affecting functional properties ($p = 0.042$). Analysis revealed distinct differences between coarse and fine particles in cellulose content and OHC ($p < 0.05$), whereas lignin, hemicellulose content, and WHC remained unaffected by particle size ($p > 0.05$) (Figure 2). The coarse fraction exhibited higher cellulose content but lower RS levels compared to the fine fraction. This divergence arises from the milling process: coarser particles retain more intact fibrous structures rich in cellulose, whereas finer particles expose inner cell contents, promoting the release of soluble sugars.[33] Additionally, starch granules in the fine fraction may undergo partial hydrolysis during milling, further increasing RS levels.[34] The functional properties of wheat bran, including WHC and OHC, were not significantly influenced by particle size ($p > 0.05$).

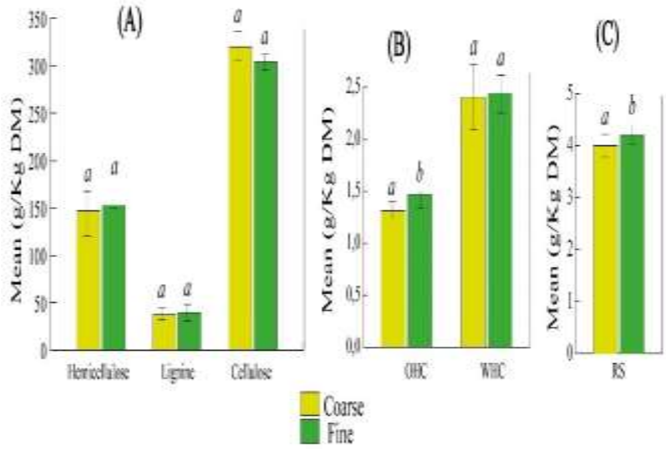

Figure 2: Effect of bran particle size on fiber composition (A); functional properties (B); and RS (C). WHC: water-holding capacity; OHC: oil-holding capacity; RS: reducing sugars.

Effect of type of bran on composition and functional properties

The type of wheat bran significantly influenced its chemical composition and functional properties, as evidenced by the data presented in Figure 3. After cellulase treatment, the hemicellulose content decreased to 125 ± 12.0 g/kg in durum wheat bran and 150 ± 11.6 g/kg in soft wheat bran. This may be due to differences in the structural composition of the two wheat varieties. Durum wheat bran may have a more accessible hemicellulose structure, making it more susceptible to enzymatic degradation.[35] There was no significant difference between durum and soft wheat bran concerning lignin content after cellulase treatment. After cellulase treatment, the lignin content decreased to 32 ± 3.3 g/kg in durum wheat bran and 36 ± 2.2 g/kg in soft wheat bran. Additionally, after cellulase treatment, the cellulose content decreased to 280 ± 15 g/kg in durum wheat bran and 324.5 ± 15 g/kg in soft wheat bran.

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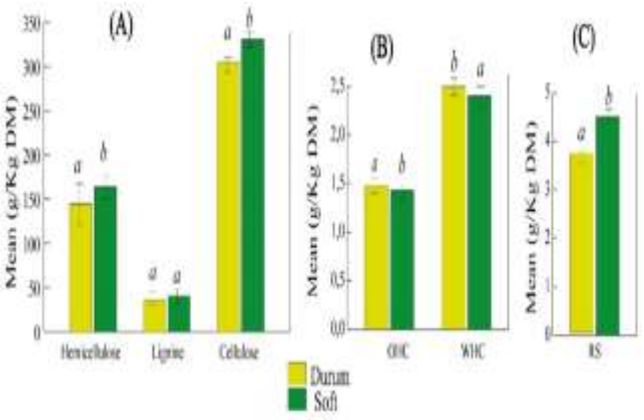

Figure 3: Effect of bran type on fiber composition (A); functional properties (B); and RS (C). WHC: water-holding capacity; OHC: oil-holding capacity; RS: reducing sugars.

After cellulase treatment, the OHC decreased to 1.41 ± 0.06 mg/g in durum wheat bran and 1.44 ± 0.07 mg/g in soft wheat bran. On the other hand, the WHC increased to 2.77 ± 0.40 mg/g in durum wheat bran and 2.59 ± 0.44 mg/g in soft wheat bran. The type of wheat bran significantly influenced the amount of RS following cellulase treatment. In durum wheat bran, RS increased by an average of 3.10 mg/g after cellulase treatment, whereas in soft wheat bran, the RS increase was lower, averaging 1.00 mg/g. As shown in the results, soft wheat bran contains a higher lignin content, which resists cellulase activity. This likely explains the greater RS increase observed in durum wheat bran.

Effect of separation method on composition and functional properties

The separation method (grinding vs. sifting) significantly influenced the chemical composition and functional properties of wheat bran, as presented in Figure 4. Grinding generally retained more cellulose and enhanced OHC, while sifting retained more hemicellulose and enhanced cellulose degradation after enzymatic treatment. Ground bran, with its higher cellulose content (337.9 ± 13.1 g/kg untreated, 328.2 ± 21.4 g/kg treated) and greater OHC (1.55 ± 0.13 mg/g untreated, 1.42 ± 0.07 mg/g treated), is better suited for improving the oil-binding capacity and texture of food products. The greater increase in WHC after enzymatic treatment (2.76 ± 0.31 mg/g) also suggests that grinding enhances the hydration properties of bran, making it ideal for applications requiring improved dough consistency and texture.[36]

Sifted bran, with its higher hemicellulose content (177.3 ± 16.7 g/kg untreated, 147.0 ± 24.1 g/kg treated) and greater cellulose degradation after enzymatic treatment (288.7 ± 26.4 g/kg), may be more amenable to enzymatic modification to improve its functionality. However, its lower OHC (1.44 ± 0.09 mg/g untreated, 1.43 ± 0.05 mg/g treated) and WHC (2.22 ± 0.48 mg/g untreated, 2.60 ± 0.52 mg/g treated) compared to ground bran may limit its application in certain food products. The separation method influenced RS levels following cellulase treatment of wheat bran. In durum wheat bran, grinding increased RS with an overall increase of 4.2 mg/g compared to sifting. Sifting also enhanced RS with an increase of 4.3 mg/g. In soft wheat bran, the trend was less consistent.

Sensory evaluation of cookies

The sensory evaluation involved 124 participants from Fez and Meknes, Morocco, who evaluated the taste and appearance of cookies made with different combinations of wheat bran type, treatment, particle size, and separation method. The results are compared to a control cookie (100% white flour), as shown in Table 2. The findings of this study underscore the intricate role of dietary fiber in shaping the functional and sensory properties of cookies. While cellulose, hemicellulose, and lignin are fundamental structural components of bran, the correlation analysis (Figure 5) revealed that their individual presence does not exert a significant influence on key sensory attributes, such as taste and appearance. This suggests that the quality of cookies is not directly determined by specific fiber content alone but rather by the interplay and balance of different components.

Influence of structural and functional ratios on sensory attributes of bran-enriched cookies

The results (Figure 5) showed the strong positive correlations between the ratio of (cellulose + hemicellulose + RS) to lignin ([C + H + RS] / L) and taste (r = 0.74), as well as between the combined presence of RS and cellulose (RS + C) and taste (r = 0.72). These findings underscore the significance of balancing these components to achieve desirable sensory outcomes.

Table 2: Effects of study parameters on sensory attributes of cookies.

Wheat bran	Treatment	Particle texture	Separation method	Taste score	Appearance
Durum	Treated	Coarse	Grinding	15.7 ± 2.8^b	14.6 ± 2.9^b
Soft	Treated	Coarse	Grinding	15.2 ± 2.6^b	14.2 ± 3^b
Durum	Untreated	Coarse	Grinding	14.2 ± 2.8^b	14.0 ± 2.6^b
Soft	Untreated	Coarse	Grinding	15.5 ± 2.5^b	14.6 ± 2.8^b
Durum	Treated	Fine	Grinding	15 ± 3^b	14.9 ± 2.8^b
Soft	Treated	Fine	Grinding	14.5 ± 2.3^b	13.9 ± 2.8^b
Durum	Untreated	Fine	Grinding	13.9 ± 3.1^a	13.8 ± 2.9^a
Soft	Untreated	Fine	Grinding	15.2 ± 1.9^b	12.9 ± 1.8^b
Durum	Treated	Coarse	Sifting	15.2 ± 2.4^b	13.5 ± 2.5^b
Soft	Treated	Coarse	Sifting	14.44 ± 2.4^b	13.3 ± 2.6^b
Durum	Untreated	Coarse	Sifting	13.9 ± 2.9^b	13.7 ± 2.4^b
Soft	Untreated	Coarse	Sifting	1.6 ± 3.1^b	13 ± 2.5^b
Durum	Treated	Fine	Sifting	13.5 ± 2.7^b	14.4 ± 2.5^b
Soft	Treated	Fine	Sifting	14.8 ± 3^b	14.2 ± 2.7^b
Durum	Untreated	Fine	Sifting	14.8 ± 2.7^b	14 ± 2.7^b
Soft	Untreated	Fine	Sifting	14.6 ± 3^b	13.6 ± 2.7^a
Control 1				14.8 ± 2.7^b	14.2 ± 2.7^b
Control 2				14.61 ± 2.47^b	13.49 ± 2.53^b

Values within the same column followed by different superscript letters (a, b, c, d) are significantly different ($p < 0.05$). Control 1= durum wheat flour without bran; Control 2 = soft wheat flour without bran

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This suggests that a higher proportion of C, H, and RS relative to L enhances the taste of cookies, likely due to the combined effects of improved sweetness (from RS) and better texture (from C and H). Conversely, lignin, when present in higher amounts, appears to have a negative impact, potentially due to its indigestible nature, which can lead to a coarse or dry texture.[37]
The moderate positive correlation between ([C + H + RS] / L) and appearance (r = 0.53) indicates that the balance of these components also plays a role in the visual appeal of cookies. A higher ratio of C, H, and RS to L may lead to a more uniform texture and desirable color, contributing to overall appearance.[37] Additionally, the positive correlation between (H – L) and appearance (r = 0.63) suggests that hemicellulose, when present in higher proportions relative to lignin, improves the visual quality of cookies. This could be attributed to the role of hemicellulose in enhancing dough structure and texture.[38,39] The correlation analysis also revealed the influence of functional properties, such as WHC and OHC, on sensory attributes. The positive correlation between (WHC – OHC) and taste (r = 0.50) suggests that better hydration and texture, as influenced by these properties, contribute to improved sensory quality.[40] Similarly, the positive correlation between (WHC – OHC) and appearance (r = 0.54) highlights the importance of these functional properties in achieving a visually appealing product.

Effect of cellulase treatment on sensory attributes of bran-enriched cookies
Treated bran generally received higher scores than untreated bran for both taste (14.79 ± 2.74 vs. 14.59 ± 2.74) and appearance (14.13 ± 2.72 vs. 13.70 ± 2.58), with the effect being more pronounced in durum wheat samples. However, the differences were not always statistically significant (Table 2). Although cellulase treatment significantly altered fiber composition (particularly cellulose and hemicellulose) and functional properties (OHC and WHC), its impact on sensory attributes (taste and appearance) was limited. This suggests that other factors (not analyzed in this study) beyond fiber breakdown and functional properties, such as flavor development, texture perception, and interactions with other ingredients, play a key role in determining consumer preference.[41] These findings suggest that the cookie formulations used in this study, particularly their bran content (see Materials and Methods), were sufficient to achieve optimal quality without cellulase treatment, indicating that enzymatic modification may not be essential for improving sensory attributes in this context. Durum bran treatment led to a notable improvement in taste, especially in combinations with coarse particles and grinding, where the taste score increased from 14.2 (untreated) to 15.7 (treated). This suggests that cellulase treatment enhances the flavour profile of durum bran, likely by breaking down cellulose and improving the texture and palatability of the cookies.[42,43]

Effect of particle size on sensory attributes of bran-enriched cookies
Coarse bran (1.2 mm < particle size ≤ 2 mm) generally received higher scores for taste (14.78 ± 2.3) and appearance (13.76 ± 2.4) than fine bran (14.44 ± 2.4 for taste and 13.79 ± 2.1 for appearance), particularly in the case of durum wheat. This suggests a general preference for larger particle sizes in terms of sensory attributes. However, the statistical analysis reveals that particle size alone did not have a significant impact on taste (p = 0.27) or appearance (p = 0.32), except for soft fine bran. Fine bran (particle size ≤ 0.8 mm), especially when untreated, often scored lower in appearance, suggesting that finer particles may negatively impact sensory attributes. This indicates that coarser bran contributes more favorably to the sensory qualities of the cookies, likely due to its ability to retain moisture and create a more desirable texture.

Effect of type of bran on sensory attributes of bran-enriched cookies
As shown in Table 2, the type of bran had a significant effect on both taste (p = 0.03) and appearance (p = 0.04). Soft bran had a slightly higher mean taste score (14.9) compared to durum bran (14.8). Meanwhile, durum bran had a higher mean appearance score (14.1) compared to soft bran (13.7). These results suggest that soft bran enhanced taste, while durum bran improved the visual appeal of cookies. The higher taste score of soft bran may be due to its finer texture and potentially lower lignin content (Table 2), which enhances mouthfeel and reduces the perception of roughness or bitterness. In contrast, durum bran's better appearance score might be attributed to its higher pigment content, which could contribute to a richer color and a more uniform surface. These findings align with previous studies suggesting that bran characteristics, such as particle size and fiber composition, impact sensory attributes in baked goods.[44] The finer structure of soft bran likely allows it to integrate more uniformly into the dough, resulting in a smoother texture and enhanced taste. Conversely, the coarser texture of durum bran may create a grainier appearance but contribute to a visually distinct final product.[33] The significant effect of bran type on sensory properties highlights the importance of selecting the appropriate bran depending on the desired product characteristics. If taste is prioritized, soft bran is preferable, whereas durum bran appears more suitable for improving cookie appearance.

Effects of separation methods on sensory attributes of bran-enriched cookies
The method of bran separation had a notable impact on both taste and appearance (p < 0.04). In general, the grinding method resulted in higher sensory scores compared to sifting. For example, the durum-treated coarse-ground sample achieved a taste score of 15.7 and an appearance score of 14.6, whereas the durum-treated coarse-sifted sample scored 15.2 for taste and 13.5 for appearance. The sifting method generally yielded lower scores, especially in untreated samples; for instance, the soft, untreated, coarse-sifted sample recorded an appearance score of only 13.0. These findings suggest that grinding improves the sensory qualities of bran-enriched cookies by producing a finer, more uniform texture that integrates better into the dough.[44,45] In contrast, sifting may lead to coarser, uneven bran particles, potentially affecting the surface texture and color of the final product. The lower appearance scores associated with sifting, especially in untreated samples, may be due to the presence of larger bran fragments, which could create a rougher, less appealing cookie surface.[8,24,44] Similarly, the lower taste scores could be attributed to the uneven distribution of bran, which might enhance the perception of dryness or grittiness.[9,24,43,47] The improved results with the grinding method aligns with previous studies indicating that finer bran particle size enhances the overall acceptability of fiber-enriched baked goods. Reducing particle size can help mitigate the negative sensory effects often associated with high-fiber ingredients by promoting better hydration and integration within the dough matrix.[17]

Effect of demographic factors on sensory attributes of bran-enriched cookies
The results indicated that demographic factors such as gender, cooking habits, and education level had minimal effects on sensory attributes (taste and appearance). A statistically significant difference in appearance was found between females and males, with males having a higher mean than females (p-value = 0.0181). However, no statistically significant difference in taste was observed between genders (p-value = 0.8391), as the means for both were nearly identical.
No significant difference in appearance was found based on cooking habits (p = 0.81), with both groups showing very similar means. Similarly, there was no significant difference in taste based on cooking habits (p = 0.7681), with both groups displaying nearly identical means. Additionally, there was no significant difference in terms of appearance between individuals with lower and higher levels of education (p = 0.342). Consistently, no significant difference was detected in taste perception between these two groups (p = 0.2623). However, the significant difference in appearance between males and females suggests that gender may influence sensory evaluations, particularly in the perception of appearance. The results of the analysis of variance (Welch's ANOVA) indicate a statistically significant difference in mean taste among the specialization groups (p = 0.0008073). The taste score was significantly higher in social sciences compared to biological sciences (difference ≈ 0.98, p = 0.0034). Taste score was significantly lower in technical sciences compared to social sciences (difference ≈ -0.89, p = 0.0027). No other pairwise comparisons showed statistically significant differences (p > 0.05). The Welch's ANOVA results for appearance indicate that there is no statistically significant difference in

mean appearance scores among the SPEC groups ($p = 0.1071$). The type of specialization (SPEC) does not significantly influence the appearance scores. This suggests that students from different specializations perceive the appearance of Moroccan cookies in a comparable way, showing no significant differences in preference.

Sensory perception analysis

The first two principal components (PC1 and PC2) explained 70.74% of the total inertia in the dataset, suggesting that they captured a significant portion of the variability in the sensory attributes and variables (Figure 4). The analysis of the first two dimensions revealed that they explained 70.74% of the total inertia, indicating that the first two dimensions provided meaningful insights into the relationships between the sensory attributes and other variables (e.g., lignin, WHC, ADF). Based on the ANOVA results and the sensory evaluation data, it was observed that the wheat bran treatment had a significant effect on the sensory properties of the cookies, particularly in relation to the taste and appearance. The particle size of the wheat bran and the cellulase treatment influenced the sensory characteristics, with certain combinations showing higher overall liking scores. The bran: cellulase-separation method interaction was found to significantly affect the sensory outcomes, highlighting the potential of specific treatments in enhancing the flavour and texture of the cookies.[47]

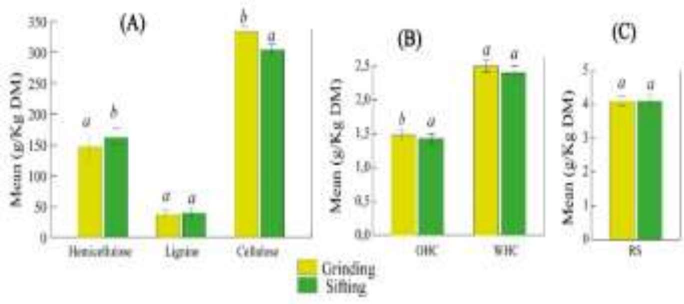

Figure 4: Effects of separation methods on fiber composition (A); WHC, OHC (B); and RS (C). WHC: water-holding capacity; OHC: oil-holding capacity; RS: reducing sugars.

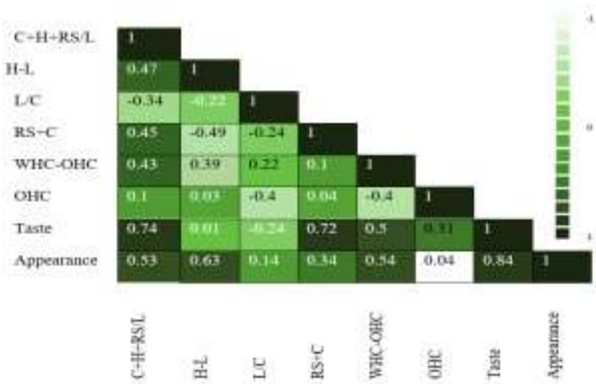

Figure 5: Pearson correlation coefficients between fiber content and functional properties of cookies.

Conclusion

The particle size of wheat bran and cellulase treatment significantly influenced the sensory characteristics, with specific combinations yielding higher overall liking scores. Cellulase treatment effectively modified bran structure by reducing cellulose (28–32%) and hemicellulose (17–25%) content while enhancing WHC by 18–22%, thereby improving its technological functionality for food applications. These findings provide practical guidance for food product development and support the ecological valorization of agro-industrial by-products. Future research should focus on optimizing treatment conditions and conducting broader consumer studies to facilitate the development of nutritious and appealing bran-enriched products aligned with sustainability goals.

Conflict of Interest

The authors declare no conflict of interest.

Authors' Declaration

The authors hereby declare that the work presented in this article is original and that any liability for claims relating to the content of this article will be borne by them.

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