Corncob flour as an alternative ingredient for muffins: technological and nutritional perspectives

Tatiane Monteiro dos Santos [1], Irene Andressa [2] *, Glauce Kelly Silva do Nascimento [3], Nathália de Andrade Neves [4], Marcio Schmiele [5]

[1] monteirotatiane167@gmail.com, [3]glaucekellysn@hotmail.com, [4] andradeneves.nathalia@gmail.com, [5] marcio.sc@ict.ufvjm.edu.br. Institute of Science and Technology, Federal University of Jequitinhonha and Mucuri Valleys (UFVJM), Diamantina, Minas Gerais, Brazil
[2] irene.andressa@hotmail.com. Department of Food Science and Technology, Federal University of Viçosa (UFV), Viçosa, Minas Gerais, Brazil
*Corresponding author

Abstract

The growing demand for environmental sustainability and functional foods has driven the development of new products and food ingredients derived from alternative, cost-effective sources. This study aimed to evaluate the effects of partially replacing wheat flour with corncob flour (CF) at levels of 0% (control), 10%, 20%, 30%, 40%, and 50% on the physicochemical and technological properties of both the dough (pH, specific gravity, and texture) and the muffins (pH, specific volume, water activity, moisture, total titratable acidity, instrumental color, texture, and proximate composition). The high fiber content of CF significantly influenced ($p < 0.05$) the technological properties of the dough, increasing rigidity and reducing specific gravity. In the final product, CF incorporation decreased volume and resilience, while firmness, hardness, adhesiveness, and chewiness intensified. The formulation with a 10% CF replacement exhibited the most favorable characteristics, particularly in terms of dough apparent gravity (0.83 g/mL), specific volume (2.64 L/kg), and firmness (7.05 N). Therefore, the partial substitution of wheat flour with 10% CF appears to be a promising strategy from both technological and nutritional perspectives, mainly due to the increased dietary fiber content, while also contributing to cost reduction and the valorization of an agri-food co-product.
Keywords: bakery; innovation; new products; sustainability; unconventional fibers.

Farinha de sabugo de milho como ingrediente alternativo para muffins: perspectivas tecnológicas e nutricionais

Resumo

A crescente demanda por sustentabilidade ambiental e alimentos funcionais tem impulsionado o desenvolvimento de novos produtos e ingredientes alimentícios derivados de fontes alternativas e econômicas. Este estudo teve como objetivo avaliar os efeitos da substituição parcial da farinha de trigo pela farinha de sabugo de milho (FC) nos níveis de 0% (controle), 10%, 20%, 30%, 40% e 50% nas propriedades físico-químicas e tecnológicas tanto da massa (pH, gravidade específica e textura) quanto dos muffins (pH, volume específico, atividade de água, umidade, acidez titulável total, cor instrumental, textura e composição centesimal). O alto teor de fibras da FC influenciou significativamente ($p < 0,05$) as propriedades tecnológicas da massa, aumentando a rigidez e reduzindo a gravidade específica. No produto final, a incorporação de FC diminuiu o volume e a resiliência, enquanto a firmeza, dureza, adesividade e mastigabilidade se intensificaram. A formulação com substituição de 10% de FC apresentou as características mais favoráveis, principalmente em termos de gravidade aparente da massa (0,83 g/mL), volume específico (2,64 L/kg) e firmeza (7,05 N). Portanto, a substituição parcial da farinha de trigo por 10% de FC parece ser uma estratégia promissora tanto do ponto de vista tecnológico quanto nutricional, principalmente pelo aumento do teor de fibras alimentares, contribuindo também para a redução de custos e a valorização de um coproduto agroalimentar.
Palavras-chave: *fibras não convencionais; inovação; novos produtos; panificação; sustentabilidade.*

1 Introduction

In recent years, increasing concerns about environmental preservation and healthy eating have propelled research into developing new ingredients and products for the food industry. Consequently, agri-food co-products have garnered growing attention due to their abundance, affordability, and appealing nutritional value, especially regarding dietary fiber content (Muñoz-Tebar *et al.*, 2023). The sustainable use of natural resources and co-products to create safe and nutritious food that contributes to combating hunger aligns with the goals of sustainable development and incorporates the principles of the circular economy (Vlaicu; Untea; Oancea, 2024).

Among these co-products, corn cob is the primary by-product of corn processing. In Brazil, corn cultivation holds significant economic and social importance, as most producers are small-scale farmers who cultivate native seeds naturally selected based on the specific conditions of the planting region. Therefore, the use of corncob flour (CF) in food as a non-conventional dietary fiber source presents a viable and promising alternative for increasing the income of small farmers while enhancing the nutritional value of food matrices and adding value to an agro-industrial by-product (Nascimento *et al.*, 2024).

The use of non-conventional flours in bakery products has become increasingly widespread, allowing for the utilization of agro-food co-products , diversification of products, and enhancement of nutritional value. Bakery products rank among the most widely consumed and produced foods globally, offering affordability, accessibility, and appeal across all age groups (Salehi; Aghajanzadeh, 2020). Muffins, typically sold in individual portions (averaging 60 g), have gained prominence and popularity in recent years due to their convenience (Silva *et al.*, 2022).

Health consciousness and convenience are expected to be major food trends in Brazil in the coming years, with dietary fiber emerging as a key area of interest for food production (Duarte; Teixeira; Silva, 2021). However, incorporating dietary fiber into bakery products remains a challenge for the industry, as it often affects the technological and sensory attributes of the final product, precise volume, and texture. In muffin-type cakes, however, the negative effects of dietary fiber addition are mitigated by the higher fat content compared to other baked goods, which aids in greater gas retention in the dough during baking. This process is further supported by mixing techniques and leavening agents, with sodium bicarbonate being the most commonly used for cakes (Giri *et al.*, 2024).

Therefore, incorporating corncob flour into muffins has the potential to reduce formulation costs while increasing dietary fiber content. As the application of corn cob derivatives in food systems remains limited, this study aimed to evaluate the impacts of partially replacing refined wheat flour with CF on the physicochemical and technological properties of dough and muffins.

This paper is organized into sections that explore the topic in detail. Following the introduction, the methodology (Section 2) explains the procedures used to collect and analyze the data. In the results and discussion section (Section 3), the main findings are presented, analyzed, and interpreted in light of the existing literature. Finally, the conclusion (Section 4) summarizes the key findings and suggests directions for future research.

2 Material and methods

The Creole corn cobs were supplied by the Crioulo Corn Project at the Institute of Agricultural Sciences, UFVJM (2020 harvest), and registered in the National System for the Management of Genetic Heritage and Associated Traditional Knowledge (SisGen) under number A5C29C1. The cobs were stored in high-density polyethylene containers, properly sealed, and protected from light. The grinding process was carried out to obtain flour, following the methodology described by Nascimento *et al.* (2024).

The raw materials utilized in this study comprised wheat flour, corncob flour, fresh eggs, whole milk, sucrose, hydrogenated vegetable fat, a dough booster (consisting of corn starch as a carrier, sodium bicarbonate, monocalcium phosphate, and calcium carbonate), and a commercial emulsifier (including monoglycerides of distilled fatty acids, fatty acid salts, sorbitan monostearate, and polyoxyethylene sorbitan monostearate). All ingredients were sourced from local stores in Diamantina, Minas Gerais (MG), Brazil.

2.1 Experimental design

The study utilized a completely randomized design, in which wheat flour was partially replaced with corncob flour based on the weight of the flour, as presented in Table 1. All analyses were conducted in triplicate.

Table 1 – Muffin formulations based on flour

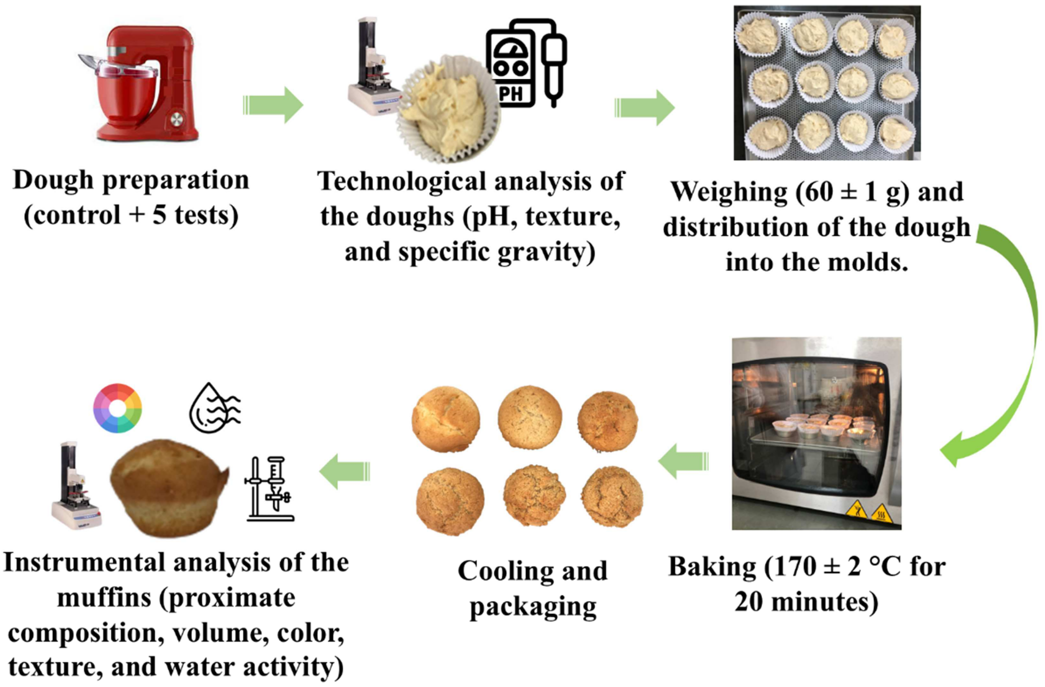
Ingredient (%)	C	F1	F2	F3	F4	F5
Refined wheat flour	100	90	80	70	60	50
Corncob flour	–	10	20	30	40	50
Hydrogenated vegetable fat	40	40	40	40	40	40
Fresh egg	50	50	50	50	50	50
Sucrose	58.75	58.75	58.75	58.75	58.75	58.75
UHT milk	45	45	45	45	45	45
Dough booster	2.5	2.5	2.5	2.5	2.5	2.5
Commercial emulsifier	1	1	1	1	1	1

Source: research data

2.2 Cake batter

Muffins were prepared following the methodology outlined by Lima *et al*. (2022) (Figure 1). Hydrogenated vegetable fat and sugar were homogenized at maximum speed in an Orbit Kitchen 600 planetary mixer (Cadence, Brazil) using a wire whisk for 10 minutes to incorporate air, forming the cream phase. Subsequently, manually pre-homogenized eggs were added, and mixing continued at the same speed for an additional 5 minutes.

Figure 1 – Muffin preparation process



Source: elaborate by authors

Once the cream phase was completed, the remaining ingredients were added according to Table 1. The mixture was then homogenized at minimum speed for 5 minutes using a paddle-type beater.

Aliquots of the batter were subjected to pH, texture, and specific gravity analyses. Finally, the dough booster was manually incorporated.

After preparation, the batters were portioned (60 ± 1 g) into waterproof paper molds (Regina Culinária, Brazil), which were placed inside aluminum molds of the same size. Baking was performed in a ConventionLine oven (Venâncio, Brazil), preheated to 170 ± 2 °C, for 20 minutes. The samples were then cooled at room temperature for 2 hours and stored in polypropylene packaging for 12 hours. Before analysis, the samples were mechanically sliced using an FPV12 slicer (Venâncio, Brazil) to obtain 12 mm thick slices.

2.3 Dough analysis

The specific gravity of the dough was determined following the American Association of Cereal Chemists International (AACCI) method 55-50.01 (AACCI, 2010). The results were expressed in g.cm-3, with analyses conducted in triplicate.

The pH analysis was performed according to AOAC method 981.12 (AOAC, 2019) using an mPA210 bench potentiometer (Tecnopon, Brazil). The electrode was directly inserted into the sample, and measurements were taken in triplicate.

Instrumental texture parameters of the dough were evaluated based on the methodology proposed by Souza and Schmiele (2021). The analysis was conducted using a TA-XT Plus texture analyzer (Stable Micro Systems, England) equipped with a 10 mm diameter P/0.5S cylindrical probe and an HDP/90 platform. The following parameters were established: pre-test, test, and post-test speeds of 3.0, 1.0, and 1.0 mm/s, respectively; penetration distance of 40%; and a detection threshold of 0.025 N. The parameters analyzed included hardness (N), adhesiveness (N), and impulse (N·s). All analyses were performed in triplicate.

2.4 Muffins and flour analysis

The muffins and flour samples (wheat flour and corncob flour) were subjected to moisture (method 44-15.02), ash (method 08-01.01), protein (method 46-13.01; N = 5.70 for wheat flour and muffins, $N = 6.25$ for corncob flour), and lipid (method 30-25.01) analyses, according to AACCI (AACCI, 2010). Digestible carbohydrates, including available sugars (expressed as sucrose) and starch, were analyzed using method 982.14, while total dietary fiber was quantified following AOAC method 978.10 (AOAC, 2019). All analyses were conducted in triplicate, and results were expressed in g/100 g.

Instrumental color parameters of the muffin crumbs and flours were determined following the method described by Silva *et al.* (2021). The samples were placed in Petri dishes and analyzed using a CM-5 Konica Minolta colorimeter (Chiyoda, Japan) in the L*, a*, b* color space. Readings were conducted in triplicate with a D65 illuminant, a 10° observer viewing angle, and RSIN calibration mode. The color difference (ΔE) between the muffins and the control sample (C) was calculated using Equation 1:

$$\Delta E = \sqrt{(\Delta E^{*})^{2} + (\Delta a^{*})^{2} + (\Delta b^{*})^{2}} \qquad (1)$$

The specific volume of muffins (L/kg) was evaluated in triplicate using the millet displacement method, following AACCI method 10-05.01 (AACCI, 2010).

Total titratable acidity was determined in triplicate using AOAC method 942.15 (AOAC, 2019) and expressed in meq of KOH.g-1 of the sample. Water activity was measured based on AACCI method 44-15.02 (AACCI, 2010) using an Aqualab 4TE Duo hydrometer (Decagon, Brazil) at a constant temperature of 25 ± 1 ºC. All analyses were performed in triplicate.

Instrumental texture profile analysis was conducted according to AACCI method 74-09.01 (AACCI, 2010). Ten repetitions were performed for each test using two overlapping 12 mm thick slices. Parameters such as firmness (N), hardness (N), cohesiveness, elasticity, gumminess (N), chewiness (N), and resilience were evaluated using a TA-XT Plus texture analyzer with a P/36R probe and an HDP/90 platform in compression mode. Equipment settings included: pre-test, test, and post-test speeds of 1.0, 1.0, and 5.0 mm/s, respectively; compression of 40%; time between cycles of 1 s; and a detection threshold of 0.049 N.

The data obtained were subjected to variance analysis and mean comparison using the Scott-Knott test at a 5% significance level.

3 Results and discussion

The results found for the characterization of muffins with the addition of corncob flour are presented in this section.

3.1Physicochemical characteristics of flour

The proximate composition of wheat flour and corncob flour is presented in Table 2. Brazilian legislation classifies wheat flour based on its composition, including moisture, protein, and ash content. According to these criteria, the wheat flour used in this study is classified as Type 1 (Brazil, 2005).

Table 2 – Proximate composition and instrumental color parameters of corn and wheat cob flours

Parameter[§]		**Corncob flour**	**Wheat flour**
Moisture (g/100 g) [#]		5.54 ± 0.33	12.88 ± 0.14
Digestible carbohydrates (g/100 g) [#]		25.58 ± 0.07	61.46 ± 0.33
Proteins (g/100 g) [#]		1.56 ± 0.14	13.45 ± 0.47
Ash (g/100 g) [#]		1.00 ± 0.03	0.80 ± 0.01
Lipids (g/100 g) [#]		1.07 ± 0.04	1.41 ± 0.03
Dietary fibers (g/100 g) [#]		65.25 ± 0.36	10.00 ± 0.47
Instrumental color	L^*	74.47 ± 0.15	87.79 ± 0.06
	a^*	3.56 ± 0.03	-0.10 ± 0.01
	b^*	18.88 ± 0.08	11.87 ± 0.06

[§] All parameters showed statistically significant differences according to Student's t-test ($p < 0.05$). Values expressed on a wet basis

Source: research data

The flours exhibited distinct proximate compositions. The lower moisture and digestible carbohydrate contents in corncob flour may contribute to its enhanced microbiological stability (Nascimento *et al*., 2024). In contrast, flours with higher dietary fiber content generally have larger particle sizes due to the material's lower friability (as shown in Figure 1), which can directly influence bakery products' specific volume and texture. This effect occurs because fiber interferes with gluten network formation, resulting in structural discontinuities. Consequently, this negatively affects dough structure and the overall quality of baked goods (Cappelli *et al*., 2025).

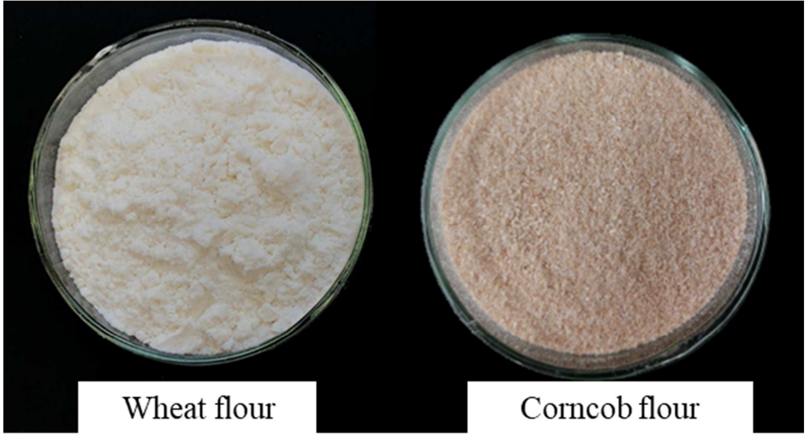
The corncob flour a higher ash content than wheat flour. According to Hoang *et al*. (2022) corncobs can be considered a valuable source of proteins and non-essential minerals, including phosphorus, potassium, magnesium and manganese. Additionally, they naturally exhibit a higher ash content compared to wheat flour. Corncobs can also have antinutritional compounds in this composition. These compounds are undesirable as they inhibit the bioavailability and bioaccessibility of nutrients, such as minerals, in the human body (Nascimento *et al*., 2024). However, the concentrations of phytic acid and oxalic acid (0.49% and 0.03%, respectively) in corncob flour are relatively low, supporting the potential use of this co-product for food applications (Viroli *et al*., 2022).

According to the Brazilian Food Composition Table (Núcleo de Estudos e Pesquisas em Alimentação – NEPA, 2011), refined wheat flour contains, on average, 13% moisture, 9.8% protein, 1.4% lipids, 75.1% digestible carbohydrates, 2.3% dietary fiber, and 0.8% ash. The values obtained in this study are consistent with these averages, except for protein, digestible carbohydrate, and ash content.

According to Laze *et al*. (2019), variations in the protein and carbohydrate content of wheat grains may result from soil and climate conditions in the growing region, as well as genetic differences among cultivars. High temperatures, intense solar radiation, and low rainfall during the grain-filling stage can increase protein content. Fiber concentration, in turn, is influenced by the milling process, as bran contains the highest fiber content, and milling conditions impact the final fiber concentration in wheat flour (Zhou *et al.*, 2021). Additionally, Kulathunga *et al.* (2021) emphasize that numerous methodologies employed for fiber quantification in flour fail to account for fructooligosaccharides, which may result in an underestimation of dietary fiber content.

The samples also varied in their instrumental color parameters, as measured by the CIE-LAB system (Table 2), and these differences are illustrated in Figure 2. Wheat flour displayed higher luminosity (L value) and lower a* and b* values compared to corncob flour. The color of wheat flour is influenced by both intrinsic factors (such as maturation stage and genetic characteristics) and extrinsic factors (including cultivation conditions, extraction degree, bleaching process, and particle size) (Gutkoski *et al.*, 2011). As color is a critical quality parameter, it plays a key role in consumer sensory acceptance of the final product (Li *et al.*, 2011). Some studies indicate that while certain consumers perceive darker-colored muffins as healthier, others may find the color alteration unfamiliar, leading to reduced acceptability. Thus, consumer acceptance depends on both the target audience and the extent of the color modification (Boff *et al.*, 2022).

Figure 2 – Visual appearance of wheat flour and corncob flour



Source: research data

Unlike wheat flour, corncob flour exhibited lower luminosity and higher a* and b* values. These results can be attributed to the presence of pigments, such as anthocyanins, in its matrix. In addition to particle size and cultivation conditions, the color of corncob flour is also influenced by factors such as cob variety and maturation stage.

3.2 Properties of dough

The properties of dough are crucial for predicting the technological and sensory quality of cakes, primarily through instrumental parameters such as texture and apparent gravity. The characteristics of muffin dough are presented in Table 3.

Table 3 – Characteristics of muffin dough with partial replacement of refined wheat flour with corncob flour

Formulations	**Specific gravity (g/mL)**	**pH**	**Instrumental texture**		
			Hardness (N)	**Adhesiveness (N)**	**Impulse (N.s)**
C	0.85 ± 0.01^{b}	6.11 ± 0.03^{a}	0.127 ± 0.002^{f}	-0.046 ± 0.001^{a}	3.49 ± 0.03^{e}
F1	0.83 ± 0.01^{b}	5.88 ± 0.04^{b}	0.196 ± 0.002^{e}	-0.070 ± 0.002^{a}	5.79 ± 0.05^{d}
F2	0.92 ± 0.01^{a}	5.92 ± 0.02^{b}	0.275 ± 0.002^{d}	-0.100 ± 0.001^{a}	7.46 ± 0.07^{d}
F3	0.88 ± 0.02^{a}	5.84 ± 0.02^{c}	0.418 ± 0.009^{c}	-0.141 ± 0.005^{a}	11.31 ± 0.28^{c}
F4	0.92 ± 0.02^{a}	5.73 ± 0.02^{d}	1.236 ± 0.024^{b}	-0.438 ± 0.015^{b}	34.13 ± 1.75^{b}
F5	0.90 ± 0.03^{a}	5.83 ± 0.03^{c}	2.262 ± 0.055^{a}	-0.452 ± 0.027^{c}	67.27 ± 1.18^{a}

Values correspond to the arithmetic mean of three repetitions ± standard deviation. Means with different letters in the same column indicate statistically significant difference ($p < 0.05$) according to the Scott-Knott test.

Legend: C: Control; F1: 10% corncob flour; F2: 20% corncob flour; F3: 30% corncob flour; F4: 40% corncob flour; F5: 50% corncob flour

Source: research data

Specific gravity is directly related to the dough's ability to trap and retain air. According to Table 3, specific gravity increased in samples where wheat flour was replaced with corncob flour at over 10% (tests F2, F3, F4, and F5). This increase is due to the coalescence of air bubbles resulting from the physical rupture caused by the denser FS particles, which have higher dietary fiber content (Masmoudi *et al.*, 2020).

This characteristic of the dough can significantly influence the sensory and instrumental traits of the final product. Inefficient aeration leads to an inadequate alveolar structure, marked by large, sparse alveoli with non-uniform distribution. As a result, the final product may have a compact crumb, reduced volume, and undesirable instrumental texture parameters, such as high firmness and hardness values (Ali *et al.*, 2023).

However, in the test with a 10% replacement (F1) of wheat flour with corncob flour , there was no significant difference in specific gravity compared to the control. This indicates that, at this concentration, the added fibers did not obstruct the dough's ability to incorporate and retain air, which could positively influence the volume and texture of the final product.

The effectiveness of dough boosters is pH-dependent, with sodium bicarbonate acting preferentially at a pH between 6.0 and 6.5 (Lima *et al.*, 2022). The decomposition of sodium bicarbonate to produce carbon dioxide alkalizes the environment, hindering CO_2 distribution within the system. However, commercial dough boosters contain added acids to regulate pH and promote even CO_2 distribution in the dough.

In the present study, partially replacing wheat flour with corncob flour led to a reduction in the pH of the test doughs (Table 3), since corncob flour is naturally more acidic than traditional baking flours. Consequently, this decrease in hydrogen ion potential may enhance CO_2 distribution uniformity within the samples, which could benefit the alveolar structure, symmetry maintenance, volume, and texture of the final product.

In bakery products, texture is a key technological and sensory attribute. Instrumental texture parameters of cake dough provide insight into the system's behavior regarding CO_2 dissipation, retention, and expansion stability. According to Lima *et al.* (2022), cake batters should display a soft, cohesive texture with slight adhesiveness to support optimal volume and alveolar structure, ultimately enhancing crumb softness, a desirable property of this product.

As indicated in Table 3, the hardness, adhesiveness, and impulse parameters of the doughs increased with higher FS replacement levels. This trend is undesirable, as increased dough rigidity hinders the retention of incorporated air, supported by the observed rise in apparent gravity with increasing FS content (Table 3). Greater rigidity reduces the system's expansion capacity, ultimately compromising the sensory and technological quality of the finished product.

3.3 Properties of muffins

The approximate composition of muffins prepared with corncob flour replacement differed among samples, as expected, given their distinct compositions, particularly regarding protein, starch, and ash content (Table 4).

Table 4 – Proximate composition of muffins with partial replacement of wheat flour with corn flour

Analysis	**C**	**F1**	**F2**	**F3**	**F4**	**F5**
Starch (%)	27.26 ± 0.18^a	25.71 ± 0.54^a	21.61 ± 0.35^b	20.90 ± 0.13^b	20.29 ± 0.87^b	17.54 ± 0.38^c
Proteins (%)	7.45 ± 0.10^a	6.96 ± 0.07^b	6.36 ± 0.05^c	6.18 ± 0.09^d	6.07 ± 0.08^d	5.37 ± 0.08^e
Lipids (%)	17.57 ± 0.20^a	17.51 ± 0.22^a	17.03 ± 0.22^b	17.09 ± 0.23^b	17.34 ± 0.26^a	16.71 ± 0.21^b
moisture (%)	21.75 ± 0.06^a	21.97 ± 0.23^a	20.25 ± 0.07^c	21.14 ± 0.13^b	21.33 ± 0.11^b	21.75 ± 0.14^a
Ash (%)^{ns}	0.99 ± 0.01	1.07 ± 0.61	1.07 ± 0.07	1.04 ± 0.04	1.09 ± 0.02	1.09 ± 0.02
Sugars (% sucrose)	16.34 ± 0.13	16.15 ± 0.05	16.49 ± 0.10	16.68 ± 0.16	16.63 ± 0.64	16.77 ± 0.21
Total dietary fiber (%)*	8.63	10.63	18.76	16.98	17.24	20.77
Specific	2.84 ± 0.13^a	2.64 ± 0.03^b	2.33 ± 0.02^d	2.50 ± 0.05^c	2.08 ± 0.09^e	2.00 ± 0.05^e

volume (L/kg)						
Water activity	0.87 ± 0.01^{c}	0.88 ± 0.01^{a}	0.86 ± 0.01^{f}	0.87 ± 0.01^{d}	0.87 ± 0.02^{e}	0.88 ± 0.01^{b}
Total titratable acidity (meq KOH/g)	0.06 ± 0.01^{b}	0.08 ± 0.01^{b}	0.07 ± 0.01^{b}	0.07 ± 0.01^{b}	0.08 ± 0.01^{b}	0.10 ± 0.02^{a}

Values correspond to the arithmetic mean of three repetitions ± standard deviation. Means with different letters in the same row indicate statistically significant difference ($p < 0.05$) according to the Scott-Knott test. Ns: non-significant data ($p > 0.05$); *Total dietary fiber: calculated by the difference between the other components.

Legend: C: Control; F1: 10% corncob flour; F2: 20% corncob flour; F3: 30% corncob flour; F4: 40% corncob flour; F5: 50% corncob flour.

Source: research data

Lower protein content was observed in samples containing corncob flour compared to the control due to compositional differences between the flours (Table 2). Corncob flour lacks gluten-forming proteins, making it a promising ingredient for developing gluten-free products targeted at individuals with celiac disease or gluten intolerance. Additionally, corncob flour supplementation increased the ash content of the samples, though this difference was not statistically significant, aligning with the naturally higher mineral content of corncob flour.

The lipid content of the samples also differed from that of the control, but these differences, while significant, were not substantial. The results regarding the hydrogen ion potential of the dough align with the final product's acidity, which increased with higher wheat flour replacement levels due to the naturally acidic nature of corncob flour. Despite this, the influence of phytic and oxalic acids on the bioavailability and bioaccessibility of minerals in the formulation warrants further investigation. Viroli *et al.* (2022) emphasize the importance of exploring the relationship between acidity, antinutritional acid content, cob maturity, and seasonal variations.

Replacing wheat flour with corncob flour at levels above 10% (tests F2, F3, F4, and F5) resulted in lower moisture content than the control (C). This outcome can be attributed to the incorporation of dietary fibers, which alter moisture retention due to hydroxyl groups that facilitate water retention post-baking. This characteristic may be advantageous for maintaining a moist texture and enhancing sensory perception (Cauvain; 2015). However, interactions between hydroxyl (–OH) groups in dietary fibers and water molecules were insufficient to significantly alter water activity levels across samples.

Starch and egg proteins play a fundamental role in structuring the dough during baking, directly influencing the volume and textural properties of cakes. A reduction in starch content, combined with the detrimental effects of dietary fibers from corncob flour on air bubble coalescence and retention, contributes to the observed decrease in specific volume. This reduction is proportional to the level of corncob flour substitution. Due to its high hygroscopicity, dietary fiber enhances the dough’s water retention capacity, increasing its viscosity. Additionally, the incorporation leads to a reduction in gluten content due to a dilution effect, which in turn limits the entrapment of air bubbles—key contributors to the final product's volume. Since starch gelatinization during baking plays a crucial role in the structural development of bakery products, a decrease in starch content further alters the textural and structural properties of muffins.

In recent years, the demand for fiber-enriched foods has increased due to the well-documented health benefits of dietary fiber, including a reduced risk of cardiovascular diseases, diabetes, and obesity, as well as improved intestinal transit and increased faecal volume, among others (Kemski *et al.*, 2022; Ito *et al.*, 2023; Khorasaniha *et al.*, 2023). Although higher levels of wheat flour replacement with corncob flour negatively affect the technological properties of muffins, the incorporation of dietary fiber offers significant health benefits and enhances the product’s functional appeal. Furthermore, corncob flour presents a cost-effective alternative for formulation while expanding the range of products available to consumers.

The mastication process is essential for perceiving the texture and flavor of food, as it increases the chewing surface and stimulates salivary secretion, facilitating proper swallowing (Jia *et al.*, 2021). In this context, texture profile analysis (TPA) provides a rapid and cost-effective instrumental method to simulate food mastication.

In bakery products, the instrumental texture is closely linked to a specific volume, dough aeration, and alveolar structure. Parameters such as firmness (N) (force required to compress ¾ of the sample), crumb hardness (N) (force needed to deform 40% of the sample), and cohesiveness (N) (force required to break the food) are not highly pronounced, indicating a soft crumb, a highly desirable characteristic, particularly in slices of bread and cakes (Teotônio *et al.*, 2021). The instrumental texture parameters of the muffins are presented in Table 5.

Table 5 – Instrumental texture parameters of muffins with different levels of corncob flour addition

Sample	**Firmness (N)**	**Hardness (N)**	**Adhesiveness(N)**	**Elasticity**
C	6.87 ± 0.63^{e}	8.42 ± 0.82^{e}	-0.048 ± 0.024^{a}	0.788 ± 0.044^{a}
F1	7.05 ± 0.56^{e}	8.84 ± 0.51^{e}	-0.047 ± 0.005^{a}	0.741 ± 0.024^{b}
F2	10.43 ± 0.70^{d}	13.76 ± 1.03^{d}	-0.074 ±0.005^{c}	0.655 ±0.032^{c}
F3	12.48 ± 0.21^{c}	15.98 ± 1.44^{c}	-0.062 ± 0.006^{b}	0.623 ± 0.040^{d}
F4	19.84 ± 1.31^{b}	26.52 ± 1.90^{b}	-0.054 ± 0.007^{a}	0.600 ± 0.019^{d}
F5	22.35 ± 1.19^{a}	28.96 ± 1.83^{a}	-0.079 ± 0.012^{c}	0.531 ± 0.014^{e}
Sample	**Cohesiveness**	**Gumminess (N)**	**Chewyness (N)**	**Resilience**
C	0.445 ± 0.012^{a}	3.77 ± 0.44^{c}	2.88 ± 0.29^{d}	0.155 ± 0.007^{a}
F1	0.395 ± 0.022^{b}	3.80 ± 0.47^{c}	2.76 ± 0.32^{d}	0.130 ± 0.006^{b}
F2	0.340 ± 0.009^{c}	4.69 ± 0.45^{b}	3.10 ± 0.29^{c}	0.103 ± 0.002^{c}
F3	0.311 ± 0.007^{d}	4.93 ± 0.40^{b}	3.12 ± 0.22^{c}	0.094 ± 0.002^{d}
F4	0.310 ± 0.012^{d}	7.94 ± 0.59^{a}	4.87 ± 0.40^{a}	0.094 ± 0.003^{d}
F5	0.253 ± 0.009^{e}	7.53 ± 0.45^{a}	4.06 ± 0.29^{b}	0.073 ± 0.002^{e}

Values represent the arithmetic mean of three repetitions ± standard deviation. #Arithmetic means of eight repetitions. Scott-Knott test was used; means with different letters in the same column indicate statistically significant difference ($p < 0.05$)
Legend: C: Control; F1: 10% corncob flour; F2: 20% corncob flour; F3: 30% corncob flour; F4: 40% corncob flour; F5: 50% corncob flour.
Source: research data

As shown in Table 5, increasing corncob flour substitution for wheat flour resulted in higher instrumental firmness, hardness, and cohesiveness values, alongside a reduction in elasticity (the ability of the sample to regain its height after the first compression cycle) and resilience (sample height recovery rate after compression). These findings can be attributed to the detrimental effects of dietary fiber on aeration and CO_2 distribution within the dough. This relationship is further supported by the increase in the specific gravity of the batter (Table 3) and the reduction in the specific volume of the final product (Table 4) as corncob flour substitution levels increased.

These findings also explain the greater force required for mastication until swallowing (gumminess) and the longer chewing time needed before swallowing (chewability) in samples with higher corncob flour content. On the other hand, prolonged chewing times have been associated with mental stress relief (Tasaka *et al.*, 2014) and enhanced satiety perception.

Color is a critical factor in the sensory acceptance of food products. In cakes, crumb color is influenced by the ingredients used, while crust color results from the Maillard reaction, caramelization, and ingredient composition (Schmiele *et al.*, 2011). The instrumental color parameters of the muffins are presented in Table 6.

Table 6 – Instrumental color parameters of muffins with different levels of corncob flour and wheat and cob flour blends

Samples	***L****	***a****	***b****	**ΔE**
C	77.86 ± 0.47^{a}	2.19 ± 0.12^{d}	26.50 ± 0.24^{d}	–
F1	68.31 ± 0.95^{b}	4.53 ± 0.39^{c}	27.22 ± 0.19^{c}	9.86 ± 0.99^{d}
F2	65.24 ± 0.27^{c}	5.50 ± 0.11^{b}	27.58 ± 0.22^{b}	13.10 ± 0.29^{c}
F3	62.62 ± 0.46^{d}	6.05 ± 0.07^{a}	28.07 ± 0.19^{a}	15.80 ± 0.47^{b}
F4	61.39 ± 0.55^{e}	6.15 ± 0.12^{a}	27.68 ± 0.27^{b}	16.99 ± 0.55^{a}
F5	61.23 ± 0.36^{e}	6.07 ± 0.08^{a}	27.36 ± 0.21^{c}	17.10 ± 0.37^{a}

Values represent the arithmetic mean of three repetitions ± standard deviation. #Arithmetic means of eight repetitions. Scott-Knott test was used; means with different letters in the same column indicate statistically significant difference ($p < 0.05$).
Legend: C: Control; F1: 10% corncob flour; F2: 20% corncob flour; F3: 30% corncob flour; F4: 40% corncob flour; F5: 50% corncob flour
Source: research data

As observed in Table 6, replacing wheat flour with corncob flour led to decreased sample luminosity, indicating crumb darkening. This result was expected due to corncob flour's naturally darker color (lower *L**) compared to FT. Additionally, a reduction in specific volume may further decrease *L**, as it increases the concentration of ingredient pigments per unit area (Neves *et al*., 2021).

The samples exhibited color tones shifting toward red (+*a**) and yellow (+*b**), attributed to the presence of anthocyanins in corncob flour nd carotenoids in wheat flour, fresh eggs, UHT whole milk, and the lipid fraction, which significantly influenced the instrumental color parameters.

Recent years have seen growing interest in different corn varieties due to their bioactive compound content, including pigmented grains. However, incorporating ingredients from alternative varieties, such as purple corncob, may further alter product color. According to Nascimento *et al.* (2023), even at low concentrations (5% wheat flour replacement), purple corncob significantly changes the coloration of baked goods due to its high anthocyanin content, leading to reduced brightness and increased *a** and *b** values in sliced bread.

In the present study, all tests yielded ΔE values above 5, meaning the color differences could be perceived by untrained panelists (Mokrzycki; Tatol, 2011). While the addition of FS may provide health benefits, its impact on muffin color could lead to consumer rejection due to sensory memory associations with the conventional product. Conversely, Meza *et al.* (2020) suggested that darker products might be linked to whole-grain characteristics, potentially enhancing the perception of health benefits.

For fiber-enriched food products, packaging information should highlight the product's functional benefits to enhance purchase intention while ensuring sensory and nutritional quality (Nascimento *et al*., 2024).

5 Conclusions

The partial substitution of wheat flour with corncob flour adversely affected the technological properties of the dough and the final product, particularly concerning apparent gravity, volume, and texture. However, with a 10% substitution, the most favourable technological results were obtained, alongside an increase in the fibre content of the final product. Consequently, from an instrumental standpoint, a 10% replacement of wheat flour with corncob flour has proven satisfactory and holds potential for industrial applications, while also contributing to a greater variety of products for consumers. Future studies should include sensory analysis to further assess consumer acceptance and the sensory attributes of the final product, especially regarding acceptance.

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Declaration of competing interest

The authors declare no conflicts of interest regarding the content of this manuscript.

Author contributions

SANTOS, T. M.; NASCIMENTO, G. K. S.: study/research design; data analysis and/or interpretation. **ANDRESSA, I.; NEVES, N. A**.: data analysis and/or interpretation; final revision with critical and intellectual contributions to the manuscript. **SCHMIELE, M.:** study/research design; data analysis and/or interpretation; final revision with critical and intellectual contributions to the manuscript. All authors contributed to the writing, discussion, review, and approval of the final version of the article.

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