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Preparation, characterization and application of coquinho-azedo *(Butia capitata)* agroindustry byproduct flour in bakery products

Elaboração, caracterização e aplicação da farinha do coproduto da agroindústria de coquinho-azedo *(Butia capitata)* em produtos de panificação

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Highlights

Products from the depulping of coquinho-azedo contain bioactive compounds.
The full use of fruits has regional economic, social, and environmental impacts.
By-products can be transformed into food ingredients, such as flour.
Bread added with coquinho-azedo byproduct has good sensory acceptance.

Abstract

Coquinho-azedo, a typical fruit from the Cerrado region, shows potential in bioactive compounds. The byproduct resulting from its pulping was reused as an ingredient in the formulation of bread. The fresh sample was dried at temperatures of 45, 55 and 65 °C for 2h01, 01h52 and 00h48, respectively. The selected sample was crushed, sieved and the finest fraction used to produce bread added with 7.5 and 15% of the resulting flour. The standard bread followed the formulation without adding the byproduct. The moisture, ash, protein, lipid, carbohydrates, acidity, carotenoid and vitamin C contents of the fresh byproduct, the drying products and the three types of bread produced were determined. The breads added with the alternative flour were submitted to sensory analysis, using the triangular test to discriminate the samples, the acceptance test by the hedonic scale and the consumption and purchase intention tests. The dry sample submitted to 45 °C, which maintained the highest vitamin C content and preserved carotenoid content, was used for bread production. In the byproduct-enriched

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breads, there was no significant difference in moisture, protein and lipid content between the standard samples added with 7.5 and 15% of the alternative flour. Acidity, carotenoid and vitamin C content were significantly higher in the alternative flour formulations in relation to the standard sample. In technological analyses, adding the highest alternative flour content caused a significant decrease in the specific volume, greater darkening (L*) and a tendency towards brown (a*) and yellow (b*) crumbs. The triangular discriminative test demonstrated a noticeable sensory difference between the two breads, at the 0.1% significance level. Bread enriched with 7.5% coquinho-azedo byproduct flour showed better results for the acceptance test, consumption and purchase intention. Thus, adding the coquinho-azedo byproduct flour influenced the physicochemical, technological and sensory aspects of the bread.
Key words: Cerrado. Composition. Formulation. Reuse.

Resumo

O coquinho-azedo é um fruto típico da região do Cerrado e demonstra potencial em compostos bioativos. O coproduto decorrente do seu despolpamento foi reaproveitado para aplicação como ingrediente na formulação de pão de forma. A amostra in natura foi submetida à secagem nas temperaturas de 45, 55 e 65 °C por 02h01, 01h52 e 00h48, respectivamente. A amostra selecionada foi triturada, peneirada e utilizou-se a fração mais fina para produção de pães de forma com adição de 7,5 e 15% de farinha obtida em relação à farinha de trigo. O pão padrão seguiu a formulação sem adição. Foram determinados os teores de umidade, cinzas, proteínas, lipídeos, carboidratos, acidez, carotenoides e vitamina C do coproduto in natura, dos produtos da secagem e dos três tipos de pães produzidos. Os pães de forma com adição da farinha alternativa foram submetidos à análise sensorial, sendo aplicado o teste triangular para discriminação das amostras, teste de aceitação por escala hedônica e testes de intenção de consumo e compra. Dentre as amostras secas, a submetida a 45 °C manteve estatisticamente o maior teor de vitamina C e houve preservação no conteúdo de carotenoides, sendo então utilizada para produção dos pães. Nos pães de forma, não houve diferença significativa entre as amostras padrão, com 7,5% e com 15% de adição da farinha alternativa para os teores de umidade, proteínas e lipídeos. Os teores de acidez, carotenoides e vitamina C foram significativamente mais elevados nas formulações com adição em relação à amostra padrão. Para as análises tecnológicas, a adição do maior teor da farinha alternativa ocasionou diminuição significativa no volume específico, maior escurecimento (L*) e tendência ao marrom (a*) e amarelo (b*) no miolo. Pelo teste discriminativo triangular, houve diferença sensorial perceptível entre os dois pães, ao nível de 0,1% de significância. O pão de forma enriquecido com 7,5% de farinha de coproduto de coquinho apresentou melhores resultados para o teste de aceitação e para a intenção de consumo e compra. Desse modo, evidenciou-se que a adição da farinha do coproduto de coquinho azedo influenciou nos aspectos físico-químicos, tecnológicos e sensoriais do pão de forma.
Palavras-chave: Cerrado. Composição. Formulação. Reaproveitamento.

Introduction

The coquinho-azedo is a fruit derived from the palm tree Butia capitata, typically found in the Brazilian Cerrado. The pulp of the fruit has a strong aroma, is widely used by the population in northern Minas Gerais state, and is a good source of vitamin C (Faria et al., 2008). It also contains carotenoid substances, particularly beta-carotene, at a ratio of 1.9 mg per 100g of pulp, representing 58% of the total carotenoids (Empresa Brasileira de Pesquisa Agropecuária [EMBRAPA], 2006).

During harvesting, the commercialization of coquinho-azedo is a significant source of income for agro-extractivists (EMBRAPA, 2010a). The fruit plays an important social and economic role in northern Minas Gerais, providing employment and income (Moura et al., 2010). The harvest, which takes place between November and February, enriches the diet of local communities and encourages conservation of the species (Faria et al., 2008).

The term "byproduct" refers to certain products that arise during the industrial processing stages of a main product (Maia, 2022). The peel and seeds of some fruits are byproducts generated during juice processing (EMBRAPA, 2009), which can be used as ingredients in food formulations. Aspects of coquinho-azedo have been studied by several authors; however, data on the use of the fruit's byproducts are still preliminary, since most existing studies focus on the pulp.

The use of coquinho-azedo byproduct flour is gaining traction in the search for more sustainable and efficient practices in the food industry. This innovative process not only transforms food byproducts into a valuable ingredient, but also paves the way for more economical and sustainable production. In this context, products linked to the full use of food are emerging, using parts that are often neglected but contain nutrients and vitamins that promote better health (M. T. Silva et al., 2022). Flour is a versatile product and can be applied in the formulation of various foods, such as bakery products.

Bread, which comes in numerous varieties, is influenced by cereal crops, consumer habits, and tastes (Ziglio et al., 2007), and is consumed worldwide. Consisting of essential nutrients and energy-providing components, bread consumption by a large portion of the population helps meet part of daily caloric needs, making it increasingly necessary to incorporate additional substances during its processing (Lima, 2007). Adding coquinho-azedo byproducts to bread production facilitates the alternative use of this co-product.

Thus, the present study aimed to incorporate coquinho-azedo byproduct flour into bread production, addressing aspects of the residue, drying products, and the development of formulations with different levels of the alternative flour.

Material and Methods

Experimental materials

The coquinho-azedo byproduct used was supplied by the Cooperativa Grande Sertão, located in Montes Claros, Minas Gerais state.

Drying parameters of the coquinho-azedo byproduct

The drying process was based on the methodology described by Cano-Chauca et al. (2004), with modifications. Fifty grams of the sample was evenly spread across food dehydrator trays (Pardal Tee) lined with cotton fabric. The dehydrator was preheated for 1 hour, and the trays placed vertically inside. Drying occurred at 45, 55, and 65 °C for 2h01, 1h52, and 00h48, respectively, based on the results of preliminary tests that evaluated the behavior of the drying curves to obtain flour with a moisture content of no more than 15% (Machado et al., 2023).

Flour yield analysis

Yield was determined by grinding 25g of the dry byproduct sample in a household blender, followed by sieving through a 30 Mesh/Tyler sieve. The passing fraction was then further sieved using a 50 Mesh/Tyler sieve. The fractions retained on the sieves were ground again in a Splabor A11BS32 mixer and re-sieved through the aforementioned mesh sizes. The final fractions that passed through each sieve were weighed to evaluate the yield (R), which was calculated as the ratio between the final (Mf) and initial mass (Mi), according to Equation 1.

$$R = \frac{Mf}{Mi} x100 \qquad \text{(Eq. 1)}$$

The experiment was conducted with four replicates.

Bread production

The flour from drying at 45 °C for 2h01 in a tray dryer, with a particle size of 50 Mesh/Tyler, was used. The other ingredients for the sliced bread production were purchased from local stores in Montes Claros, MG.

Three types of bread were produced: standard bread; bread added with 7.5% coquinho-azedo byproduct flour; and bread added with 15% jelly flour byproduct flour, in relation to wheat flour. The breads were made according to the methodology described by Chagman and Huamán (2010), with modifications. The ingredients were weighed in advance (Table 1). Next, 60% heat flour, 55% water, and all the dry yeast were mixed in a planetary mixer and left to ferment at 32°C for 40 minutes. After fermentation, the remaining ingredients were added to the dough and mixed again. The dough was rolled, divided, shaped, and placed in pans. Fermentation was carried out at 32°C for 1 hour and 30 minutes and the dough was then baked in an electric oven at 180°C for 30 minutes. After baking, the breads were cooled at room temperature for 1 hour and then removed from the pans. The experiment was conducted with three repetitions for each bread type.

Table 1
Formulation of standard bread and breads added with the coquinho-azedo byproduct flour

Ingredients	SF	7.5% JF	15% JF
Wheat flour (g)	200	200	200
Byproduct flour from coquinho-azedo kernels (g)	0	15	30
Crystal sugar (g)	28	28	28
Margarine 70% lipids (g)	8	8	8
Dry yeast (g)	6	6	6
Salt (g)	3	3	3
Flour improver (g)	2	2	2
Water (mL)	110	120	130
Antimold agent (g)	0.5	0.5	0.5
Total dough in each mold (g)	357.5	382.5	407.5

Caption: SF: standard formulation; 7.5% JF: formulation added with 7.5% coquinho-azedobyproduct flour in relation to wheat flour; 15% JF: formulation added with 15% coquinho-azedo byproduct flour in relation to wheat flour.

Physicochemical analyses

The samples of fresh coquinho-azedo byproducts, samples after drying, and the breads produced were characterized for the following physicochemical parameters: moisture, determined by drying in an oven at 105 °C until constant weight (Instituto Adolfo Lutz [IAL], 2008); ash content, determined by incineration in a muffle furnace (IAL, 2008); total protein content, quantified by the Micro-Kjeldahl method, with total nitrogen determination using a conversion factor of 6.25 (IAL, 2008); lipid content, determined by the modified Bligh and Dyer (1959) method; and acidity of alcohol-soluble substances in flours and similar products (IAL, 2008). Each analysis was conducted with five replicates. The total carbohydrate content (on a dry basis) was calculated by subtracting the sum of the protein, ash, and lipid contents on a dry basis from 100.

Analysis of carotenoids and vitamin C

Total carotenoid determination was carried out according to Fonseca et al. (2021), adjusting centrifugation to 7000 rpm. Vitamin C was analyzed following the methodology using potassium iodate (IAL, 2008). The analyses were conducted in triplicate.

Technological analysis

Technological analysis was based on the determination of specific volume from the ratio between the apparent volume (cm^3) and breadweight (g), with results expressed in cm^3 g^{-1}. The apparent volume was determined by millet seed displacement (Gayardo et al., 2015). Colorimetric analysis of the bread crust and crumb was performed using a portable KM-CR-400 Basic reflection colorimeter (Konica Monitta), with results presented using parameters L*, a*, b*.

Luminosity (L*) ranges from zero (black) to 100 (white); chromaticity coordinates a* and b* range from -a* (green) to +a* (red), and from -b* (blue) to +b* (yellow). Each analysis was conducted with six replicates for each bread sample.

Sensory analysis

The study was approved by the Research Ethics Committee of the Federal University of Minas Gerais (UFMG) (Ethical Appreciation Certificate: 97454718.1.0000.5149) and conducted in the Sensory Analysis Laboratory of the Institute of Agricultural Sciences at UFMG, Montes Claros Campus. The testers did not receive any prior training.

The samples used were breads added with 7.5 and 15% of coquinho-azedo byproduct flour.

Initially, the testers were explained about the study and asked to read and sign the Informed Consent Form (ICF). They were directed to individual sensory analysis booths, under white light, and instructed on how to complete the sensory evaluation form.

According to the methodology of the Adolfo Lutz Institute (IAL, 2008), the triangular discrimination test (method 155/IV) was used to detect small sensory differences between samples. Three samples were placed on disposable plates (coded with three-digit numbers) and presented simultaneously and randomly to the testers, who were informed that two samples were the same and one was different. They were asked to taste the samples and identify the different one on the evaluation form. A glass of water was provided to the testers for palate cleansing.

For data analysis, the number of correct answers was summed and compared to the Triangular Test Table (unilateral, p = 1/3), which contains the minimum number of correct answers required to establish significance at various probability levels (IAL, 2008).

The acceptance test (method 165/IV), with a nine-point hedonic scale ranging from "like extremely" (9) to "dislike extremely" (1), was applied to the two bread samples (IAL, 2008).

The samples were placed on disposable plates, coded with three-digit numbers, and monadically served to the testers. The testers were asked to taste the samples and record on the provided form how much they liked or disliked the product in terms of appearance, color, flavor, texture, aroma, sweetness, acidity (sour taste), and overall impression. A glass of water was provided for palate cleansing between samples.

Consumption intention tests (method 167/IV), using a seven-point hedonic scale, where (7) corresponds to "would always eat" and (1) to "would never eat"; and purchase intention tests (method 167/IV), with a five-point hedonic scale, ranging from "would certainly buy" (5) to "would certainly not buy" (IAL, 2008) were applied.

To calculate the Acceptability Index (AI), the following formula was used: AI (%) = A x 100 / B, where A = the average score obtained for the product and B = the maximum score given to the product (E. Teixeira et al., 1987). The results were reported as the average of the scores assigned by the testers.

The sensory form also included a section for testers to indicate whether they perceived any Cerrado fruit, and if so, were asked to specify which fruit.

Data analysis

The collected data were submitted to analysis of variance (ANOVA) and Tukey's test at a 95% confidence level, using The Jamovi Project (2023).

Results and Discussion

Physicochemical characterization of the fresh byproduct and the drying products

The coquinho-azedo byproduct had an initial moisture content of 67.83% (Table 2). This is lower than that found by Neris et al. (2018) in ripe banana peel (87.19%) and Ferreira and Pena (2010) in yellow passion fruit peel (85.3%), and higher than that found by Rocha and Santiago (2009) in baru peel and pulp (21.05%).

Table 2*
Physicochemical characterization of the coquinho-azedo byproduct samples

Parameters	Fresh	Dried at 45 °C	Dried at 55 °C	Dried at 65 °C
Moisture (%)	67.83 ± 0.39 a	7.82 ± 0.39 c	7.17 ± 0.73 c	14.50 ± 0.52 b
Ash (%)	7.63 ± 0.51 a	2.21 ± 0.09 b	2.19 ± 0.07 b	2.27 ± 0.11 b
Proteins (%)	4.71 ± 0.29 a	3.86 ± 0.12 b	4.12 ± 0.18 b	3.98 ± 0.16 b
Lipids (%)	8.68 ± 0.27 a	3.18 ± 0.22 c	3.53 ± 0.31c	3.97 ± 0.18 b
Carbohydrates (%)	78.98	90.75	90.16	89.78
Acidity (%)	7.21 ± 0.18 a	5.12 ± 0.06 c	5.19 ± 0.06 c	6.04 ± 0.15 b
Carotenoids (μg g^{-1})	7.10 ± 2.18 ns	8.41 ± 0.86 ns	7.92 ± 0.88 ns	7.82 ± 0.19 ns
Vitamin C (mg $100g^{-1}$)	69.9 ± 4.58 a	40.09 ± 1.08 b	34.50 ± 1.57 c	28.17 ± 0.89 d

Caption: Drying was carried out at 45, 55, and 65°C for 121.30, 111.59, and 48.17 minutes, respectively.
***Note:** Results are on a dry weight basis, except for moisture. Total carbohydrates by difference (d.w.) = 100 - [% proteins (d.w.) + % ash (d.w.) + % lipids (d.w.)]. Identical letters in the same row do not differ statistically according to Tukey's test at 5% probability.

According to Brasil (2022), starches, bran, and flours must present a maximum moisture content of 15%. All drying samples were below this percentage and in compliance with the law. In the sample dried at 65°C, the final moisture content was higher than that dried at 45 and 55°C. According to EMBRAPA (2010b), the moisture content of food decreases until it reaches the equilibrium moisture content, which is defined by temperature and relative humidity. This marks the end of the drying process, meaning that the equilibrium moisture content is attained by exposing the food for an extended period to a stable temperature and relative humidity. The difference in moisture content between the three samples was influenced by the difference in relative humidity, since each drying process occurred on different days. During sample drying at 65, 55, and 45°C, relative humidity was 61.33, 48.33, and 46.50%, respectively, which supports EMBRAPA's (2010b) statement. The dried samples showed higher moisture values (Table 2) than those found by Feitosa et al. (2019) in the production of flour from mango (6.52%), pineapple (6.48%), acerola (4.65%), guava (1.59%), and soursop (4.02%) residues, dried at 60°C for 24 to 48 hours. This difference can be explained by the composition of the byproducts and the difference in drying time, which was longer than that applied for the jelly pulp byproduct flour.

For ash content, the dried samples differed statistically from their fresh counterparts (Table 2). Ash content decreased after drying, which may have been due to mineral volatilization with the heat applied during the process. In the present study, the ash contents found in the dried samples were higher than those reported by E. I. G. Silva et al. (2020), who obtained 2.0 g per 100g in tamarind seed flour, and similar to those recorded by Vieira et al. (2019) in pineapple residue flour (2.15%).

With respect to protein content, the three dried samples did not differ statistically (Table 2), the values being lower than those found by Morais et al. (2019), who reported 4.64% for buriti peel flour, and Menezes et al. (2019), who obtained 4.14% in jatobá-do-Cerrado (*Hymenaea stigonocarpa*) fruit peel flour. According to Sousa et al. (2011), although fruits are generally not potential source of protein, the compound is predominantly present in the peels and seeds. For fresh jelly pulp, protein contents of 0.83% were found by Nascimento et al. (2020), 0.74% by Barbosa et al. (2021), and 0.30% by Faria et al. (2008), which are lower than those found in this study for the fresh byproduct, corroborating Sousa et al. (2011).

With regard to lipid content, the samples dried at temperatures of 45 and 55°C showed statistically similar averages (Table 2). The lipid content of the dried samples differed significantly from that of the fresh sample ($p<0.05$) and was higher than that found by Honório (2022) for flour made from the stem of Cerrado gueroba (2.54%), but lower than that found by Rigo et al. (2017) in malt bagasse residue flour (5.90%).

The dried samples differed significantly from their fresh counterparts in terms of acidity (Table 2), with higher total acidity than that found by T. A. Santos et al. (2020), who reported 1.8% for flour made from the jabuticaba extract used in whole juice formulation. D. A. Silva (2017) performed a physicochemical characterization of umbu-cajá residues and flours and acerola residues, and observed total acidity of 0.91 and 0.71 g of citric acid per 100 g, respectively.

With respect tocarotenoid content, the samples dried at 45, 55, and 65 did not differ statistically from their fresh counterparts according to Tukey's test at 5% probability (Table 2), indicating that drying did not degrade this component. Morais et al. (2019) observed a significant increase in carotenoid content between fresh (0.52%) and dried (2.08%) buriti peel samples, also suggesting that drying did not degrade carotenoid content.

Finally, vitamin C exhibited a decline in this component in the dried compared to the fresh samples (Table 2), with a reduction in content as the drying temperature increased. This behavior was expected, since vitamin C is an unstable vitamin, susceptible to degradation caused by temperature variations and exposure to oxygen during drying (Lavarda, 2011). The sample dried at 45°C had the highest vitamin C content.

The gentler drying process produced higher vitamin C values and preserved carotenoid content, both of which are important components in the composition of food products. In addition, in preliminary studies, the drying model at 45°C was the most suitable for the coquinho-azedo byproduct sample, according to the coefficient of determination (Machado et al., 2023). Thus, the flour produced at this temperature was selected for food product application.

Physicochemical characterization of the breads made with the the byproduct flour

Table 3 presents the results obtained for the centesimal analysis of the standard bread and breads added with the alternative flour.

Table 3*
Physicochemical characterization of the standard bread and breads added with coquinho-azedo byproduct flour

Parameters	SF	7.5% JF	15% JF
Moisture (%)	25.51 ± 1.00 ns	26.34 ± 1.70 ns	27.02± 1.89 ns
Ash (%)	2.23 ± 0.04 a	2.08 ± 0.07 b	2.12 ± 0.07 b
Proteins (%)	9.70 ± 0.21 ns	9.99 ± 0.30 ns	9.47 ± 0.68 ns
Lipids (%)	2.19 ± 0.09 ns	2.22 ± 0.10 ns	2.34 ± 0.20 ns
Carbohydrates (%)	85.88	85.71	86.07
Acidity (%)	1.56 ± 0.11 c	2.55 ± 0.13 b	2.86 ± 0.12 a
Carotenoids (μg g^{-1})	4.48 ± 0.39 c	6.06 ± 0.97 b	9.08 ± 0.74 a
Vitamin C (mg $100g^{-1}$)	0.84 ± 0.10 b	1.39 ± 0.12 a	1.10 ± 0.08 a

Caption: SF: standard formulation; 7.5% JF: formulation added with 7.5% coquinho-azedo byproduct flour in relation to wheat flour; 10% JF: formulation added with 15% coquinho-azedo byproduct flour in relation to wheat flour.
***Note:** Identical letters in the same row do not differ statistically according to Tukey's test at 5% probability.

There was no significant difference in moisture, protein, and lipid content between the standard samples, and those added with 7.5 and 15% coquinho-azedo byproduct flour, demonstrating that the levels applied did not significantly impact these components in the final product.

To date, there are no studies in the literature on breads added with coquinho-azedo byproduct flour. However, several authors have studied the incorporation of residual flours into baked goods, either by adding them to the formulation or by partially replacing wheat flour.

In their studies on bread fortified with cashew peduncle byproduct flour, Conceição et al. (2022) analyzed the differences between the control bread containing 16% wheat flour, and bread added with 2-6% and 10-16% cashew peduncle flour, thus also adding low levels of byproduct flour. The authors found no significant difference in moisture (34.62 g $100g^{-1}$) or ash content (1.40 g $100g^{-1}$) between the different breads.

Rocha and Santiago (2009) evaluated bread formulations added with 25, 50, 75%, and 100% of baru shell and pulp as a replacement for wheat bran, as well as a standard bread. They found no significant differences between the formulations for moisture content (34.55 g $100g^{-1}$) or protein content (13.60 g $100g^{-1}$). For lipids, there was a difference only in the sample added with 75%, and for ash content, no significant difference was observed except between the standard samples (0%) and those added with 100%.

F. Teixeira et al. (2018) conducted research on the physicochemical analysis of standard mini bread and that added with 21% eggplant peel flour. There was a significant difference between the two samples in terms of moisture (25.79 and 31.63 g $100g^{-1}$, respectively) and ash content (0.83 and 1.22 g $100g^{-1}$, respectively). However, no statistical difference was observed for protein (7.53 g $100g^{-1}$) and lipid (9.20 g $100g^{-1}$) content.

As observed, the centesimal composition of the breads varies according to the formulation, the characteristics of the flours used, and the amount replaced or added. For the breads added with the coquinho-azedz byproduct flour, moisture content was lower than that reported in the other studies. This may result in less susceptibility to microbial spoilage. Protein, lipid, and ash levels varied from those of the other studies, mainly due to the formulation used.

In breads added with coquinho-azedo byproduct flour, acidity, carotenoid, and vitamin C levels were higher than in the standard formulation. In the 15% coquinho-azedo formulation, carotenoid and acidity levels were higher, which is expected due to the larger amount of byproduct flour in the formulation. However, for vitamin C content, this sample did not differ significantly from that added with 7.5%, indicating that vitamin C, originally present in the formulation with a higher added amount, was directly affected by the production process itself. Although the flour contained satisfactory levels of the component, the baking process lead to a substantial loss of vitamin C in the final product due to its heat sensitivity, to the point where the content was no longer significant.

Arimatéa et al. (2015) found that vitamin C contents were 5.28, 6.74, and 6.60 mg AA $100g^{-1}$, respectively, and carotenoid levels 2.07, 5.85, and 5.31 (μg g^{-1}), respectively, in standard bread, bread enriched with 55% guava residue extract, and bread enriched with 55% mangaba residue extract. The enriched samples exhibited significantly higher values for both components compared to the standard formulation, highlighting the influence of the extract on the increase of these contents. Acidity levels were 2.45, 2.77, and 2.85%, respectively, with a significant difference only between the standard sample and that containing mangaba residue extract. Thus, the authors also observed the same trend as that found in the study of bread added with coquinho-azedo byproduct.

In their study on substituting white wheat flour with forage palm flour (Opuntia ficus-indica), Alves et al. (2021) also found an increase in vitamin C in the formulation where 5% was substituted (10.60 mg $100g^{-1}$) compared to its standard counterpart (7.50 mg $100g^{-1}$). Brasil (2017) investigated the characteristics of bread added with Ubá mango pulp without added sucrose and found that the carotenoid content of the bread formulations increased compared to the standard sample as 30, 50, and 70% of the pulp was added, with average values ranging from 0.71 to 1.55 mg $100g^{-1}$.

Technological analysis of the breads made with the byproduct flour

Figure 1 shows the standard bread and those added with the alternative flour.

The standard samples added with 7.5 and 15% of coquinho-azedo byproduct flour showed a significant difference according to Tukey's test at 5% probability for all the colorimetric parameters evaluated, except for chromaticity b* of the crust in the samples added with the byproduct (Table 4). According to EMBRAPA (1997), the quality of bread made with mixed flours changes from a certain level of substitution, as do quality parameters such as volume, which tends to decrease as the substitution level increases; crust color, which will be more intense the larger the amount of proteins and sugars in the substitute flours; and crumb color, which will be better the lower the amount of substitute flour.

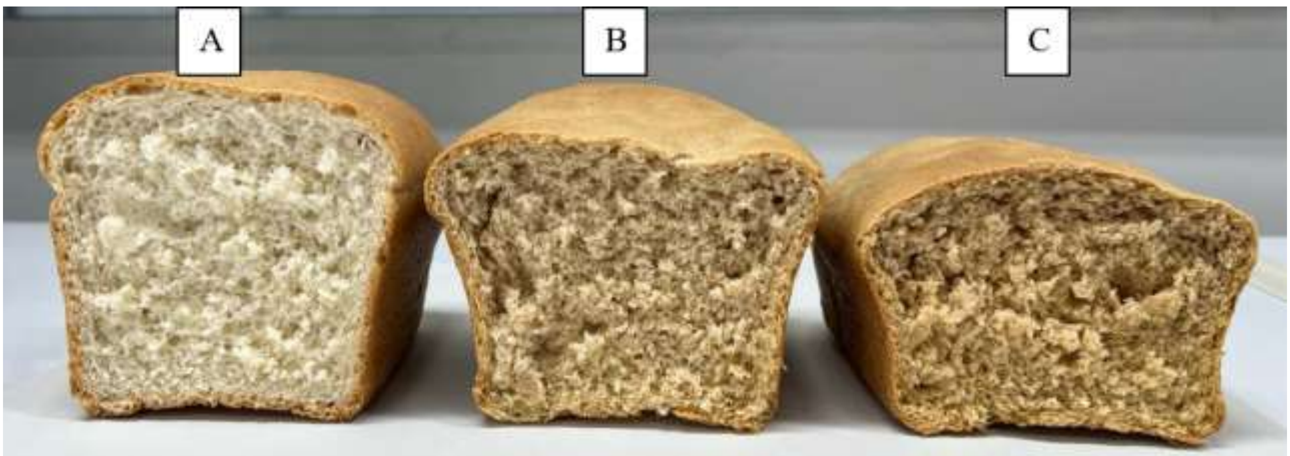

Figure 1. Comparison between breads added with the coquinho-azedo byproduct flour in different proportions.
Caption: (A): standard formulation; (B): formulation added with 7.5% coquinho-azedo byproduct flour in relation to wheat flour; (C): formulation added with 15% coquinho-azedo byproduct flour in relation to wheat flour.

Table 4*
Technological analysis of the standard bread and breads added with coquinho-azedo byproduct flour

Parameters		SF	7.5% JF	15% JF
	L*	54.59 ± 2.25 [c]	60.13 ± 1.73 [b]	65.49 ± 1.37 [a]
Crust color	a*	12.39 ± 0.89 [a]	10.11 ± 1.04 [b]	7.42 ± 0.74 [c]
	b*	31.98 ± 1.12 [b]	34.01 ± 0.62 [a]	33.31±0.33 [a]
	L*	73.71 ± 2.52 [a]	68.26 ± 1.25 [b]	66.28± 0.81 [c]
Crumb color	a*	-1.98 ± 0.07 [c]	1.85 ± 0.21 [b]	4.52 ± 0.11 [a]
	b*	14.63 ± 0.64 [c]	26.39 ± 0.63 [b]	31.24 ± 1.21 [a]
SV (cm^3 g^{-1})		4.30 ± 0.44 [a]	3.26 ± 0.12 [b]	2.19 ± 0.07 [c]

Caption: SF: standard formulation; 7.5% JF: formulation added with 7.5% coquinho-azedo byproduct flour in relation to wheat flour; 15% JF: formulation added with 15% coquinho-azedo byproduct flour in relation to wheat flour; L*: Lightness: ranges from zero (black) to 100 (white); a*: ranges from -a* (green) to +a* (red); b*: ranges from -b* (blue) to +b* (yellow); SV: Specific volume.
***Note:** Identical letters in the same row do not differ statistically according to Tukey's test at 5% probability.

With respect to the color aspects in the present study, the influence of applying coquinho-azedo byproduct flour was evident in the crust, through the decrease in luminosity and chromaticity a*, which may be related to the lower protein content in the byproduct flour compared to conventional wheat flour. This suggests a lower occurrence of the Maillard reaction, resulting in lighter products that did not tend toward a reddish tone as the amount of alternative flour increased. In chromaticity b*, the samples followed the expected trend of exhibiting a more yellowish color with the addition of coquinho-azedo byproduct flour.

In regard to crumbs, the results showed a trendtowards lower luminosity (L*), and higher redness (a*) and yellowness (b*) as the addition of the alternative flour increased. C. M. Santos et al. (2018) reported that a higher a* reflects greater darkening, since brown is a combination of green and red. Thus, greater darkening is depicted by a more reddish tone, that is, a higher a*. The b* value directly reflected the strong yellow color of the coquinho-azedo byproduct flour.

H. M. L. Silva (2016) studied the difference between formulations of standard bread and bread where wheat flour was partially subsituted (10%) by ciriguela residue flour. For both the standard and enriched bread, crumbs showed a significant reduction in L* (65.81 and 50.59, respectively) and an increase in t a* (2.18 and 3.32, respectively) and b* (15.56 and 18.40, respectively). There was a significant decrease in all parameters in the crust, with L* of 51.94 and 47.94; a* 12.43 and 9.07; and b* 29.61 and 18.74, respectively. The author notes that the reduction in L* was expected for the bread crust and crumbs made with residue flour, given that the alternative flour has a more intense color than its wheat counterpart.

C. M. Santos et al. (2018) characterized wholewheat bread enriched with papaya byproduct flour. The authors compared the control bread with the that containing 3% of mixed flour. The L* values differed between the samples, with the formulation containing mixed flour tending to darken (56.74), compared to the control (73.84). The b* coordinate showed variations between the breads, with a greater tendency toward yellow in the enriched bread when compared to the standard.

Marinho et al. (2023) evaluated the difference between standard bread and those where 10, 20, and 30% of wheat flour was substituted with cantaloupe melon peel flour. The authors observed that the standard formulation in the crumbs displayed greater luminosity, with a significant difference compared to the other samples. They noted that higher L* values indicate greater light reflectance, resulting in lighter-colored breads, which are low in sugars or contain flours and starches in the crust. According to the authors, since melon peel flour is darker than type 1 wheat flour, it was expected that, with increasing amounts of the alternative flour, the breadcrumbs would become darker. Breadcrumb color results for chromaticity a* showed that the standard formulation differed from the 10 and 20% samples (which did not differ from each other), and all three differed from the 40% sample, which had more yellow tones. The same pattern was observed for chromaticity b*.

For the studies presented, the color parameters L*, a*, and b*, specific to each study, varied according to the characteristics of the product and the production process.

In the present study, the specific volume of the bread decreased as the coquinho-azedo byproduct flour was added. According to EMBRAPA (1996), wheat flour contains proteins that form the gluten network, trapping the carbon dioxide produced during the fermentation process, which causes the bread to rise. Thus, the addition of the alternative flour significantly influenced this characteristic. It is important to note that the byproduct flour is an interesting source of fiber, which may also impact the formation and maintenance of the gluten network.

A. C. Santos (2013) evaluated the use of Tommy Atkins mango peel flour, producing bread with formulations containing 2.5, 5, 7.5, and 10% of the alternative flour. He also observed a decrease in the specific volume of the breads as the amount of alternative flour increased. The author considered that the formulation added with 5% yielded the best result (4.64 cm^3 g^{-1}), since it did not prevent the bread from rising. However, the decrease in bread volume due to the increased fiber content, hindered rising by reducing the dough's elasticity. This could also be the case for the formulations with coquinho-azedo byproduct flour.

Rodrigues (2010) studied agroindustrial waste as a source of fiber for wholewheat bread production and also reported a constant reduction in the specific volume of the breads as the amount of cupuaçu shell flour increased. The sample with 9% flour (6.27 cm^3 g^{-1}) obtained the lowest value. The author reported that it is likely that the more cupuaçu shell flour added to the dough, the lower the gluten content and the slower the bread's growth.

Rocha and Santiago (2009) studied the nutritional implications of baru pulp and shell in bread production, and found that the results suggest an interaction between wheat bran components and the shell and pulp of baru, leading to lower specific volumes in products containing a mixture of these ingredients. The samples added with 35, 50, and 75% of baru shell and pulp replacing wheat bran showed statistically identical specific volumes of 2.16 cm³ g⁻¹, which were significantly different from the standard formulation (4.09 cm³ g⁻¹).

Thus, the studies corroborated the hypothesis that coquinho-azedo byproduct flour reduced specific volume as the alternative flour was substituted or added.

Sensory analysis

In the triangular test, 32 of the 50 tasters correctly differentiated the samples. In order for a significant difference to be detected between the samples at 0.1% probability, the number of correct answers should be greater than 28, according to tabulated values (IAL, 2008). This demonstrates that there was a perceptible sensory difference between the breads added with 7.5 and 15% coquinho-azedo byproduct flour, indicating a significant difference between the samples. Coquinho-azedo has a strong and characteristic flavor, which contributed to identification when larger amounts of its byproduct flour were used.

Of the 56 tasters who participated in the acceptance test, 32 (64.00%) detected a Cerrado fruit flavor, with 22 (44.00%) correctly identifying it as coquinho-azedo.

There was good acceptance by the tasters for all sensory attributes indicated for the 7.5% byproduct flour formulation, with hedonic terms ranging between "slightly liked" (6) and "liked very much" (8). For the sample added with 15% byproduct, only the attribute "sweetness" varied between "neither liked nor disliked" (5) and "slightly liked" (6), while all other attributes showed better acceptance, ranging from "slightly liked" to "liked very much" (Table 5).

Table 5
Results obtained in the acceptance test of breads added with coquinho-azedo byproduct flour, using a hedonic scale

Attribute	Formulations	
	7.5% JF	15% JF
Appearance	7.84 ± 1.17	7.43 ± 1.33
Color	7.89 ± 1.29	7.77 ± 1.29
Aroma	7.25 ± 1.63	6.91 ± 1.69
Flavor	7.13 ± 1.42 [a]	6.38 ± 1.78 [b]
Texture	7.07 ± 1.86	6.46 ± 1.79
Sweetness	6.76 ± 1.51 [a]	5.75 ± 1.95 [b]
Acidity	6.73 ± 2.00	6.08 ± 1.75
Overall Impression	7.38 ± 1.30 [a]	6.66 ± 1.40 [b]
AI	82.00%	66.00%

Caption: 7.5% JF: Formulation added with 7.5% coquinho-azedo byproduct flour in relation to wheat flour. 15% JF: Formulation added with 15% coquinho-azedo byproduct flour in relation to wheat flour. AI: Average acceptance index.
***Note:** Identical letters in the same row do not differ statistically according to Tukey's test at 5% probability.

The difference in the amount of byproduct flour added to each formulation caused the samples to differ statistically in the attributes "flavor," "sweetness," and "overall impression," with the 7.5% byproduct sample performing best. Thus, it can be inferred that these three attributes influenced the lower performance in the acceptance index of the sample added with 15%. According to E. Teixeira et al. (1987), a good acceptance index should have values greater than 70%. Thus, in our study, only the sample added with 7.5% showed good acceptance, reaching 82% (Table 5). Since the triangular test showed differentiation between the two samples, it is suggested that future tests be conducted with 7.5 and 15% of coquinho-azedo to determine the maximum amount that can be added without compromising the sensory characteristics of the product.

Similar results to the trend observed in the present study were found by M. R. L. Santos et al. (2024), who used a 9-point structured hedonic scale in the sensory analysis of bread loaves with passion fruit peel flour. The authors found a significant difference for the breads with 5 and 15% substitution in the attributes color (7.12 and 5.91), flavor (7.03 and 5.10), and overall appearance (7.12 and 6.07). For the acceptance index, the bread with 5% of the alternative flour had a higher index (78.16) compared to the treatment with 15% (56.72). Souza et al. (2014) evaluated the incorporation and acceptability of grape pomace flour in bakery products, also through an acceptance test using a 9-point hedonic scale. Of the wholewheat bread formulations with the addition of flour from byproducts, the 5% concentration received higher scores for sensory attributes and purchase intention when compared to the 10% formulation, with significant differences in the average values for the attributes appearance (6.4 and 5.8), aroma (5.8 and 5.4), flavor (5.9 and 5.5), and overall impression (6.0 and 5.5), for the 5 and 10% formulations, respectively. The acceptability index was also higher for the 5% formulation (84.89%) compared to its 10% counterpart (81.30%).

Conceição et al. (2022) reported that when comparing the results obtained in studies with the addition of other raw materials and/or food byproducts, there is generally a strong tendency for acceptance to decrease as the percentage of these differentiated raw materials increases. This is because consumers tend to expect that new product formulations be similar in all sensory aspects to traditional ones available on the market.

The analyses show that there was a difference in the consumption and purchase intention test, with the sample added with 7.5% jelly pulp byproduct flour obtaining the highest average (Table 6). Thus, it can be inferred that the amount of the alternative flour added influenced this aspect, with the formulation containing the lowest concentration of alternative flour showing the most interest. Despite this difference, both samples were rated between "would occasionally eat" (4) and "would eat frequently" (5) for consumption, and "unsure if I would buy" (3) and "would probably buy" (4) for purchase.

Table 6
Results obtained in the consumption intention and purchase intention tests for breads added with coquinho-azedo byproduct flour

Test	Formulations	
	7.5% JF	15% JF
Consumption intention	4.84 ± 1.36	4.18 ± 1.17
Purchase intention	3.86 ± 0.88	3.44 ± 0.99

Caption: 7.5% JF: Formulation added with 7.5% coquinho-azedo byproduct flour in relation to wheat flour. 15% JF: Formulation added with 15% coquinho-azedo byproduct flour in relation to wheat flour.

Conclusions

The studies demonstrated the influence of drying on the samples. The lowest temperature (45°C) resulted in higher vitamin C values and preserved carotenoid content, these components being of great importance in the composition of food products.

The study assessed the impact of adding coquinho-azedo byproduct flour at different levels in the formulation of bread loaves. Vitamin C and carotenoid levels were higher in the formulations added with the byproduct flour compared to the standard formulation, demonstrating the influence of the flour on the components of the final product. Adding larger amounts of the alternative flour resulted in a significant decrease in specific volume, darker crumbs, and a color that leaned more toward brown and yellow tones.

The triangular discrimination test showed a significant sensory difference between the breads assessed, with the sample enriched with 7.5% coquinho-azedo byproduct flour yielding the best results in the acceptance test, acceptability index, and consumption and purchase intention.

The use of the byproduct under study, which is highly valued regionally but little known in the rest of the country, and the study of its incorporation into a popular product aimed at improving its nutritional quality, contribute to food research.

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