

**VALORIZATION OF NATIVE AMAZONIAN FRUITS IN THE BAKING INDUSTRY:
Physicochemical and Sensory Characterization of Biscuits Enriched with Buriti
(Mauritia flexuosa) and Tucumã (Astrocaryum aculeatum) Flours**

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ABSTRACT

This study investigated the potential of tucumã and buriti flours to enrich biscuits, both with and without gluten, by evaluating their physicochemical profiles (moisture, ash, protein, lipids, dietary fiber, carbohydrates, fatty acid profile, water activity, acidity, pH, minerals, and colorimetric parameters) and sensory characteristics. The incorporation of the fruits resulted in products rich in fiber and omega-9 fatty acid, increasing their nutritional value. Sensorially, tucumã obtained greater acceptance in both versions (with and without gluten), with the gluten-containing formulation standing out, demonstrating high market potential. All biscuits evaluated showed satisfactory acceptability (AI > 70%), except for the gluten-free buriti formulation, which presented challenges in aroma and flavor intensity of the fruit. Unlike most previous studies, which examined a single Amazonian fruit or a single formulation, the present work simultaneously characterized two native fruits (buriti and tucumã) in both gluten-free and gluten-containing vegan formulations, adopting a low-temperature baking strategy (110 °C) specifically designed to preserve heat-sensitive carotenoids. This dual-fruit, dual-format approach, combined with a comprehensive physicochemical and sensory assessment, provides a robust evidence base for the valorization of Amazonian biodiversity in the baking industry. This study validates the potential of Amazonian fruits as functional ingredients for the baking industry, adding nutritional and sensory value to biscuits.

Keywords: Buriti, Tucumã, Biscuit; Vegan; Dietary fiber; Omega-9; Acceptability.

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RESUMO

Este estudo investigou o potencial das farinhas de tucumã e buriti para enriquecer biscoitos, com e sem glúten, avaliando seus perfis físico-químicos (umidade, cinzas, proteínas, lipídios, fibra alimentar, carboidratos, perfil de ácidos graxos, atividade de água, acidez, pH, minerais e parâmetros colorimétricos) e características sensoriais. A incorporação das frutas resultou em produtos ricos em fibras e ácidos graxos ômega-9, aumentando seu valor nutricional. Sensorialmente, o tucumã obteve maior aceitação em ambas as versões (com e sem glúten), com destaque para a formulação com glúten, demonstrando alto potencial de mercado. Todos os biscoitos avaliados apresentaram aceitabilidade satisfatória (IA > 70%), exceto a formulação de buriti sem glúten, que apresentou desafios relacionados à intensidade do aroma e do sabor da fruta. Ao contrário da maioria dos estudos anteriores, que analisaram apenas uma fruta amazônica ou uma única formulação, o presente trabalho caracterizou simultaneamente duas frutas nativas (buriti e tucumã) em formulações veganas, tanto com quanto sem glúten, adotando uma estratégia de forneamento em baixa temperatura (110 °C) especificamente concebida para preservar carotenoides sensíveis ao calor. Essa abordagem envolvendo duas frutas e dois formatos, combinada a uma avaliação físico-química e sensorial abrangente, fornece uma base sólida de evidências para a valorização da biodiversidade amazônica na indústria de panificação. O estudo valida o potencial das frutas amazônicas como ingredientes funcionais para esse setor, agregando valor nutricional e sensorial aos biscoitos.

Keywords: Buriti; Tucumã; Biscoito; Vegano; Fibra alimentar; Ômega 9; Aceitabilidade.

1. INTRODUCTION

In Brazil, biscuits are defined as "products obtained by mixing flour(s), starch(es) and/or fecula(s) with other ingredients, subjected to kneading and cooking processes, fermented or not," and may have various shapes, textures, coatings, and fillings (BRASIL, 2005). Owing to their practicality, long shelf life, and production versatility, biscuits are widely consumed worldwide and are accessible to all social classes and age groups (Chevalier, 2000; Jacob & Leevathi, 2007; Goubgou et al, 2021).

The biscuit market demonstrates significant economic relevance. Globally, it was valued at US\$108.9 billion in 2023, with projected growth to US\$172.3 billion by 2032, exhibiting a compound annual growth rate (CAGR) of 5.90% (GUPTA, 2024). In Brazil, the sector generated R\$32.4 billion in 2023, with a production of 1.5 million tons (ABIMAPI, 2023). Although per capita consumption (7 kg/person in 2019) being lower than in other countries, biscuits have high penetration in the national market, being present in more than 90% of households (REGO et al., 2020).

Alongside economic growth, consumer behavior has shaped the industry. A study by the Food Technology Institute, Brazil Bakery & Confectionery Trends 2020 (Queiroz et al., 2014), identified five macro-trends that drive innovation in the sector: i) Premiumization and Experience: valuing products with differentiated flavors and artisanal appeal; ii) Nutrition and Functionality: seeking fortified products with high-nutritional-value ingredients, such as whole-wheat flours, oats, and fruits; iii) Naturalness and Authenticity: preference for products perceived as natural, without artificial additives and free of allergens such as gluten and lactose; iv) Sustainability and Transparency: increasing importance attributed to the social and environmental responsibility of manufacturing companies; and v) Control and Adequacy: seeking products with reduced fat, sugar, and sodium, and increased consumption of healthier ingredients (fiber, monounsaturated and polyunsaturated fatty acids, etc.).

This evolution in consumption patterns has driven research and development of biscuits with higher nutritional and functional value. The incorporation of ingredients with positive health effects has become a common practice, including the use of different flours, oats, chia, quinoa, fruits, spices, and herbs (Santos et al., 2011; Scherer et al., 2018; Nabil et al., 2020; Alves et al., 2021; Saeed et al., 2022; Krajewska and Dziki, 2023; Meenakumari et al., 2023; Goubgou et al.,

2025). Notable examples in the scientific literature include the development of biscuits with wheat substituted by green banana flour (Oliveira et al., 2020), enriched with chichá almond flour, gurguéia nut and graviola residue (Campos et al. 2022), with shea pulp (Chikpah et al., 2023), with sorghum and grasshopper (Ronoh et al., 2024), with mulberry flour (Roppolo et al., 2024), with guava flour (Mahajan et al., 2024), with raspberry flour (Santis et al., 2024); legume-based biscuits with alternative sweeteners (Lazou 2024); Yam biscuits supplemented with freeze-dried peach (Carpes et al., 2024), biscuits enriched with pea flour (Tibaldi et al., 2025), with fig flour (Geetha et al., 2025), with blueberry leaf flour (Santuccione et al., 2025), with pumpkin peel and seed flour (Asaduzzaman et al., 2025) and with artichoke bracts and transglutaminase (Dadali et al., 2025), demonstrating the potential for innovation and value aggregation.

Following this same trend of innovation and health, the production of gluten-free biscuits has established itself as a strong market trend, showing a significant increase in response to the growing demand from consumers with dietary restrictions and a broader public seeking dietary alternatives (Khairuddin et al., 2021; Mármol-Soler et al., 2022; Silva-Paz et al. 2023; Palomares-Navarro et al. 2023; Ciudad-Mulero et al., 2025; Musiienko et al., 2025). In addition to the growing demand for gluten-free products, another market niche demonstrating exponential growth potential is that of vegan products. The production of foods such as vegan biscuits has experienced rapid expansion, within a global context where this market is projected to exceed US\$31 billion by 2026. This trend is driven not only by strict vegan consumers, but also by a broad audience that includes flexitarians, people with dietary restrictions such as lactose intolerance, and a growing number of individuals seeking healthier, more ethical and sustainable options (Révillion et al., 2020).

Recognized as one of the richest biomes on the planet, the Amazon rainforest is home to a vast array of native fruit-bearing plants with considerable economic, technological, sensory, and functional potential. However, although many of these species are familiar regionally, they are largely underutilized commercially, presenting a significant opportunity for innovation in the food industry. One such application is their incorporation into bakery products, such as biscuits. Notably, species from the Arecaceae family, which includes buriti and tucumã, stand out as ideal candidates. Their high lipid content, an indispensable component for the structure and quality of biscuits, justifies this choice, making them raw materials with great potential.

The tucumã (*Astrocaryum aculeatum*) is a fruit of great cultural and economic importance in the Amazon region, being considered a symbol of Manaus (Kinupp & Lorenzi, 2014). Its pulp is widely appreciated and commercialized, standing out as the main ingredient of the "x-caboquinho," a typical and popular sandwich in fairs and food establishments (Viana et al., 2010; Machado et al., 2022). The great local acceptance has driven the incorporation of tucumã into a variety of industrialized products, such as ice cream, jams, pastes, and cheeses, demonstrating its high technological potential (Hanna, 2015; Gomes et al., 2018; Jaimes et al., 2021). From a nutritional standpoint, tucumã pulp is notable for its high lipid content (approx. 59%), being rich in unsaturated fatty acids (74.40%), such as omega-3, 6, and 9. It also contains about 7% protein, 26% carbohydrates, and a high fiber content. The fruit is one of the richest sources of pro-vitamin A (52 mg/100 g), containing 21 types of carotenoids, of which trans- β -carotene represents 75% of the total (Rosso & Mercadante, 2007). Furthermore, it is a source of bioactive compounds such as riboflavin (vitamin B2) and a range of phenolic compounds, including rutin, quercetin, catechin, and gallic and caffeic acids (Sagrillo et al., 2015; Araújo et al., 2021). This rich composition of flavonoids and β -carotene has been associated with antioxidant and anti-inflammatory properties (Todorov & Pieri, 2018; Araújo et al., 2021).

The buriti (*Mauritia flexuosa*) is one of the most important palm trees in the Amazon rainforest from an ecological, economic, and social perspective (Koolen et al., 2018). Native not only to the Amazon but also to the Cerrado, Pantanal, and several South American countries (Sampaio, 2011), the fruit has high potential for sustainable extractive exploitation, promoting income generation and improving the quality of life in rural communities (Rabelo & França, 2015). Its pulp stands out for its rich and diverse nutritional profile. It is notable for being one of the largest sources of pro-vitamin A (carotenoids) among fruits, with levels that can exceed those of carrots and cabbage (Cândido et al., 2015). β -carotene is the most abundant carotenoid, although others are also present in considerable quantities (Souza et al., 2020; Barboza et al., 2022). The lipid fraction, the main component of the pulp, is composed mostly of unsaturated fatty acids (79.69%), with oleic acid predominating (73.33%) (Cândido et al., 2015). In addition, the pulp contains vitamins C and E, fiber, and a variety of phenolic compounds such as quinic acid, caffeic acid, quercetin, and catechin, which give the fruit a high antioxidant capacity (Bataglion et al., 2015; Resende et al., 2019; Todorov & Pietri, 2018). The use of tucumã and buriti fruits as ingredients in biscuit production not only promotes differentiated flavors and nutritionally enriches the products, but also promotes the valorization of local socio-biodiversity and fosters a sustainable bioeconomy. Despite the

growing number of studies on fruit-enriched biscuits, most have focused on a single fruit and a single formulation, and few have addressed the technological challenge of preserving heat-sensitive bioactive pigments during baking. The present study advances beyond this state of the art by (i) simultaneously evaluating two nutritionally complementary Amazonian fruits, buriti and tucumã; (ii) developing both gluten-free and gluten-containing vegan formulations for each fruit; and (iii) employing a reduced baking temperature (110 °C) as a deliberate strategy to preserve carotenoids and limit excessive browning, an aspect rarely explored in the literature. This combination of ingredients, formats, and process conditions constitutes the main differential of the present work. Against this background, the present study aimed to analyze vegan biscuits, in gluten-free and gluten-containing versions, enriched with buriti and tucumã flours. To validate their technological potential, physicochemical and sensory characterizations of the products were carried out, generating essential data for their commercial viability and for the promotion of sustainable value chains in the Amazon.

2. METHODOLOGY

2.1 Reception of the fruits and obtaining the pulp

The buriti and tucumã fruits were acquired directly from local producers in the municipalities of Careiro da Várzea and Presidente Figueiredo, respectively. Access to the genetic resources was registered in the National System for the Management of Genetic Resources and Associated Traditional Knowledge (SISGEN) under code AF65CD0. After reception, the fruits underwent specific preparation routines (Oliveira et al., 2024). Tucumã fruits were processed immediately: after manual peeling, the pulp was cut into strips with a knife sanitized with peracetic acid. Buriti fruits were stored until complete ripening, evidenced by the change in peel color from light red to dark red. To facilitate pulp extraction, which was done manually with a spoon or knife, the ripe buriti fruits were submerged in water for 12 hours. Before processing (tucumã) or after ripening (buriti), both fruits underwent the same sanitization protocol: washing in running water, followed by sanitization by immersion in a sodium hypochlorite solution (200 ppm) for 15 minutes and a final rinse in potable water. The resulting pulps (tucumã strips and buriti pulp) were placed on trays and immediately sent for drying in an oven.

2.2. Obtaining the flours

To obtain the flours, the pulps were uniformly distributed on trays and dried in a forced-air oven (Lucadema) at 60°C for approximately 12 hours, until they reached a water activity (A_w) between 0.2 and 0.4. Subsequently, the dehydrated material was cooled to room temperature, ground in a blender, and sieved to ensure uniform particle size. Finally, the flours were packaged in vacuum-sealed bags.

2.3. Biscuit Preparation

The biscuits were prepared following the Manley method (2000), which involved weighing the ingredients, mixing (KitchenAid mixer), manual shaping, baking in a WICTORY convection oven (WCV-535D) at 110 °C for 50 minutes for the tucumã cookie and 60 minutes for the buriti biscuit, cooling, and packaging. The dough preparation was carried out in a planetary mixer, following these steps: (1) the fruit flour, the other flours, the refined sugar, the palm fat, and the emulsifier were added to the bowl and mixed at low speed, (2) the water was added in a continuous and gradual flow until completely absorbed by the dry components, (3) finally, the baking powder was incorporated into the mixture, and (4) the mixer speed was adjusted to medium, and the dough was beaten until it had a smooth and homogeneous consistency. The dough was placed in the Elegance model cookie press (Marcato), and the biscuits were shaped directly onto perforated stainless steel trays. After baking, the products were cooled to room temperature and then packaged in sealed kraft box pouches with a zip-lock closure.

Four biscuit formulations were developed, two with buriti flour and two with tucumã flour, each with a gluten-free and a gluten-containing version. A base of ingredients – composed of sugar, palm fat, oat flour, water, emulsifier, and chemical leavening agent – was common to all treatments. In the gluten-containing formulations, wheat flour was used, supplemented with 26% buriti flour or 23% tucumã flour. In the gluten-free formulations, wheat flour was replaced by a mixture of chestnut flour and pea protein concentrate. In these cases, the fruit flour content was 29% for the buriti biscuit and 30% for the tucumã biscuit.

2.4. Physicochemical Analyses

Analyses were performed in triplicate and the results represent the mean and standard deviation, with the exception of the fiber determination, which was performed in duplicate.

2.4.1. Moisture Determination

Moisture determination was performed in a forced-air oven (Quimis) at 105 °C for 3 hours and then until constant weight (IAL 2008).

2.4.2. Water Activity (*A_w*) Determination

A_w determination was performed using a HygroPalm AW portable instrument (Rotronic).

2.4.3. Protein Determination

Protein determination was performed using the Kjeldahl method and a factor of 5.75 was used (IAL 2008).

2.4.4. Lipid determination

Lipid determination was performed using a Soxhlet apparatus and hexane as a nonpolar organic solvent (IAL 2008).

2.4.5. Ash Determination

Ash determination was performed in a muffle furnace (Quimis) at 550 °C for 3 hours and then until constant weight (IAL 2008).

2.4.6. Fiber Determination

Soluble, insoluble, and total fiber were determined by the enzymatic-gravimetric method and MES-TRIS buffer according to AOAC Method 935.49 (2019).

2.4.7. Carbohydrate and Energy Value Determination

The carbohydrate content was calculated by difference, considering 100 - (g/100g moisture + g/100g ash + g/100g total fat + g/100g protein + g/100g total dietary fiber). The energy value was calculated by summing the percentages of protein and carbohydrates multiplied by a factor of 4 (kcal/g), total fat multiplied by a factor of 9 (kcal/g), and soluble dietary fiber multiplied by a factor of 2 (kcal/g) (Brazil, 2005).

2.4.8. Determination of the fatty acid profile

The lipid fraction was cold extracted with petroleum ether under agitation overnight. The lipid fraction was saponified with a 2% NaOH solution in methanol, followed by esterification with

ammonium chloride, sulfuric acid, and methanol, according to Hartmann and Lago (1973). The methyl esters were injected into a gas chromatograph equipped with an FID detector, autosampler, CP-Sil 88 capillary column (100 m, 0.25 mm internal diameter and 0.20 μ m film thickness), hydrogen as carrier gas (flow rate of 0.9 mL/min). The column oven temperature was programmed to 130 °C for 12 minutes, with a heating ramp from 130 °C to 230 °C (3 °C/min), and the temperature remained at 230 °C for 10 minutes. The injector was a split type, with a ratio of 1:75 and a temperature of 260 °C. The FID detector was maintained at 260 °C, with a flow rate of 30 mL/min for both the carrier gas and the auxiliary gas (nitrogen).

2.4.9. Mineral Determination

The samples were heated on a hot plate and incinerated in a muffle furnace (Fornitec) for 10 h at 450°C. The ashes were moistened with water purified by reverse osmosis (Gehaka), followed by the addition of 37% hydrochloric acid (Merck) and transfer to a 50 mL volumetric flask using purified water. Analytical blanks were prepared following the same procedure, omitting the sample (adapted from AOAC 2012). Mineral quantification was performed using an inductively coupled plasma optical emission spectrometer (ICP OES 5100 VDV, Agilent Technologies, Tokyo, Japan) equipped with a 27 MHz radio frequency (RF) source using a simultaneous optical detector, peristaltic pump, double-pass cyclonic nebulization chamber, 1.8 mm quartz torch, seaspray nebulizer, and radial view (calcium, iron, potassium, and sodium). Liquid argon of high purity (Air Liquide, São Paulo, Brazil) was used as the plasma gas, and the optimized operating conditions of the ICP OES were: plasma power 1.20 kW; argon flow rate 12.0 L min⁻¹; auxiliary argon flow rate 1.0 L min⁻¹; nebulization flow rate 0.7 L min⁻¹; number of replicates 3; The stabilization and reading time was 14 s, and the wavelengths were 317.933 nm (Ca); 259.940 nm (Fe); 766.491 nm (K) and 589.592 nm (Na). Analytical curves for the minerals were prepared from dilutions of analytical standards of 10 and 1000 mg/100 mL (Specsol - Quimlab, Jacareí, Brazil) in the ranges of 0.041 to 41.0 mg/100 mL for Ca and Na; 0.001 to 1.0 mg/100 mL for Fe, with correlation coefficients (r) greater than 0.9999.

2.4.10. Determination of colorimetric parameters

The colorimetric parameters (L^* , a^* , b^* , C^* , h°), using the CIELab system, were determined with the aid of the Delta Vista spectrophotometer (Delta Color). The coordinate L^* represents luminosity, a^* represents the green/red color component, and b^* the blue/yellow color

component. The hue angle (h°) is the qualitative attribute of color, while saturation (C^*) is the quantitative attribute. The color difference (ΔE) between gluten-containing and gluten-free cookies for the same fruit was calculated using the CIE2000 formula in the ColorMine software. This formula was chosen for its greater precision and agreement with human perception compared to previous methods (ΔE_{76} and ΔE_{94}).

2.4.11. pH Determination

The pH was determined using a benchtop digital pH meter (Hanna Instruments - HI 2221), previously calibrated with pH 7 and 4 buffer solutions.

2.4.12. Total Acidity Determination

Total acidity was determined by the volumetric method using 0.1 N NaOH solution, and the result was expressed as a percentage v/m (IAL 2008).

2.5. Sensory Analysis

This research was approved by the Research Ethics Committee (CAAE 74414423.5.0000.8119) of the Federal Institute of Education, Science and Technology of Amazonas (IFAM). The sensory analysis was conducted with a panel of 30 untrained consumers. The acceptability of the biscuits was evaluated in terms of appearance, aroma, flavor, sweetness, texture, fruit flavor intensity (FFI), and overall impression (OI), using a structured 9-point hedonic scale, anchored at the extremes "1 - extremely disliked" and "9 - extremely liked" (Meilgaard et al., 2007). The acceptability index (A.I.) for each attribute was determined using the equation $A.I. (\%) = A \times 100 / B$, where A is the average score obtained for the product and B is the maximum score on the scale, with an A.I. with good results being considered $\geq 70\%$ (Dutcosky, 2009).

2.6. Statistical Analysis

The results were analyzed using the SISVAR software and expressed as means and standard deviations. Analysis of variance (ANOVA) and Tukey's test were used to verify the differences between the means, considering a significance level of 5% ($p \leq 0.05$) and a confidence interval of 95%, respectively.

3. RESULTS AND DISCUSSION

3.1. Physicochemical Characterization

The proximate composition of the biscuits (Table 1) reveals significant differences between the gluten-containing and gluten-free versions. For both fruits, tucumã and buriti, the gluten-free formulations exhibited higher levels of moisture, ash, protein, and lipids, resulting in a higher energy value and lower carbohydrate content. This variation is directly attributed to differences in ingredients: while the gluten-containing versions used wheat flour, the gluten-free versions replaced it with a mixture of chestnut flour and pea protein concentrate, in addition to a higher percentage of fruit flours (29-30% versus 23-26%). Thus, the pea protein concentrate justifies the increase in protein content, while the higher proportion of fruit flour and the addition of chestnut flour are responsible for the higher levels of lipids and ash.

In a study on biscuits made with buriti flour, Santos et al. (2011) reported formulations with and without oats, containing 10% buriti flour, sugar, starch, margarine, wheat flour, and water. For the biscuits with and without oats, the authors found the following values, respectively: moisture of 4.21% and 4.45%; ash of 1.79% and 1.60%; lipids of 16.87% and 22.46%; protein of 3.73% and 2.42%; fiber of 3.42% and 7.71%; and carbohydrates of 73.43% and 69.0%. Compared with the presente results, the values reported by Santos et al. (2011) for moisture and carbohydrates were higher, whereas the ash, lipid, and fiber contents were lower. The only exception was the protein content, since the value found for the gluten-containing buriti biscuits in this study (2.0%) was similar to that reported for the oat biscuits (2.42%) by those authors.

Table 1. Proximate composition of biscuits with Amazonian fruits, with gluten (C/G) and without gluten (S/G).

	Tucumã C/G	Tucumã S/G	Buriti C/G	Buriti S/G
Moisture	1.6 ± 0.0723 ^c	3.3 ± 0.0317 ^a	2.6 ± 0.2068 ^b	3.3 ± 0.3357 ^a
Ash	2.7 ± 0.0239 ^b	4.5 ± 0.1411 ^a	2.6 ± 0.1704 ^b	4.7 ± 0.0078 ^a
Protein	6.4 ± 0.0541 ^b	10.7 ± 0.3025 ^a	2.0 ± 0.0451 ^c	10.6 ± 0.4400 ^a
Lipids	27.7 ± 0.1609 ^c	36.2 ± 0.4158 ^a	25.0 ± 0.1669 ^d	32.0 ± 0.1470 ^b
Insoluble fiber	14.5 ± 0.9655 ^b	18.4 ± 0.9861 ^a	9.57 ^c ± 0.7103	16.6 ± 1.5631 ^{ab}
Soluble fiber	2.7 ± 0.1373 ^a	3.0 ± 0.2703 ^a	0.7 ± 0.1343 ^c	1.7 ± 0.1704 ^b
Total dietary fiber	17.2 ± 0.8281 ^b	21.7 ± 0.7158 ^a	10.3 ± 0.5759 ^c	18.3 ± 1.3927 ^b
Carbohydrates	44.4 ± 0.1387 ^b	23.7 ± 0.6235 ^d	57.5 ± 0.2352 ^a	31.1 ± 0.1988 ^c
Energy value	458 ± 1.43 ^a	469 ± 3.04 ^a	464 ± 4.77 ^{ab}	458 ± 4.67 ^a

* Different letters on the same line indicate a statistically significant difference at $p < 0.05$ according to Tukey's test.

Source: The authors (2026)

In the analysis of the proximate composition (Table 1), the biscuits formulated with tucumã (1.6% to 3.3%) and buriti (2.6% to 3.3%) showed low moisture content. These values contrast with the considerably higher levels reported in other studies with functional biscuits, such as those made with artichoke bracts (12.98% to 14.98%; Dadali et al., 2025) or blueberry leaves (8.7% to 9.3%; Santuccion et al., 2025). On the other hand, the results of this study are consistent with those of Mahajan et al. (2024), who found moisture between 2.64% and 2.85% in biscuits enriched with guava flour. A low moisture content is a positive indicator for the microbiological stability and shelf life of the product, since it reduces the water available for the growth of spoilage microorganisms and for hydrolytic reactions. This characteristic is particularly relevant for the commercial viability of the developed biscuits, as it supports a longer storage period without compromising quality.

The ash content, which reflects mineral content, was higher in the gluten-free formulations (4.5% and 4.7%) compared to their gluten-containing versions (2.6% and 2.7%). This increase is directly attributed to the substitution of wheat flour with ingredients of higher mineral density, such as the higher percentage of fruit flours and chestnut flour. Notably, the ash content of the gluten-free biscuits exceeded the values reported in a wide range of studies, including biscuits with artichoke bracts (1.92-2.32%; Dadali et al., 2025), blueberry leaves (3.6-3.7%; Santuccion et al., 2025), and guava flour (1.42-1.97%; Mahajan et al., 2024). The high ash content suggests a significant mineral enrichment in the gluten-free formulations, reinforcing their potential as a functional food.

The analysis of protein content revealed a significant increase in gluten-free formulations (10.7% and 10.6%) compared to the gluten-containing versions (6.4% and 2.0%). This result is a direct consequence of the addition of pea protein concentrate, a key functional ingredient. The choice of this concentrate was deliberate to position the biscuits as a high value-added product, meeting the demand for gluten-free, vegan, and healthy-looking foods. The literature endorses the benefits of pea protein, which include bioactive peptides, anabolic properties, high satiety effect, and hypoglycemic and hypotensive potential (Stilling, 2020; Wang et al., 2022), reinforcing the formulation's success in achieving its functional objectives. Additionally, the variation in protein content between the gluten-containing biscuits, tucumã (6.4%) and buriti (2.0%), can be attributed to the natural composition of the fruit flours. This hypothesis is supported by Oliveira et al. (2024), who demonstrated that tucumã flour has an inherently higher protein content than buriti flour. Contextualizing our results, the gluten-free biscuits presented a robust protein profile, comparable to other functional products such as blueberry leaf biscuits (10.7%-11.5%) studied by Santuccione et al. (2025) and superior to several alternatives, such as biscuits with freeze-dried peach (7.21%-7.66%) by Carpes et al. (2024), biscuits with shea pulp (8.20% and 9.63%) by Chikpah et al. (2023) and biscuits with guava flour (7.48% and 8.56%) by Mahajan et al. (2024), highlighting the effectiveness of formulations with Amazonian fruits. From a nutritional standpoint, the protein levels achieved in the gluten-free versions are relevant, since they approach the content of conventional wheat-based products while offering the additional benefits of a plant-based, gluten-free matrix. This positions the biscuits as a viable protein source within a vegan diet, a segment in which adequate protein intake is often a concern.

The total dietary fiber content in biscuits enriched with Amazonian fruits varied, ranging from 17.2% to 21.78% for formulations with tucumã and from 10.29% to 18.28% for those with buriti (Table 1). In both formulations, the insoluble fiber fraction was predominant, corresponding to approximately 84% and 90% of the total fiber content in tucumã and buriti biscuits, respectively. The high values of total dietary fiber qualified the developed biscuits (with and without gluten) for the claim of "source of fiber," according to current Brazilian legislation (BRASIL, 2020). These results exceed the minimum required of 10% of the daily reference value (25 g) per serving (30 g), highlighting the potential of these native fruits for the development of functional foods. The values obtained are analogous to those reported by Boeira et al. (2026) for pupunha biscuits (19.18% to 20.28%), and higher than those found by Dadali et al. (2025) in biscuits with artichoke bracts (2.28% to 7.97%) and by Santuccione et

al. (2025) in biscuits with blueberry leaves (6.5% to 7.8%). The predominance of the insoluble fraction is consistent with the structural tissues of the fruit flours and is associated with benefits such as improved intestinal transit and increased fecal bulk. Together with the soluble fraction, this fiber profile may contribute to glycemic control and satiety, reinforcing the functional positioning of the biscuits beyond their basic nutritional value.

The lipid content followed a similar trend to that of protein, with higher values in gluten-free biscuits (27% and 36%) compared to gluten-containing formulations (21% and 25%). Additionally, biscuits containing tucumã showed a higher lipid content than those containing buriti. This result corroborates the findings of Oliveira et al. (2024), who reported higher lipid concentrations in tucumã flour (55.20%–67.23%) compared to buriti flour (45.08%–50.91%). The lipid levels observed in this study are consistent with those reported for cookies enriched with peach palm (25%-26.4%, Ribeiro et al., 2021), ginger (26.17%-27.50%, Arogundade et al., 2023), shea pulp (25.08%-27.09%, Chikpah et al., 2023), sorghum and grasshopper (20.97%-26.38%, Ronoh et al., 2024) and sweet potato peel (34.2%-34.8%, Bakar et al., 2022). However, they were higher than those found in biscuits with chia mucilage (9.63%-12.55%, Rocha et al., 2020), multigrain biscuits with sweet potato (21.04%-21.12%, Meenakumari et al., 2023), guava flour (22.22%-24.75%, Mahajan et al., 2024), blueberry leaf powder (21.2%-21.7%, Santucci et al., 2025) and pumpkin seeds (12.03%-13.95%) and pumpkin peel (10.84%-11.00%, Asaduzzaman et al., 2025), indicating the significant impact of adding Amazonian fruits on the lipid composition of the final product. The trans fatty acid content of 0.05 - 0.07 g/100 g (C 18:2 - omega 6 t) found in tucumã biscuits is within the limits established by Anvisa (Brazil, 2020) in Normative Instruction 75, Annex IV, which establishes that trans fats should be less than or equal to 0.1 g per reference portion, per 100 g or mL. When considering the individual packaging of the biscuits, the levels observed are insignificant and in accordance with Brazilian legislation. As the biscuits contain percentages of monounsaturated and polyunsaturated fats in their composition, the formation of trans fatty acids probably resulted from the high temperature applied to the products during baking, which can cause geometric isomerization of the double bonds. Although the lipid content is relatively high, the quality of this fraction is favorable, since it is dominated by unsaturated fatty acids, as detailed below. This distinction between the quantity and the quality of the lipid fraction is essential to correctly interpret the nutritional value of the developed biscuits.

The fatty acid profile in tucumã and buriti biscuits (Table 2) was marked by the predominance of unsaturated fatty acids (UFAs) over saturated fatty acids (SFAs), in a ratio ranging from 2:1 to almost 3:1. Specifically, UFAs accounted for 64-70% in buriti biscuits and 68-73% in tucumã biscuits. This favorable ratio of unsaturated to saturated fatty acids (SFAs) is similar to that observed by Avila-Nava et al. (2022) in biscuits formulated with chaya and amaranth. Within the unsaturated fraction, monounsaturated fatty acids (MUFAs) were predominant (79-86%), with oleic acid (omega-9) constituting approximately 99% of this total. In the polyunsaturated fatty acid (PUFA) fraction, linoleic acid (omega-6) predominated, representing 92-94%. This profile suggests that the formulated biscuits may offer a healthier lipid quality than traditional products. These results are consistent with those of Ruiz et al. (2026), who also reported high levels of fatty acids in biscuits with sachá inchi oil and cake, reinforcing the functional potential of the developed biscuits and adding value to Amazonian raw materials.

The predominance of oleic and linoleic acids in biscuits gives them significant functional potential. The oleic acid content found in biscuits allows the use of the claim "source of omega-9" on the label, according to IN 75/2020 (Brazil 2020). Oleic acid, the major component in this study, is associated with antioxidant, anti-inflammatory, and antitumor properties, in addition to helping prevent obesity, metabolic syndrome, and reducing the risk of heart disease (Tutunchi et al., 2020; Katariya et al., 2021; Pastor et al., 2021; Santa-Maria et al., 2023). Similarly, linoleic acid, an essential fatty acid, plays a protective role against cardiovascular disease, certain types of cancer, and all-cause mortality (Sadeghi et al., 2025). Therefore, the incorporation of tucumã and buriti nutritionally enriches the biscuits, making them a healthier alternative. From a technological perspective, the high content of unsaturated fatty acids also explains the higher oxidative susceptibility of these products, which reinforces the importance of the low water activity achieved and of adequate packaging to preserve quality during storage.

Table 2. Determination of the fatty acid profile in biscuits with Amazonian fruits with gluten (C/G) and without gluten (S/G)

fatty acid (g/100g)		Buriti C/G	Buriti S/G	Tucumã C/G	Tucumã S/G
C 12:0	lauric	0.02 ± 0.00	-	-	-
C 14:0	myristic	0.08 ± 0.00	0.06 ± 0.00	0.07 ± 0.00	0.06 ± 0.00
C 16:0	palmitic	6.27 ± 0.01	6.25 ± 0.01	5.07 ± 0.01	5.37 ± 0.01
C 16:1 omega 7	palmitoleic	0.03 ± 0.00	0.04 ± 0.00		0.02 ± 0.00
C 17:0	margaric	0.02 ± 0.00	0.03 ± 0.00	0.03 ± 0.00	0.04 ± 0.00
C 18:0	stearic	0.87 ± 0.00	1.33 ± 0.00	2.25 ± 0.01	3.57 ± 0.00
C 18:1 omega 9	oleic	10.84 ± 0.01	14.41 ± 0.00	13.14 ± 0.00	19.66 ± 0.00
C 18:2 omega 6	linoleic	1.66 ± 0.00	3.34 ± 0.001	2.90 ± 0.00	5.01 ± 0.01
C 18:2 omega 6 t	trans-linoleic	-	-	0.05 ± 0.00	0.07 ± 0.00
C 20:0	arachidic	0.04 ± 0.00	0.05 ± 0.00	0.08 ± 0.00	0.11 ± 0.00
C 20:1 omega 9	cis-11-eicosenoic	0.09 ± 0.00	0.10 ± 0.00	0.05 ± 0.00	0.34 ± 0.00
C 18:3 omega 3 α	alpha-linolenic	0.15 ± 0.00	0.20 ± 0.00	0.21 ± 0.00	0.34 ± 0.00
Total fatty acids (g/100g) [%]					
Saturated		7.31 ± 0.01	7.72 ± 0.01	7.50 ± 0.01	9.16 ± 0.01
Monounsaturated		10.96 ± 0.01	14.56 ± 0.01	13.19 ± 0.01	19.75 ± 0.00
Polyunsaturated		1.81 ± 0.00	3.54 ± 0.01	3.11 ± 0.00	5.35 ± 0.00
Omega 3		0.15 ± 0.00	0.20 ± 0.00	0.21 ± 0.00	0.34 ± 0.00
Omega 6		1.66 ± 0.00	3.34 ± 0.01	2.90 ± 0.00	5.00 ± 0.01

Source: The authors (2026)

The mineral composition of the biscuits (Table 3), varied significantly depending on the fruit (tucumã and buriti) and the formulation (with and without gluten). Biscuits with tucumã stood out for their higher average potassium content, while those with buriti showed higher levels of calcium. Notably, the gluten-free formulations, for both fruits, showed higher levels of calcium, iron, and potassium. Regarding sodium, the values were similar between the gluten-free versions, but the buriti biscuit with gluten exhibited a higher content than the tucumã biscuit. Despite these variations, the nutritional contribution per reference serving (30 g) was not sufficient to classify the products as a "Source" of minerals, according to the minimum criterion of 15% of the Recommended Daily Value (RDV) established by IN 75/2020 (Brazil 2020). The maximum contributions achieved were 5.07% of the RDI for calcium, 7.22% for iron, 5.70% for potassium, and 4.56% for sodium. When contextualizing these findings with the literature, it is observed that the calcium, potassium, and sodium levels were higher than those reported by Campos et al. (2022) in biscuits with Cerrado fruits. On the other hand, the iron levels in the gluten-free versions (3.11 to 3.37 mg/100g), although higher than those of

Campos et al. (2022), were lower than those found by Mahajan et al. (2024) in biscuits with guava flour (3.00 to 6.14 mg/100g). In contrast, Santuccioni et al. (2025) reported substantially higher calcium values (1,108 to 1,174 mg/100g) and lower sodium values (97 to 103 mg/100g) in biscuits with blueberry leaf powder, highlighting how different functional ingredients modulate the final mineral profile. Although the biscuits do not reach the regulatory threshold to be labeled as a mineral source, their mineral contribution should not be disregarded, since they complement the mineral intake of the diet, particularly in the gluten-free versions, which showed the highest calcium, iron, and potassium contents.

Table 3. Determination of minerals in biscuits with Amazonian fruits, with gluten (C/G) and without gluten (S/G)

	(mg/100g)			
	Calcium	Iron	Potassium	Sodium
Buriti SG	169 ± 1.00 ^a	3.37 ± 0.13 ^a	485 ± 3.00 ^b	304 ± 1.00 ^a
Buriti CG	129 ± 1.00 ^b	1.65 ± 0.03 ^c	407 ± 2.00 ^d	286 ± 2.00 ^b
Tucumã SG	84 ± 1.00 ^c	3.11 ± 0.04 ^a	665 ± 1.00 ^a	298 ± 2.00 ^a
Tucumã CG	43.9 ± 0.30 ^d	2.15 ± 0.02 ^b	438 ± 1.00 ^c	179 ± 1.00 ^c

* Different letters in the same column indicate a statistically significant difference at $p < 0.05$ according to Tukey's test.
 Source: The authors (2026)

The water activity (A_w) of the biscuits showed low and consistent values, ranging from 0.35 to 0.38 (Table 4). This parameter is fundamental for the stability of food products, as values below 0.6 are effective in preventing microbial growth. Additionally, the observed A_w range is considered ideal for minimizing lipid oxidation, which, according to Labuza (1980), occurs more slowly at values between 0.2 and 0.4. Oxidation is a particular concern in products with unsaturated fatty acids, such as those present in buriti and tucumã, due to their greater reactivity. Therefore, the A_w of the developed biscuits not only ensures microbiological stability but also contributes to oxidative stability, being a key factor for the product's shelf life. The pH and titratable acidity values varied according to the fruit and formulation used (Table 4). The biscuits made with buriti exhibited higher acidity and lower pH, reflecting the intrinsic characteristics of this fruit. It was also observed that the formulations with gluten consistently presented higher acidity and lower pH compared to the gluten-free versions for both fruits. Compared to the literature, the A_w values (0.35-0.38) were lower and acidity (0.56-1.45) higher than those reported by Carpes et al. (2024) for yam biscuits with freeze-dried peach, which recorded A_w between 0.55 and 0.59 and acidity from 0.40 to 0.66%.

Table 4. Determination of A_w , pH and acidity in biscuits with Amazonian fruits with gluten (C/G) and without gluten (S/G).

	Tucumã C/G	Tucumã S/G	Buriti C/G	Buriti S/G
A_w	0.38 ± 0.0010^a	0.37 ± 0.0010^b	0.38 ± 0.0026^a	0.35 ± 0.0012^c
Acidity	0.95 ± 0.0704^b	0.56 ± 0.0003^c	1.45 ± 0.0706^a	0.74 ± 0.0515^b
pH	6.10 ± 0.0283^a	6.12 ± 0.0361^a	4.04 ± 0.0058^c	4.99 ± 0.0416^b

* Different letters on the same line indicate a statistically significant difference at $p < 0.05$ according to Tukey's test.

Source: The authors (2026)

The perception of color in food exerts a significant influence on the consumer, serving as a primary indicator of quality, freshness, and even nutrient content. However, technological treatments applied during processing can profoundly affect this characteristic (Molina et al., 2023). For buriti and tucumã fruits, the subjects of this study, the vibrant coloration of their pulps is attributed to a high content of carotenoids, notably β -carotene, which are known for their instability. Natural colorants are inherently more sensitive to environmental factors such as heat, light, pH, and oxygen compared to their synthetic counterparts, frequently resulting in color loss during processing and storage (Divya et al., 2025). The biscuit baking process is particularly challenging for the retention of heat-sensitive pigments. This step involves complex changes such as starch gelatinization, protein denaturation, and, crucially for appearance, crust color formation. Surface color, an attribute closely linked to aroma and texture, results primarily from the Maillard reaction (Roppolo et al., 2024). Conventional baking temperatures, generally around 180°C , accelerate this reaction but are excessively high for the stability of carotenoids. Therefore, adopting a reduced baking temperature of 110°C in this study was a deliberate methodological decision, aiming to mitigate carotenoid degradation and simultaneously moderate the intensity of the Maillard reaction to avoid excessive browning of the biscuits. This strategy proved effective, as evidenced by the yellow-orange hue (h° between 70.21° and 73.16°) and the high color saturation (C) of the final products, which indicate that the characteristic pigmentation of the fruits was largely preserved. This result represents a relevant contribution of the present study, demonstrating that it is possible to obtain visually attractive biscuits without resorting to synthetic colorants, in line with the consumer trend toward naturalness. A preliminary study by Menezes et al. (2025) evaluated the stability of β -carotene (provitamin A) during the production of biscuits with tucumã. The content of the compound, initially 31.6 mg/100g in the flour, was reduced to 8.9 mg/100g in the dough and 5.5 mg/100g in the final biscuit, indicating a 38% loss during processing. Despite this reduction, the final product can still be classified as a food with a "high content"

of β -carotene, according to current legislation (BRAZIL, 2020). The tucumã and buriti biscuits, both with and without gluten, are shown in Figure 1, and the results of the colorimetric parameters are in Table 5. The color difference (ΔE), the distance between two colors in the CIELAB color space (L^* , a^* , b^*), was greater among the tucumã biscuits (4.12) with and without gluten than among the buriti biscuits (2.93) with and without gluten (Table 5), which can be easily visualized in Figure 1.

Figure 1. Cookies with Amazonian fruits, gluten-free (S/G) and with gluten (C/G).



Source: The authors (2026)

The hue angle (h°) values for the biscuits ranged from 70.21° to 73.16° , positioning the biscuits with a yellow-orange coloration. For both fruits, the gluten-free version showed a coloration tending towards orange and the one with gluten tending towards yellow (Figure 1), with the biscuit with tucumã containing gluten showing a more yellowish coloration, corroborated by the lower value of the a^* coordinate (Table 5).

Table 5. Determination of colorimetric parameters in biscuits with Amazonian fruits with gluten (C/G) and without gluten (S/G).

		L^*	a^*	b^*	C^*	h°	ΔE
Tucumã	C/G	$61.59^b \pm 0.98$	$14.8^c \pm 0.12$	$48.91^c \pm 0.83$	$51.10^c \pm 0.78$	$73.16^a \pm 0.32$	4.12
	S/G	$57.67^c \pm 0.28$	$18.67^a \pm 0.72$	$51.88^b \pm 1.60$	$55.14^b \pm 1.74$	$70.21^c \pm 0.44$	
Buriti	C/G	$60.20^b \pm 1.37$	$17.79^b \pm 0.73$	$50.97^b \pm 0.16$	$53.98^b \pm 0.39$	$70.77^{bc} \pm 0.68$	2.93
	S/G	$63.33^a \pm 0.18$	$18.69^a \pm 0.22$	$54.90^a \pm 0.60$	$58.00^a \pm 0.64$	$71.20^b \pm 0.03$	

* Different letters in the same column indicate a statistically significant difference at $p < 0.05$ according to Tukey's test..

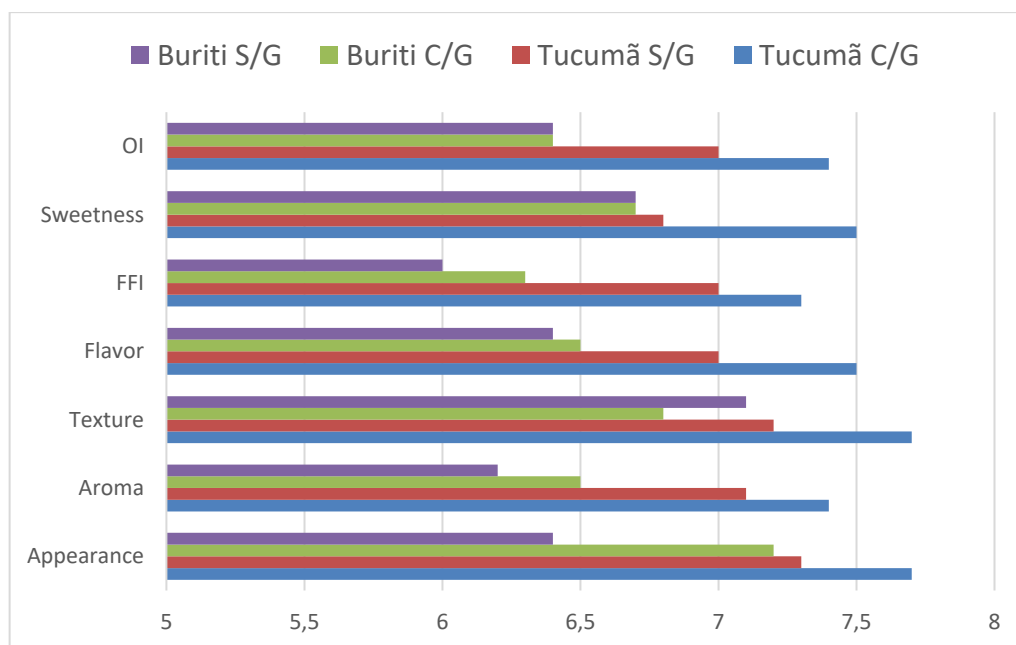
Source: The authors (2026)

The sensory evaluation (Figure 2) revealed a positive reception for all formulations, with average scores ranging from 6.0 to 7.7 on the hedonic scale. Consistently, the biscuits formulated with tucumã obtained higher scores (averages of 6.8 to 7.7) in all attributes when compared to those with buriti (averages of 6.0 to 7.2). These results are comparable to those

of Asaduzzaman et al. (2025), who reported satisfactory sensory characteristics with scores between 6.0 and 8.3 in biscuits enriched with pumpkin by-products. Additionally, the presence of gluten positively impacted acceptance, resulting in higher scores for most attributes in both fruits. This sensory advantage of tucumã can be attributed to the high acceptance of the tucumã fruit itself among consumers, who readily recognized its characteristic flavor in the biscuit, which positively influenced their overall perception of the product. In contrast, the aroma and flavor of buriti, although equally characteristic of the fruit, may have been less familiar or less appreciated by the panel, which limited its acceptance, particularly in the gluten-free version. The positive influence of gluten on acceptance is consistent with the better structural and textural properties conferred by the wheat protein network, which tends to produce biscuits with a more familiar and pleasant mouthfeel.

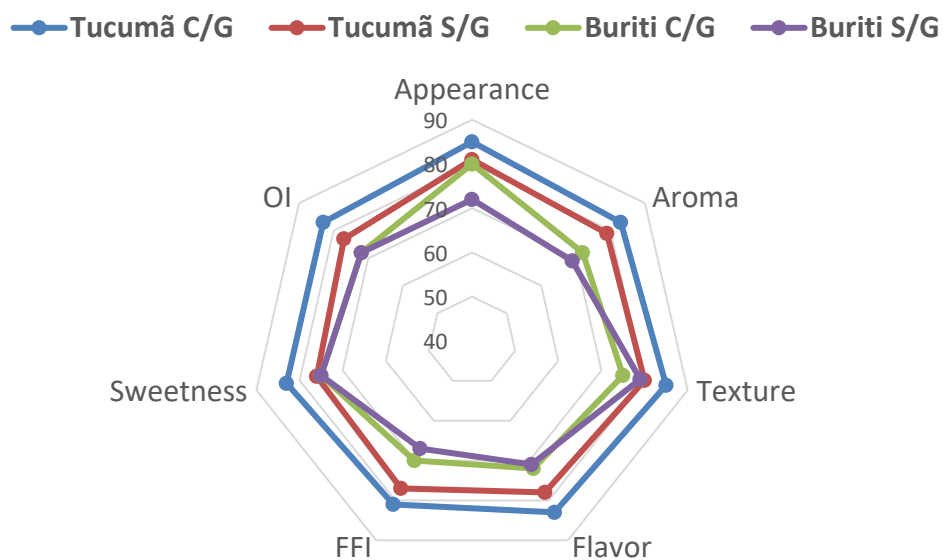
To contextualize these results, the Acceptability Index (A.I.) was calculated for each formulation (Figure 3). According to Dutcosky's (2009) criterion, a product is considered satisfactory when it reaches a minimum A.I. of 70%. All formulations exceeded this threshold in most attributes, confirming their market viability (Figure 3). The only exception was the gluten-free buriti biscuit, which presented an A.I. lower than 70% for the attributes "aroma" and "fruit flavor intensity". The preference hierarchy was clear, with the gluten-containing tucumã biscuit leading in all attributes, followed by the gluten-free tucumã version, the gluten-containing buriti version, and lastly, the gluten-free buriti version. These findings indicate that, while tucumã can be incorporated directly with excellent results, buriti requires formulation adjustments, such as flavor masking or combination with other ingredients, to overcome the sensory limitations observed in its gluten-free version. This distinction provides practical guidance for the food industry on how to best exploit each fruit.

Figure 2. Results obtained in the acceptability evaluation for the attributes appearance, aroma, texture, flavor, fruit flavor intensity (FFI), sweetness and overall impression (OI) of biscuits with Amazonian fruits tucumã and buriti with (C/G) and without gluten (S/G).



Source: The authors (2026)

Figure 3. Acceptability index (%) of gluten-free (S/G) and gluten-containing (C/G) biscuits with Amazonian fruits.



Source: The authors (2026)

4. CONCLUSION

This study demonstrated that the incorporation of tucumã and buriti flours is an effective strategy to add nutritional and sensory value to biscuits, promoting the valorization of native Amazonian fruits in the baking industry. Nutritionally, all formulations were confirmed as sources of dietary fiber and omega-9 fatty acids, with a substantial contribution of minerals and proteins, particularly in the gluten-free versions, which also presented a favorable fatty acid profile and adequate physicochemical stability. The adoption of a reduced baking temperature proved to be a successful strategy to preserve the characteristic pigmentation of the fruits, resulting in visually attractive products without synthetic colorants.

Sensorially, the tucumã biscuit demonstrated clear superiority, achieving high acceptability in all evaluated attributes, with the gluten-containing version standing out as a product of high market potential. Buriti, although viable, presented sensory challenges, especially in its gluten-free version, which did not reach the acceptability index for aroma and fruit flavor intensity.

Taken together, the results indicate that tucumã is a promising ingredient ready for direct application, while buriti requires adjustments in future formulations, such as combination with other ingredients or flavor optimization, to improve its sensory profile. This study reinforces the potential of Amazonian biodiversity for innovation in the food industry and provides a scientific basis for the development of sustainable value chains, contributing to the consolidation of a bioeconomy based on native fruits.

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