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The Use of Fruits From Brazilian Biodiversity for The Functional Ricotta Development

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Abstract: *This study evaluated the addition of 15% native Brazilian fruit pulps (red araçá, butiá, guabiroba, and uvaia) to fresh ricottas to enhance their functional and nutritional properties. Five formulations were analyzed for physicochemical characteristics, bioactive compounds, color, texture, and mineral composition. Fruit addition lowered pH and water activity without altering moisture. Ricottas with araçá and guabiroba exhibited the highest phenolic content, and all fruit-enriched samples demonstrated greater antioxidant activity than the control, particularly those containing guabiroba. Carotenoid profiles were expanded, with increases in β-carotene and the presence of α-carotene, β-cryptoxanthin, and λ-carotene. The mineral content was also enhanced: araçá contributed more potassium, guabiroba contributed more magnesium, and butiá contributed more sodium. Calcium, phosphorus, and zinc levels remained unchanged, and no toxic metals were detected. Color shifted toward reddish-yellow tones, and texture became softer and more fragile in fruit-containing samples. Overall, incorporating native fruits into ricottas adds nutritional and functional value, supporting innovation in dairy products.*

Keywords: dairy products, fresh cheese, bioactive compounds, functional food.

INTRODUCTION

Ricotta is a fresh cheese obtained mainly from whey, which may or may not contain added milk, and is coagulated by the combined action of heat and an acidic solution. Originating from the liquid byproduct, or whey, resulting from the enzymatic coagulation process of milk during cheese production, Ricotta is a dairy product recognized for its sustainable practices in the dairy industry (Mangione et al., 2025). By reusing whey, a byproduct that often presents environmental challenges due to its disposal, ricotta production helps to minimize waste and promote a more sustainable approach to dairy processing (Carota et al., 2017; Soumati et al., 2023). Rich in sulfur amino acids, Ricotta has a low-fat content. However, this type of cheese is not a product rich in bioactive compounds (Foschi et al., 2025), such as native Brazilian fruits.

According to Mariko et al. (2017), Brazil is the country with the greatest biodiversity of native fruits in the world. Among these native fruits, the red araça (*Psidium longipetiolatum*), butiá (*Butia odorata*), guabiroba *(Campomanesia xanthocarpa* O. Berg), and uvaia (*Eugenia pyriformis* Cambess) stand out. These fruits are widely valued for their high content of phenolic compounds, which are secondary metabolites known for their antioxidant properties (da Fonseca Antunes et al., 2024; da Silva et al., 2022; Gwozdz et al., 2023; Prestes et al., 2022). When incorporated into the human diet, these compounds can neutralize reactive oxygen species and free radicals, reducing the risk of degenerative diseases associated with aging.

In recent years, there has been an increase in interest in the use of pulps from native Brazilian fruits for products with functional claims, highlighting the high content of phenolic compounds, antioxidant potential and vitamin and mineral content in ingredients such as edible films, beverages and supplements(Prestes et al., 2024, 2025; Silva-Rodrigues et al., 2020). However, several native fruits remain commercially underutilized, despite their nutritional value, being explicitly described as underutilized species in recent studies de Paulo Farias et al., 2020; Tischer et al., 2023). Furthermore, the amount of research on the incorporation of these fruits into food is still considered insufficient, compared to fruits typical of temperate regions, such as those found in Europe and North America.

In addition to their nutritional and potential health benefits, native fruits play a fundamental role in maintaining Brazilian biodiversity. Species such as araça, guabiroba, and uvaia provide food for local fauna, and many are cultivated by small farmers in agroecological systems, promoting sustainable agricultural practices. To increase their economic and environmental value, developing food products based on the pulp of these fruits can represent a sustainable strategy, strengthen the bioeconomy, and encourage conservation efforts by generating new market opportunities (Rodrigues et al., 2021; Silva et al., 2025).

Growing consumer awareness of the health benefits of fruits has driven the incorporation of fruits rich in bioactive compounds, such as polyphenols and carotenoids, into diets. In this context, native Brazilian fruits have been gaining prominence as promising sources of these metabolites, which possess antioxidant and anti-inflammatory properties. This potential has sparked the interest of the food industry, which is seeking to explore the use of these fruits — especially in the form of pulp — in the development of new products with functional claims, aiming to meet the demand for healthier foods aligned with principles of sustainability and appreciation of biodiversity(Rodríguez-Cortina & Hernández-Carrión, 2025).

The addition of fruit pulps to ricotta cheese can cause changes in their properties. Thus, the objective of this study was to develop ricottas containing pulps of native Brazilian fruits (red araça, butiá, guabiroba, and uvaia), characterized by their physical, chemical, and functional properties.

MATERIAL AND METHODS

Material

The whey used in this study came from Minas Frescal cheese, which was obtained using the following materials: pasteurized whole milk (Tirol®, Treze Tílias, SC, Brazil) containing 3.2 g/100 g of proteins, 3 g/100 g of lipids and 4.7 g/100 g of carbohydrates, and rennet (protease enzyme) Ha La® (Valinhos, SP, Brazil) with a coagulant power of 1:3,000. In the preparation of the ricottas, the previously obtained whey and pasteurized whole milk (Tirol®, Treze Tílias, SC, Brazil) were used, in addition to Heinig® alcohol vinegar (Brusque, SC) containing a total acidity of 4 g/100 g of acetic acid. Pulps of red araça (Encontro de Sabores®, Passo Fundo, RS, Brazil), butiá (Encontro de Sabores®, Passo Fundo, RS, Brazil), guabiroba (Heide® vegetable extracts, Pinhais, PR, Brazil), and uvaia (Encontro de Sabores®, Passo Fundo, RS, Brazil) were added to the ricottas (Table 1). All reagents used were of analytical grade, and, when necessary, solutions were prepared and standardized.

Table 1. Composition of the pulps added to Ricotta.

Pulp	Composition (g/100g)		
	Protein	Lipids	Carbohydrates
Red araçá	2.5	1.0	14.3
Butiá	1.9	2.0	22.8
Guabiroba	2.3	3.0	4.5
Uvaia	1.8	2.0	10.0

Ricotta production

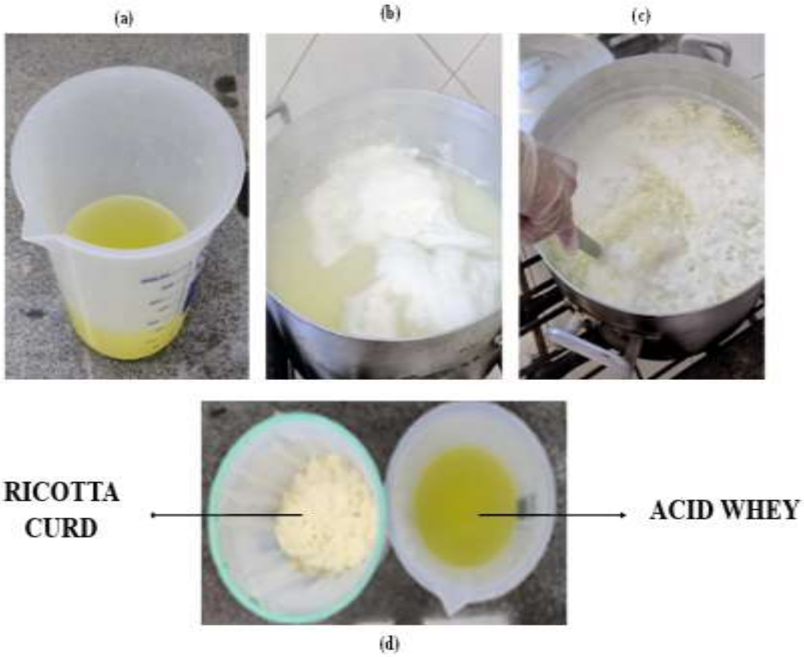
The ricotta cheese samples were prepared using whey from Minas Frescal cheese. Thus, Minas Frescal cheese was first prepared. Rennet (quantity as specified by the manufacturer) was previously diluted in water and added to the heated whole pasteurized milk (37 ± 2 °C) (Figure 1a). This mixture was maintained at a temperature of 40 ± 1 °C for approximately 40 minutes, until the mass coagulated (Figure 1b). Then, the coagulated mass was cut and stirred (Figure 1c) to separate the whey from the coagulated mass. The whey was reserved to produce Ricotta.

The whey from the production of Minas Frescal cheese was heated to a temperature ≥ 80 °C (Figure 2a). 30% (v/v) whole pasteurized milk was added to the whey, and the mixture was heated again (≥ 80 °C) (Figure 2b). After heating, 3% (v/v) vinegar was added, resulting in instant coagulation of the ricotta curd (Figure 2c). This coagulation process yielded the ricotta curd and acid whey (Figure 2d). The ricotta curd was weighed and separated into 5 equal parts. In four equal portions, 15% (m/m) of red araça pulp (RA) (Figure 3a), 15% (m/m) of butiá pulp (RB) (Figure 3b), 15% (m/m) of guabiroba pulp (RG) (Figure 3c) and 15% (m/m) of uvaia pulp (RU) (Figure 3d) were added. The pulps were added to the ricotta curd, while a sample without added pulp was obtained and called the control (RC) (Figure 3e). The ricottas were packaged, kept refrigerated (5 ± 1 °C), unmolded, and stored refrigerated until the analyses were performed.

Figure 1. Stages of production of Minas Frescal cheese, aiming to obtain whey to be used in the preparation of Ricotta, where (a) addition of rennet to heated milk, (b) coagulation of the mass, and (c) cutting and stirring of the mass.

(a) **(b)** **(c)**

Figure 2. Main steps to obtain ricotta curd (a) whey, (b) whey with heated pasteurized milk, (c) coagulated ricotta mass, and (d) ricotta mass and acid whey



Physicochemical analysis
The pH values of the ricotta cheese samples were determined using a digital pH meter (Kasvi®, São Paulo, Brazil). The water activity (Aa) of the ricotta cheese samples was measured at a temperature of 25 ± 1 °C using the Aqualab® 4TE analyzer (Decagon Devices, USA), after stabilizing the ricotta cheese samples for a period of 15 minutes. The moisture content (g/100 g) of the ricotta cheese samples was determined by oven drying until a constant weight was achieved (AOAC, 2019).

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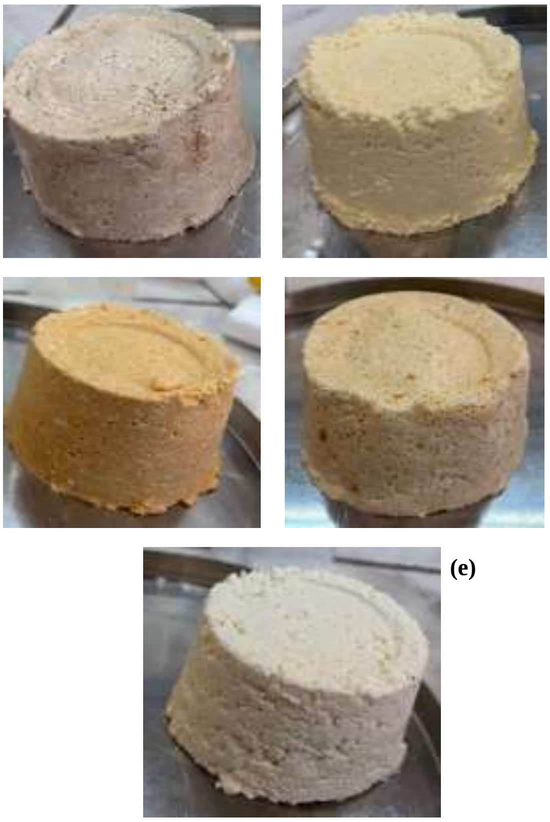
Figure 3. Ricottas prepared with the addition of 15% (m/m) of (a) red araça pulp (RA), (b) butia pulp (RB), (c) guabiroba pulp (RG), (d) uvaia pulp (RU), and (e) control (RC), without the addition of pulp.



Total phenolic compounds

Total phenolic compounds (TPC) were determined by colorimetric analysis using the Folin-Ciocalteau reagent, following the protocols of Singleton and Rossi (1965) with adaptations. The reaction occurred in the dark, at room temperature, for 90 min, and the absorbance was measured at 725 nm using a Shimadzu®-1800 UV–VIS® spectrophotometer (Kioto, Japan). The results were expressed as µM GAE (gallic acid equivalent) per g.

Antioxidant capacity

The antioxidant capacity of ricotta cheese samples was determined by the DPPH (2,2-diphenyl-1-picrylhydrazyl) free radical method, following the procedure of Brand-Williams et al. (1995). The reaction was performed in the dark at room temperature for 30 minutes. Absorbance was measured using a UV/VIS spectrophotometer (Shimadzu®, Kyoto, Japan) at 515 nm, with results expressed as µM TEAC (Trolox equivalent) per g. Antioxidant capacity was also determined by the $ABTS^+$ (2,2'-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid)) radical inhibition activity of ricotta cheese samples, according to Re et al. (1999) in a UV/VIS spectrophotometer (Shimadzu®, Kyoto, Japan) at 734 nm. Results were expressed as µM TEAC/g.

Individual phenolic compounds
The concentrations of individual phenolic compounds were determined using high-performance liquid chromatography with a diode array detector (HPLC-DAD), employing an Agilent 1260 Infinity system equipped with an autosampler, gradient elution, and multi-wavelength detection at 280, 320, and 360 nm. Chromatographic separation was performed on a Pursuit 5 C18 column (250 × 4.6 mm i.d., 5 µm particle size), with a flow rate of 1.0 mL/min, an injection volume of 20 µL, and column temperature maintained at 25°C.

Eluent A consisted of 980 mL of ultrapure water and 20 mL of glacial acetic acid (analytical grade). In comparison, Eluent B was prepared by mixing 800 mL of acetonitrile with 200 mL of Eluent A. Individual stock standard solutions were prepared in methanol at a concentration of 100 mg/L. A mixed standard solution at 10 mg/L was prepared using the initial mobile phase composition (95% Eluent A and 5% Eluent B), which was also used for the serial dilutions to construct the calibration curve. Sample extracts were diluted at a 1:4 ratio (v/v) in the same initial mobile phase before injection.

The analysis of phenolic compounds—namely gallic, protocatechuic, vanillic, syringic, trans-cinnamic, caffeic, and *p*-coumaric acids, as well as the flavonoids rutin and quercetin—was conducted according to the method described by Burin et al. (2014)

Carotenoid content
Carotenoid quantification was performed according to the protocol described by Rodriguez-Amaya (2001), with minor modifications. For the extraction procedure, 1 gram of sample was combined with 20 mL of acetone in a 50 mL Falcon® tube. The mixture was homogenized using a vortex mixer (Biomixer®, Jacareí, São Paulo, Brazil) and subsequently subjected to ultrasonic treatment at 25°C for 30 minutes. The extract was then filtered using filter paper and a funnel. In a separatory burette, 4 mL of petroleum ether was introduced, followed by the acetone extract and 3 mL of ultrapure water (Type 2). The mixture was allowed to rest until phase separation occurred. In cases where separation did not happen spontaneously, a few drops of NaOH solution were added to facilitate it. Once the phases were separated, the lower (aqueous and colorless) phase was discarded, retaining only the upper colored phase. This colored fraction was transferred to a volumetric flask through a filter paper containing sodium sulfate to remove residual moisture. The burette was rinsed with additional petroleum ether to ensure complete recovery of the extract. Carotenoid concentrations were determined using a UV-Vis spectrophotometer (Shimadzu®, Barueri, São Paulo, Brazil) with the following wavelengths: 450 nm for β-carotene, 444 nm for α-carotene, 452 nm for β-cryptoxanthin, and 462 nm for λ-carotene. Results were expressed as micrograms of carotenoids per 100 mL of sample (µg/100 mL).

Colorimetric analysis
The color characteristics of the ricotta cheese samples were assessed using a sphere-type spectrophotometer (Model SP60 Series, X-Rite Inc., Grand Rapids, MI, USA). The results were recorded according to the CIELAB color space and expressed in terms of L* (lightness), a*, and b* coordinates. Measurements were obtained directly from the device. The L* value, which ranges from 0 to 100, represents the brightness scale, from black (0) to white (100). The a* value indicates the chromatic shift from red (+a*) to green (−a*), while the b* value corresponds to the transition from yellow (+b*) to blue (−b*).

Texture profile analysis

Texture profile analysis of ricotta cheese samples was performed using a TA-XT plus® texturometer (Stable Micro Systems, Texture Exponent software, Surrey, United Kingdom). An aluminum test specimen with a diameter of 25 mm was used to compress the ricotta samples. Measurements were made at 5 ± 1 °C, with a test speed of 1.0 mm/s and 10.0 mm, as described by Buriti, Cardarelli, and Saad (2008). Force data as a function of time were obtained for the two compression and decompression cycles, using the TA-XT plus software.

Multi-element profile

The ricotta cheese samples underwent preliminary digestion using a microwave-assisted system (Microwave Reaction System, Multiwave PRO, Anton Paar, Graz, Austria), equipped with internal digestion vessels and operated under conditions of up to 1200 W microwave power, 200 ± 1 °C internal temperature, and 20 bar pressure. For sample preparation, different extraction techniques were employed: ultrasound-assisted extraction was carried out in an ultrasonic bath (model 60/2, Nova Instruments, Piracicaba, SP, Brazil) at 50 Hz and ambient temperature (25 ± 1 °C), while alkaline solubilization was performed using a water bath with a heated plate (C-MAG HS 7, IKA, Campinas, SP, Brazil). In parallel, the dry ashing technique utilized a muffle furnace (model LF0613, Jung, Blumenau, SC, Brazil) at 550 ± 1 °C, with the resulting ashes dissolved in concentrated HCl at 80 ± 1 °C. The prepared samples, each weighing 2.218 g, were centrifuged using a bench centrifuge (model 206 BL, Fanem, Guarulhos, SP, Brazil).

The elemental profile of the samples was determined using Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) (model iCAP 6000, Thermo Scientific, Waltham, MA, USA). The elements monitored and their respective emission wavelengths included: Ca (315.887 nm), Cr (267.716 nm), Cu (324.754 nm), Fe (259.940 nm), K (766.490 nm), Mg (279.553 nm), Na (589.592 nm), P (213.618 nm), Zn (213.856 nm), with scandium (Sc, 361.384 nm) employed as the internal standard. These elements were selected based on their nutritional and technological relevance in dairy matrices, as well as the operational specifications of the ICP OES system, which featured a V-Groove nebulizer and a cyclonic spray chamber. This configuration enables the introduction of samples with elevated levels of dissolved solids, though proper pre-treatment of the samples remains essential. Analytical conditions included a radial viewing mode, a pump speed of 60 rpm, a plasma gas flow rate of 12 L/min, an RF power of 1300 W, auxiliary gas at 1 L/min, and nebulizer gas at 0.4 L/min. High-purity argon (≥ 99.95%, Air Liquide, Rio de Janeiro, RJ, Brazil) was used as the plasma, auxiliary, and nebulizer gas.

Calibration curves for quantitative analysis were constructed using standard solutions ranging from 0.1 to 10 mg/L. Ultrapure water (Master System, Gehaka, São Paulo, SP, Brazil) was used in the preparation of all standards and sample dilutions. The chemical reagents included nitric acid (14.4 mol/L) and hydrochloric acid (12 mol/L) (Quimis, São Paulo, SP, Brazil), as well as 25% (w/w) tetramethylammonium hydroxide (Sigma-Aldrich, Germany) in water. Nitric acid was further purified using a polytetrafluoroethylene sub-boiling distillation unit (model BSB-939-IR, Berghof, Germany). Elemental standards at 1000 mg/L were employed for calibration and recovery assessment, comprising Al, As, Ca, Cd, Co, Cr, Cu, Fe, Mn, P, Pb, S, Se, Sr, and Zn (Specsol®, Jacareí, SP, Brazil), K (MERCK®, Darmstadt, Germany), Mg (SCP Science®, Quebec, Canada), and Na (VETEC®, Duque de Caxias, RJ, Brazil).

Statistical analysis
The ricotta cheese samples were analyzed in triplicate, with three independent measurements performed for each one. Data analysis was conducted using STATISTICA 13.3 software (TIBCO® Software Inc., Palo Alto, USA). The results were presented as mean ± standard deviation. Significant differences ($p < 0.05$) were observed using analysis of variance (ANOVA) and Tukey's HSD test at a 95% confidence level.

RESULTS AND DISCUSSION

Table 2 presents the results of the physicochemical analyses of the processed ricotta cheese samples. The incorporation of fruit pulps (red araçá, butiá, guabiroba, and uvaia) contributed to a reduction in pH values. Similar behavior was observed by Gutiérrez-Álzate et al. (2023) and Wang et al. (2023) when cupuaçu and jujuba pulps were used to produce fermented dairy products. According to Gutiérrez-Álzate et al. (2023), fruit pulps are rich in organic acids that directly reduce the pH when mixed with dairy products. In addition to acids, fruit pulps contain polyphenols that can further influence the acid-base balance in dairy matrices, contributing to a lower pH (Waweru et al., 2024).

Table 2. Results of the physicochemical analyses of the control ricotta samples (without fruit pulp) and ricottas containing 15% of red araçá, butiá, guabiroba, or uvaia pulp.

Samples	pH	Aw	Moisture (g/100g)
RC	5.72 ± 0.02[a]	0.93 ± 0.01[a]	63.41 ± 3.10[a]
RA	5.24 ± 0.04[d]	0.87 ± 0.01[b]	66.44 ± 1.10[a]
RB	5.35 ± 0.04[c]	0.89 ± 0.02[b]	64.42 ± 2.02[a]
RG	5.47 ± 0.05[b]	0.87 ± 0.01[b]	63.82 ± 2.62[a]
RU	5.28 ± 0.04[cd]	0.87 ± 0.01[b]	65.29 ± 1.15[a]

Note: Results presented as mean ± standard deviation. Aw is the water activity. [a-d] Different lowercase letters in the same column indicate significant difference between samples ($p < 0.05$). RC= Control Ricotta; RA= Ricotta with 15% of red araçá pulp; RB= Ricotta with 15% of butiá pulp; RG= Ricotta with 15% of guabiroba pulp; RU= Ricotta with 15% of uvaia pulp.

The water activity of ricotta cheeses decreased ($p < 0.05$) with the addition of guabiroba pulp. This decrease was also observed by Waweru et al. (2024) when adding ≥ 15% of wild apricot pulp (*Dovyalis cafra*), an African fruit, to yogurt. Studies suggest that adding fruit pulp to dairy products, such as cheese, can decrease water activity due to the increased water retention capacity (Gutiérrez-Álzate et al., 2023; Waweru et al., 2024). Gutiérrez-Álzate et al. (2023) highlighted that fruit pulps contain dietary fibers that can retain water in the dairy matrix, increasing the water retention capacity of the product. Thus, when water is retained more firmly by these fibers and pulp particles, there is less free water available. This reduction in free (unbound) water results in a decrease in water activity, which is a measure of the water available for microbial activity and deterioration. Regarding the moisture content of ricotta cheeses added with 15% pulp from red araçá, butiá, guabiroba, and uvaia fruits, respectively, no differences were observed ($p > 0.05$). The same behavior was verified by El-Loly et al. (2024) using values of ≤ 15% papaya pulp in processed cheeses.

Table 3 contains the results obtained for the total phenolic content and antioxidant capacity of the control ricotta cheeses (without the addition of fruit pulp) and those incorporated with 15% of red araçá, butiá, guabiroba, and uvaia pulps. The lowest ($p < 0.05$) phenolic compound content was found for the control ricotta and the Ricotta added with uvaia pulp. Thus, when comparing the total phenolic compound contents between the control cheese and the ricottas with the same amount of different fruit pulps (15%), similarity or increasing ($p < 0.05$) was observed between the control Ricotta = ricotta with uvaia pulp < Ricotta with red araçá pulp = ricotta with butiá pulp < Ricotta with guabiroba pulp. Thus, the cheeses added with red araçá and butiá pulps resulted in a 20% increase in total phenolic compound content compared to the control cheese, while the addition of guabiroba pulp contributed to a 67% increase. The addition of 15% Uvaia pulp to ricotta cheese did not demonstrate a significant increase in the total phenolic compound content. Silva et al. (2014) emphasized that uvaia would be a fruit rich in carotenoids, but it was characterized by presenting lower levels of total phenolic compounds than other native Brazilian fruits. The results demonstrate that ricotta cheese added with 15% of guabiroba pulp is more prominent in terms of the content of phenolic compounds when compared to other ricotta cheeses added with red araçá, butiá, and uvaia pulp.

The antioxidant capacity attributed to the addition of red araçá, butiá, guabiroba, and uvaia pulps in ricotta cheeses was estimated using the DPPH and ABTS+ methods, with the results presented in Table 3. By the DPPH method, it was observed that the ricotta cheese samples with 15% of uvaia, butiá, red araçá, and guabiroba pulp showed a gradual increase of 137% < 340% < 430% < 520% in antioxidant capacity, respectively, when compared to the control ricotta. A similar behavior was observed by the $ABTS^+$ method, whose gradual increase in the antioxidant capacity of ricottas added (15%) of uvaia, butiá, red araçá, and guabiroba pulp was 106% < 262% < 313% < 405%, respectively, also when compared to the control ricotta.

According to Stobiecka et al. (2022), consuming food products rich in natural antioxidants enhances the body's antioxidant status by protecting against oxidative stress and cellular damage. Pereira et al. (2024) cited that compounds with antioxidant capacity have been extensively studied due to their importance for human health. Phenolic compounds, considered the primary ones responsible for antioxidant capacity, act as natural antioxidants by preventing the action of free radicals, which can damage cells and tissues. In addition, antioxidants can prevent the onset of degenerative diseases, coronary heart disease, obesity, type 2 diabetes, and hypertension, possess anti-inflammatory properties, and exhibit antimutagenic and anticancer activity (Eeira et al., 2024). Related to the increase in antioxidant activity are also the carotenoids present in food (Czett et al., 2025). This antioxidant capacity is attributed to their typical chemical structure, based on a polyene backbone. The sequence of conjugated C=C bonds is responsible for their ability to scavenge free radicals and singlet oxygen. Carotenoids have been studied for their potential to improve ocular and brain function, as well as reduce the risk of cardiovascular and neoplastic diseases. Carotenoids have also been identified as key compounds in reducing the risk of several pathologies, such as arthritis, osteoarthritis, and osteoporosis. The antioxidant and anti-inflammatory properties of carotenoids also hold promise in the treatment of neurodegenerative diseases (Pinna et al., 2025).

Table 3. Results for total phenolic compounds (TPC) and antioxidant capacity of control ricotta (without added pulp) and Ricotta with the addition of 15% red araçá pulp, butiá pulp, guabiroba pulp or uvaia pulp.

Samples	TPC (μM GAE/g)	Antioxidant Capacity	
		DPPH (μM TEAC/g)	$ABTS^+$ (μM TEAC/g)
RC	4.50 ± 0.22[c]	1.70 ± 0.22[d]	5.50 ± 0.24[d]
RA	5.38 ± 0.28[b]	9.01 ± 0.46[b]	22.74 ± 1.75[b]
RB	5.43 ± 0.26[b]	7.48 ± 1.07[b]	19.92 ± 2.19[b]
RG	7.53 ± 0.46[a]	10.55 ± 0.95[a]	27.79 ± 1.85[a]
RU	4.72 ± 0.24[c]	4.04 ± 0.64[c]	11.35 ± 0.74[c]

Note: Results presented as mean ± standard deviation. [a-d] Different lowercase letters in the same column indicate significant difference between samples ($p < 0.05$). RC= Control Ricotta; RA= Ricotta with 15% of red araçá pulp; RB= Ricotta with 15% of butiá pulp; RG= Ricotta with 15% of guabiroba pulp; RU= Ricotta with 15% of uvaia pulp. DPPH is 2,2-diphenyl-1-picrylhydrazyl and $ABTS^+$ is 2,2-casino-bis(3-ethylbenzothiazoline-6-sulfonic acid). GAE is gallic acid equivalent, and TEAC is the antioxidant capacity equivalent of Trolox.

Table 4 shows the levels of carotenoids α-carotene, β-carotene, β-cryptoxanthin, and λ-carotene in the control ricotta cheeses and in the ricotta cheeses containing 15% fruit pulps. In the control sample, only β-carotene was detected, which can be attributed to the use of whole milk in its preparation. This carotenoid comprises approximately 90% of the total carotenoids in cow's milk (Chotyakul et al., 2014). Timlin et al. (2024)emphasized the significance of β-carotene as a precursor to vitamin A.

The levels of α-carotene, β-carotene, β-cryptoxanthin, and λ-carotene were higher ($p < 0.05$) for ricotta cheeses with guabiroba pulp, followed by Ricotta with uvaia pulp, Ricotta with red araçá pulp, and Ricotta with uvaia pulp. Thus, as verified for the levels of phenolic compounds and antioxidant capacity, guabiroba pulp added to Ricotta had a higher content of carotenoids. Therefore, this result demonstrated an improvement in the nutritional value of ricotta cheeses containing fruit pulp.

Regarding the bioavailability of carotenoids, Olmedilla-Alonso et al. (2020) reported that the apparent bioavailability of α-carotene and β-cryptoxanthin is higher than that of β-carotene. Specifically, α-carotene has a 55% higher bioavailability, and β-cryptoxanthin has a 686% higher bioavailability compared to β-carotene when consumed in similar amounts. Olmedilla-Alonso et al. (2020) stated that carotenoids are absorbed and used more efficiently by the body, in addition to emphasizing that both α-carotene and β-cryptoxanthin contribute significantly to vitamin A intake. In addition to their functionality, carotenoids provide an attractive color for food applications and, therefore, can be used as natural food colors (Habtegebriel et al., 2024). Therefore, determining the carotenoid content in foods is of fundamental importance.

Table 4. Results of carotenoid contents of control ricotta and with the addition of 15% red araçá pulp, butiá pulp, guabiroba pulp, or uvaia pulp.

	Ricotta samples				
	RC	**RA**	**RB**	**RG**	**RU**
α-carotene (μg/100 g)	< LD	218.26±21.28^{c}	158.52±23.54^{d}	1,090.73±27.66^{a}	342.61±35.02^{b}
β-carotene (μg/100 g)	811.00±0.02^{e}	1,046.77±23.02^{c}	982.24±25.45^{d}	1,989.25±30.12^{a}	1,180.81±37.85^{b}
β-criptoxantin (μg/100 g)	< LD	256.13±24.99^{c}	186.03±27.62^{d}	1,279.98±32.47^{a}	402.06±41.09^{b}
λ-carotene (μg/100 g)	< LD	197.14±19.23^{c}	143.18±21.26^{d}	985.17±24.99^{a}	309.45±31.62^{b}

Note: Results presented as mean ± standard deviation. $^{a\text{-}d}$ Different lowercase letters in the same column indicate significant difference between samples ($p < 0.05$). RC= Control Ricotta; RA= Ricotta with 15% of red araçá pulp; RB= Ricotta with 15% of butiá pulp; RG= Ricotta with 15% of guabiroba pulp; RU= Ricotta with 15% of uvaia pulp.

Table 5 presents the results obtained for the color parameters of the ricotta cheese samples, both without (control) and with the addition of red araçá, butiá, guabiroba, and uvaia pulps.

Table 5. Color parameters of control ricottas and those made with 15% red araçá, butiá, guabiroba, and uvaia pulps.

	Color parameters						
	L*	**a***	**b***	**ΔE1***	**ΔE2***	**ΔE3***	**ΔE4***
RC	87.31±0.50^{a}	0.52±0.10^{d}	8.85±0.40^{e}	-	-	-	-
RA	83.52±1.00^{b}	4.27±0.20^{b}	10.07±0.60^{d}	5.47	-	-	-
RB	86.14±0.80^{a}	0.23±0.10^{e}	18.68±0.90^{b}	9.90	9.86	-	-
RG	78.08±1.20^{c}	5.14±0.30^{a}	32.28±1.50^{a}	25.60	22.88	9.80	-
RU	86.52±0.70^{a}	1.36±0.10^{c}	16.05±0.80^{c}	7.29	7.30	2.89	18.33

Note: Results are presented as mean ± standard deviation. $^{a\text{-}e}$ Different lowercase letters in the same column indicate significant differences between samples ($p < 0.05$). L* indicates brightness, b* is the variation from yellow to blue, and a* is the variation from red to green. ΔE1* is the color difference between each of the ricottas with fruit pulp and the control ricotta. ΔE2* is the color difference between the Ricotta with red araçá pulp and the other ricottas with fruit pulp. ΔE3* is the color difference between the Ricotta with butiá pulp and the ricottas with guabiroba and uvaia pulp. ΔE4* is the color difference between the Ricotta with guabiroba pulp and the Ricotta with uvaia pulp. RC= Control Ricotta; RA= Ricotta with 15% of red araçá pulp; RB= Ricotta with 15% of butiá pulp; RG= Ricotta with 15% of guabiroba pulp; RU= Ricotta with 15% of uvaia pulp.

The L*, a*, and b* parameters are part of the CIE Lab* color space, a colorimetric system that describes all the perceptible colors of a given food. Regarding the L* parameter, higher ($p < 0.05$) values for lightness were found for the control ricotta cheeses with butiá and uvaia pulp. Subsequently, lower values ($p < 0.05$) were found for the lightness of the ricotta cheese samples with red araçá pulp and, finally, for the Ricotta with guabiroba pulp. According to Prestes et al. (2023), colored compounds in fruits, such as guabiroba, tend to decrease the value for lightness because the fruit pulp introduces colored compounds that darken the dairy product. Regarding the color parameter a*, all ricottas showed a tendency towards a reddish color. This parameter showed the following increase ($p < 0.05$): Ricotta with butiá pulp < control Ricotta < Ricotta with uvaia pulp < Ricotta with red araçá pulp <

Ricotta with guabiroba pulp. On the other hand, the values for b*, all the ricottas showed a tendency towards a yellowish color.Tura et al. 2024) stated that consumers prefer yellow cheeses. In ricotta cheeses, the increase ($p < 0.05$) of this parameter was verified for control ricotta < Ricotta with red araçá pulp < Ricotta with uvaia pulp < Ricotta with butiá pulp < Ricotta with guabiroba pulp. Singh et al. (2023) and El-Loly et al. (2024) highlighted that the addition of fruits would result in cheeses with a more attractive and appetizing appearance, attributed to the reddish-yellow color.

Singh et al. (2023) highlighted that natural dyes have a variety of health benefits, including antioxidant, anticancer, and anti-inflammatory properties. Thus, these authors also reported that natural pigments from carotenoid-rich fruits can be used to provide natural color in the manufacture of dairy products such as cheese. Carotenoids, such as β-carotene and cryptoxanthin, promote an outstanding and attractive visual effect (Figure 3), contributing to the sensory acceptance of the food Prestes et al., 2024; Prestes et al., 2025). In addition to their role as natural colorants, these fat-soluble compounds disperse well in the fat matrix of dairy products, favoring a uniform and stable color. The ΔE^* parameters, which indicate the color difference between the processed cheese samples, demonstrated that it was possible to notice a color difference between all the processed ricotta samples. Thus, all the ricotta samples exhibited their respective color characteristics, as shown in Figure 3. According to Quintanilla et al. (2019), ΔE^* values above 3 demonstrate that color differences between food samples are perceptible to the human eye and, therefore, could influence the acceptability of a cheese.

High-performance liquid chromatography (HPLC) analysis of individual phenolic compounds, presented in Table 6, revealed that all phenols investigated – including phenolic acids (such as gallic, protocatechuic, vanillic, syringic, caffeic, p-coumaric, and trans-cinnamic) and flavonoids (rutin and quercetin) – presented levels below the quantification limits (LOs) established by the analytical method (Table 1). The quantification limits ranged from 0.006 µg/g (caffeic acid) to 0.60 µg/g (quercetin and vanillic acid). Similar results were observed by Bakir (2025) when evaluating dairy products with the addition of phenol-rich fruits, in which the sensitivity of the analytical method employed also limited the detection of individual phenols. Similarly, Conceição et al. (2019) suggested that while polyphenol-rich fruit pulps and pomaces can enhance the nutritional and functional properties of yogurts, the dairy matrix may interfere with the extraction and detection of individual phenolic compounds by HPLC.

The low detection can be attributed to multiple factors. First, the complexity of the dairy matrix can hinder extraction efficiency, especially in systems rich in casein and lipids, which can bind to phenolic compounds, reducing their free availability for quantification. In addition, the natural concentrations of these compounds in the fruits used (even though they are recognized sources of phenols) may have been diluted by incorporation into the ricotta matrix, especially at an additional concentration of 15%.

Nevertheless, even in the absence of individual quantification, the presence of these compounds at trace levels can contribute to the overall antioxidant activity of the product, as demonstrated in this study, which related the presence of total phenolic compounds to the antioxidant capacity using methods such as DPPH and ABTS (Table 3). Thus, the lack of individual quantification does not invalidate the functional potential of the formulations, especially considering the complexity of the interactions between the matrix components.

Table 6. Quantification of individual phenolic compounds (µg/g) of Ricottas.

Phenolic compound detected	Limit of quantification (µg/g)
Gallic acid	0.07 ± 0.01
Protocatechuic acid	0.06 ± 0.01
Vanillic acid	0.60 ± 0.01
Syringic acid	0.50 ± 0.01
trans-Cinnamic acid	0.40 ± 0.01
Caffeic acid	0.006 ± 0.001
p-Coumaric acid	0.07 ± 0.01
Rutin	0.03 ± 0.01
Quercetin	0.60 ± 0.01

Note: Results presented as mean ± standard deviation.

The fortification of fresh Ricotta with 15% pulp from native Brazilian fruits resulted in significant changes in the mineral profile of the product, as shown in Table 7, with a direct impact on the levels of potassium (K), magnesium (Mg), and sodium (Na). These changes can be attributed to the intrinsic compositions of the fruits used, which are recognized for their significant content of micronutrients and bioactive compounds.

For potassium content, a significant increase was observed in all formulations containing fruit, with the highest value recorded for RA (1.72 mg/g), showing statistical differences compared to the others. This result is consistent with the naturally high levels of potassium found in araçá, which has approximately 290 mg/100 g of fruit, as well as in uvaia (227 mg/100 g), guabiroba (215 mg/100 g), and butiá (approximately 250 mg/100 g). Potassium is an essential mineral for cardiovascular and neuromuscular functions, and its addition to dairy products can enhance their functional value (Abdi-Moghadam et al., 2023; de Paulo Farias et al., 2020; Prestes et al., 2022).

Magnesium also showed significant variations between samples, with a notable increase in Ricotta with guabiroba (RG), which reached 0.17 mg/g. According to Prestes et al. (2022), this fruit is an important source of magnesium (approximately 22–26 mg/100 g), which justifies the observed increase. Magnesium is involved in more than 300 enzymatic reactions in the body, and its presence in dairy products can contribute to improving the mineral balance of the diet, especially when consumed in conjunction with calcium (Bauland et al., 2020).

The addition of fruits also resulted in significant increases in sodium levels, especially for RB (15% butiá pulp), which presented 5.28 mg/g, the highest among the samples. Although sodium is a typical component of the dairy matrix, the contribution of fruits can also be considered, since butiá has moderate amounts of sodium (2–3 mg/100 g). Despite the precautions taken to limit excess sodium in the diet, this mineral is essential for physiological functions, such as maintaining osmotic balance and regulating neuromuscular activity. Incorporating sodium from fruits, rather than directly adding salt, can positively contribute to the nutritional and functional profile of the product (Bauland et al., 2020; Goldberg & Aliani, 2021).

Table 7. Multi-element profile results of Ricotta samples with the addition of 15% native fruit pulp.

Element (mg g^{-1})	**Control**	**RU**	**RG**	**RA**	**RB**
Al (mg g^{-1})	Presence	Presence	Presence	Presence	Presence
As (mg g^{-1})	< LOD	< LOD	< LOD	< LOD	< LOD
Ca (mg g^{-1})	2.00 ± 0.05	2.01± 0.11	2.04 ± 0.03	2.03 ± 0.06	2.01 ± 0.01
Cd (mg g^{-1})	< LOD	< LOD	< LOD	< LOD	< LOD
Co (mg g^{-1})	< LOD	< LOD	< LOD	< LOD	< LOD
Cr (mg g^{-1})	< LOD	< LOD	< LOD	< LOD	< LOD
Cu (mg g^{-1})	< LOD	< LOD	< LOD	< LOD	< LOD
Fe (mg g^{-1})	< LOD	< LOD	< LOD	< LOD	< LOD
K (mg g^{-1})	1.20 ± 0.09^{d}	1.30 ± 0.04^{c}	1.45 ± 0.03^{b}	1.72 ± 0.03^{a}	1.45 ± 0.01^{b}
Mg (mg g^{-1})	0.13 ± 0.05^{d}	0.14 ± 0.01^{c}	0.17 ± 0.04^{a}	0.15 ± 0.02^{b}	0.14 ± 0.01^{c}
Mn (mg g^{-1})	< LOD	< LOD	< LOD	< LOD	< LOD
Na (mg g^{-1})	3.00 ± 0.02^{e}	4.88 ± 0.11^{d}	5.21 ± 0.0^{b}	5.15 ± 0.06^{c}	5.28 ± 0.03^{a}
P (µg g^{-1})	2.10 ± 0.05	2.11 ± 0.08	2.13 ± 0.03	2.12 ± 0.01	2.13 ± 0.03
Pb (mg g^{-1})	< LOD	< LOD	< LOD	< LOD	< LOD
S (µg g^{-1})	1.20± 0.05	1.21 ± 0.09	1.22 ± 0.02	1.21 ± 0.02	1.21 ± 0.07
Se (mg g^{-1})	< LOD	< LOD	< LOD	< LOD	< LOD
Sr (mg g^{-1})	Presence	Presence	Presence	Presence	Presence
Zn (mg g^{-1})	0.05 ± 0.01	0.05 ± 0.01	0.05 ± 0.03	0.05 ± 0.01	0.05 ± 0.02

Note: LOD: limit of detection. $^{a–e}$ In the same line, means accompanied by different letters show a significant difference ($p < 0.05$). Al: aluminum; As: arsenic; Ca: calcium; Cd: cadmium; Co: cobalt; Cr: chrome; Cu: copper; Fe: iron; K: potassium; Mg: magnesium; Mn: manganese; Na: sodium; P: phosphorus; Pb: lead; S: sulfur; Se: selenium; Sr: strontium; Zn: zinc; RG=15% guabiroba pulp; RB=15% butiá pulp, RA= 15% araçá pulp; RU=15% uvaia pulp.

In contrast, the levels of calcium and phosphorus, minerals mostly derived from the ricotta milk base, remained stable between the formulations. The average calcium values ranged from 2.00 to 2.04 mg/g, while phosphorus ranged from 2.10 to 2.13 µg/g, with no statistically significant difference. These results align with the data reported by Prestes et al. (2025), which demonstrated stability in the levels of these minerals in creamy Requeijão enriched with varying concentrations of guabiroba pulp. The maintenance of these minerals, which are essential for bone health and energy metabolism, is desirable in products intended for functional foods.

Regarding zinc, all treatments maintained constant levels (0.05 mg/g), a value compatible with the expected profile for fresh Ricotta. According to the Brazilian Food Composition Table (TBCA, 2021), whey derivatives and fresh cheeses have an average of 0.4–0.6 mg of zinc per 100 g, which corroborates the findings of this study. Zinc is an essential trace element with antioxidant, immunomodulatory, and healing properties, and its inclusion in products is considered beneficial(Lin et al., 2017).

It is essential to note that potentially toxic metals, such as lead (Pb), cadmium (Cd), arsenic (As), selenium (Se), and mercury (Hg), were all below the detection limit in all samples. Fruits native to the South and Southeast regions of Brazil tend to have low levels of heavy metal contamination when grown in non-impacted soils (Poggere et al., 2023). These data reinforce the safety of using the native fruits tested, which came from agroecological crops and sustainable extractivism.

Table 8 shows the results obtained for the texture parameters of ricotta cheeses made without fruit pulp and with the incorporation of 15% of red araçá, butiá, guabiroba, and uvaia fruit pulps, respectively.

Table 8. Results of texture parameters of control Ricotta with the addition of 15% red araçá, butiá, guabiroba, or uvaia pulp.

Texture parameters	**Ricotta samples**				
	Control	**RA**	**RB**	**RG**	**RU**
Hardness (N)	10.87±2.41^{a}	4.10±0.48^{b}	4.60±1.54^{bc}	1.94±0.01^{d}	3.35±0.32^{c}
Adhesiveness (N.s)	0.026±0.001^{c}	0.108±0.016^{a}	0.037±0.006^{b}	0.110±0.048^{a}	0.042±0.002^{b}
Resilience	1.40±0.12^{a}	1.16±0.10^{b}	1.40±0.18^{a}	1.01±0.03^{c}	1.15±0.04^{b}
Cohesiveness	0.72±0.14^{d}	1.46±0.04^{a}	1.34±0.06^{b}	1.08±0.15^{c}	1.46±0.06^{ab}
Elasticity	74.44±8.08^{a}	55.70±1.08^{c}	61.76±3.08^{b}	60.10±4.48^{b}	56.62±0.55^{c}
Chewiness	3.57±0.01^{a}	3.34±0.05^{b}	2.90±0.01^{c}	1.30±0.01^{d}	2.76±0,38^{c}

Note: Results presented as mean±standard deviation. $^{a-d}$ Different lowercase letters in the same line indicate significant difference between samples ($p < 0.05$). RG=15% guabiroba pulp; RB=15% butiá pulp, RA= 15% araçá pulp; RU=15% uvaia pulp.

When compared to the control ricotta cheese, the samples with the addition of fruit pulps showed lower values for firmness, elasticity, and chewiness ($p < 0.05$). Krentz et al. (2022) cited that elasticity is defined as the speed at which a product returns to its deformed state after the removal of the acting force. Although the moisture content of the processed ricotta cheeses did not vary ($p > 0.05$), the incorporation of fruit pulps led to changes in molecular interactions. The same behavior was reported by Tian et al. (2025) in processed cheeses, and this molecular change was responsible for a less compact structure. Thus, this molecular change would result in a decrease in the firmness, elasticity, and chewiness parameters of the cheeses. Firmness and elasticity are essential attributes for obtaining cheeses with good sliceability, confirming that both texture parameters depend on the strength and integrity of the network formed during cheese production.

Ushkalova et al. (2025) reported that, in terms of texture parameters, it is still a challenge to incorporate vegetables and their parts into cheeses. This behavior was verified with the texture parameters adhesiveness, resilience, and cohesiveness of the ricotta cheeses produced. Mefleh et al. (2022) stated that due to their higher molecular weight and functional properties, vegetable proteins can make it difficult to replicate the textures of dairy cheeses. Thus, as verified by Tojan et al. (2024), it was observed that the impact of these incorporations on the texture of ricotta cheeses depends on the type of fruit pulp used. The results for the adhesiveness of the cheeses indicated that the ricottas with red araçá and guabiroba pulp resulted in stickier cheeses ($p < 0.05$).

Regarding the resilience of the ricottas, the value obtained for the control cheese was similar ($p > 0.05$) to the values obtained for the Ricotta with butiá pulp. The Ricotta with the lowest value ($p < 0.05$) for resilience was the one added with guabiroba pulp. According to Wang et al. (2023), this reduction is attributed to the type of components present in the network formed during the cheese production process. This result indicates that the Ricotta with guabiroba pulp would have a more fragile structure. A more fragile structure results in a cheese with less firmness, and, consequently, according to Lamichhane et al. (2018), in undesirable breaks during chewing, which leads to a lower preference for the product among consumers.

The cohesiveness parameter increased ($p < 0.05$) with the addition of fruit pulp. However, this increase is related to the type of fruit pulp added to the ricotta cheese. Tian et al. (2025) reported that lower values for cohesiveness resulted in cheeses with a more rubbery texture, and this characteristic is also related to the structure of the network formed in the cheese production process. Therefore, the control ricotta was the cheese that presented the most ($p < 0.05$) rubbery texture, followed by ricottas with guabiroba pulp > with butiá pulp = with uvaia pulp ≥ with red araçá pulp. The same behavior was observed by Alqahtani et al. (2023) for processed cheese fortified with date seeds (*Phoenix dactylifera* L.) in the development of a functional food. According to these authors, adding date seed fiber to processed cheese decreased its cohesion, making it less compact and more open. Thus, the addition of fruit pulp to ricotta cheese contributes to expanding its nutritional and functional profile, presenting significant technological potential.

CONCLUSION

The production of ricotta cheese with the addition of 15% pulp from native yellow fruits — red araçá, butiá, guabiroba, and uvaia - was viable and resulted in products with improved functional properties. The addition of these pulps promoted a reduction in pH and water activity, without significantly altering the moisture content. The incorporation of guabiroba was particularly significant, promoting increases of 67% in total phenolic compounds and up to 520% in antioxidant activity (ABTS), in addition to expanding the carotenoid profile of Ricotta, including α-carotene, β-cryptoxanthin, and λ-carotene. The changes in composition also impacted the color and texture of the cheeses, giving them a more intense color and less firm, more adhesive, and less elastic structures compared to the control.

Additionally, the inclusion of pulps contributed to the enrichment of the mineral profile of the Ricotta, with a focus on potassium and magnesium content, while also preserving the stability of essential nutrients within the dairy matrix. Among all the formulations, the Ricotta with the addition of guabiroba stood out for presenting the greatest functional potential and is therefore promising as a dairy product enriched with bioactive compounds from native fruits.

FUTURE RESEARCH

Given the promising results obtained, future studies may focus on evaluating the stability of bioactive compounds during storage of enriched ricottas, including the influence of different temperature and time conditions on the maintenance of antioxidant activity, carotenoid profile, and phenolic compounds. Additionally, it would be relevant to investigate the bioaccessibility and bioavailability of these compounds after simulated digestion to demonstrate their functional benefits *in vivo*. Sensory tests with consumers are also recommended to validate the acceptance of the formulations on a large scale, considering the attributes of flavor, texture, color, and aroma. Finally, the application of other native fruits and the use of microencapsulation technologies to protect bioactive compounds during processing and storage represent promising avenues for developing new functional dairy products.

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