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DEVELOPMENT OF CREAMY REQUEIJÃO FROM MILK–WHEY BLENDS ENRICHED WITH NATIVE BRAZILIAN YELLOW FRUIT PULPS: A SUSTAINABLE APPROACH TO BIOACTIVE ENHANCEMENT

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Abstract: Cheese whey is a dairy by-product with high nutritional value and strong potential for sustainable food applications. In this study, creamy Requeijão formulated with milk–whey blends was enriched with 15% pulps of native Brazilian yellow fruits (araçá, guabiroba, uvaia, and butiá), and its physicochemical characteristics, mineral profile, carotenoid content, phenolic compounds, and antioxidant activity were evaluated. Fruit incorporation significantly altered the composition and color of the products, reducing pH (by up to 9.1%) and increasing ash content (by up to 13.6%) and yellowness (by up to 55.9%) compared with the control formulation. All fruit-enriched samples showed enhanced bioactive potential, especially the guabiroba formulation, which exhibited significant increases in carotenoids, total phenolic compounds (approximately 8-fold), and antioxidant activity in DPPH and ABTS assays. Overall, the results demonstrate that the combined use of cheese whey and native Brazilian fruits is a promising strategy for the development of innovative functional dairy products aligned with sustainability, waste valorization, and the appreciation of Brazilian biodiversity

Keywords: dairy products; circular economy; Brazilian biodiversity; agro-industrial by-products; functional product

Highlights

- Native fruit pulps improved Requeijão bioactive composition.
- Guabiroba showed the highest antioxidant and carotenoid levels.
- Fruit addition enhanced yellow coloration and mineral composition.

- Cheese whey valorization supports sustainable dairy applications.
- Native fruits increased phenolics and antioxidant activity.

Introduction

The increasing demand for sustainable food systems has intensified efforts to minimize waste and enhance the valorization of agro-industrial by-products. In the dairy sector, cheese whey is one of the most abundant residues, accounting for approximately 85–90% of the initial milk volume used in cheese production and retaining nearly 55% of its original nutrients, including lactose, soluble proteins, minerals, and bioactive compounds (El-Aidie & Khalifa, 2024; Selmi et al., 2025).

Despite its high nutritional value, whey remains underutilized and, when improperly disposed of, can pose significant environmental concerns due to its elevated organic load (Weerasingha et al., 2025). In this scenario, strategies aimed at incorporating whey into new food formulations have gained relevance, especially within the framework of circular economy and resource efficiency (Czarniecka-Skubina et al., 2025; Weerasingha et al., 2025)

Among dairy products, requeijão stands out as a widely consumed spreadable cheese in Brazil, characterized by its creamy texture and technological flexibility. Its formulation, typically based on milk proteins, fat, and emulsifying salts, allows the incorporation of additional ingredients without major structural disruption(Brasil, 1997). This characteristic makes requeijão an interesting matrix for developing products with improved nutritional and functional properties. In recent years, the addition of plant-based ingredients, particularly fruit-derived materials, has been explored to increase the levels of antioxidant compounds, such as carotenoids and phenolics, in dairy systems (El-Loly et al., 2024; Prestes et al., 2025).

Brazilian biodiversity offers a wide range of native fruits with significant potential for food innovation, although many remain underexplored in industrial applications. Yellow native fruits such as guabiroba (*Campomanesia xanthocarpa* O. Berg), araçá (*Psidium cattleianum*), butiá (*Butia* spp.), and uvaia (*Eugenia pyriformis*) are noteworthy due to their composition, which includes relevant levels of carotenoids, phenolic compounds, and vitamin C, all associated with antioxidant activity (da Fonseca Antunes et al., 2024; Machado et al., 2025; Prestes et al., 2022; Taver et al., 2022). Despite this potential, their use in dairy products is still limited and often restricted to isolated applications, which does not fully reflect the diversity of these raw materials or their possible technological interactions within complex food matrices (A. A. Prestes et al., 2024, 2025).

From a scientific perspective, an important limitation in the current literature is the fragmented approach typically adopted. Studies tend to investigate whey utilization and fruit enrichment separately, without considering the combined effects of these two strategies within the same product system. Moreover, there is still insufficient information regarding how different native fruit pulps may influence the physicochemical characteristics and functional properties of processed cheeses when incorporated under comparable formulation conditions (Soumati et al., 2023; Uribe-Velázquez et al., 2026).

Exploring these aspects is particularly relevant not only for expanding the technological understanding of such systems but also for supporting the development of products aligned with sustainability principles. The simultaneous use of whey and native fruits may contribute to reducing industrial waste while promoting the valorization of regional biodiversity, generating products with added value and potential functional appeal (Detti et al., 2025; Soumati et al., 2023).

Considering the compositional attributes of cheese whey and the bioactive profile of native Brazilian yellow fruits, it is proposed that incorporating whey as a partial substitute for milk, together with the addition of fruit pulps (guabiroba, araçá, butiá, and uvaia), can lead to a requeijão with increased levels of bioactive compounds, especially carotenoids and phenolics, as well as enhanced antioxidant activity. It is further assumed that each fruit will contribute differently to the final product, given the variability in their phytochemical composition, which may reflect distinct impacts on both functional and physicochemical characteristics.

Thus, this study aimed to develop a creamy requeijão formulated with milk and cheese whey, enriched with pulps of native Brazilian yellow fruits, and to evaluate its physicochemical properties, bioactive compound content, and antioxidant capacity.

Material and Methods

Reagents

All reagents employed throughout the analyses were of analytical grade or higher purity. Ultrapure water with a resistivity of 18.2 MΩ·cm was produced using a water purification system (MS3000, Master System, Gehaka, São Paulo, Brazil) and was used to prepare all standards, solutions, and dilutions. The reagents applied during sample preparation included acetone, sodium hydroxide (NaOH), petroleum ether, hydrochloric acid (HCl), and nitric acid (HNO_3) obtained from Quimis (São Paulo, Brazil), while tetramethylammonium hydroxide (TMAH, 25% w/w in H_2O) was acquired from Sigma-Aldrich (Germany). Prior to use, nitric acid was additionally purified through sub-boiling distillation in a PTFE distillation apparatus (Distill Acid BSB-939-IR, Berghof, Germany). Calibration standards and recovery assays were prepared from single-element stock solutions (1000 mg L^{-1}) containing Ca, Cu, P, Zn, and Sc (Specsol®, Brazil), K (Merck, Germany), Cr, Fe, and Mg (SCP Science, Canada), and Na (Vetec, Brazil).

Raw Material

Pulps from Brazilian native fruits, namely butiá, araçá, and uvaia, were obtained from Encontro de Sabores (Passo Fundo, RS, Brazil), while guabiroba pulp was supplied by EMBRAPA Florestas. These ingredients were incorporated into the requeijão formulation. Cheese whey generated during the manufacture of Minas Frescal cheese was employed as a dairy co-product in the requeijão formulation (milk-clotting enzyme (HA-LA®, coagulation power 1:3000) supplied by Chr. Hansen was used during processing, together with whole UHT milk (Tirol®, Nova Trento, SC, Brazil). The milk presented a composition of 3.2 g 100 g^{-1} protein, 3.0 g 100 g^{-1} fat, and 4.5 g 100 g^{-1} carbohydrates.

Preparation of the creamy Requeijão

Creamy Requeijão was formulated using 500 g of whey, 400 g of butter (Conaprole®, containing 84% total fat, 54% saturated fat, 4.9% trans-fat, and 770 mg/100 g sodium, with no detectable protein, carbohydrates, or dietary fiber), 984 g of ricotta cheese (Família Pepenborg®, containing 15% protein, 12% total fat, 3.5% saturated fat, no carbohydrates, and 37 mg/100 g sodium), and 3.5 g of sodium chloride. Initially, all ingredients were homogenized in a blender until a uniform mixture was obtained. The mixture was subsequently heated under continuous stirring on a conventional stove until reaching the typical consistency of creamy Requeijão, characterized by a smooth, spreadable, velvety, and slightly elastic texture.

After cooling, 15% (w/w) of native yellow fruit pulps were incorporated into the Requeijão matrix and homogenized to obtain the different formulations. The treatments consisted of: control sample (without fruit pulp addition), RA15 containing 15% araçá pulp, RG15 containing 15% guabiroba pulp, RU15 containing 15% uvaia pulp, and RB15 containing 15% butiá pulp (Figure 1).

Physicochemical analysis

The color parameters of the samples were determined using a sphere spectrophotometer (SP60 Series, X-Rite Inc., Grand Rapids, MI, USA). Measurements were expressed using the CIELAB color system in terms of the coordinates L*, a*, and b*. In this system, the L* parameter describes luminosity, ranging from 0 (dark/black) to 100 (light/white). The a* coordinate indicates the color variation between green (negative values) and red (positive values), while the b* coordinate represents the spectrum from blue (negative values) to yellow (positive values).

Total Carotenoids Content

The determination of carotenoid compounds was carried out according to the procedure described by Rodriguez-Amaya (2001), with methodological adaptations. Approximately 1 g of sample was weighed and transferred to a 50 mL Falcon® tube, followed by the addition of 20 mL of acetone. The mixture was vigorously homogenized in a vortex mixer and subsequently subjected to ultrasonic treatment for 30 min at 25 °C to improve pigment extraction efficiency.

After the extraction step, the material was filtered to separate insoluble particles from the liquid fraction. The obtained extract was transferred to a separation burette containing petroleum ether (4 mL) and ultrapure water (3 mL). The mixture remained at rest until two distinct phases formed. In cases where separation was incomplete, sodium hydroxide solution was added dropwise to facilitate phase clarification. The lower aqueous fraction, which was colorless, was discarded, while the upper organic layer containing the carotenoids was retained.

Figure 1. Creamy requeijão with the addition of 15% pulp from native yellow fruits. Note: uvaia, guabiroba, araçá, and butiá- identified as: RU15, RG15,RA15, and RB15, respectively.

To remove residual water, the organic phase was filtered through anhydrous sodium sulfate-impregnated filter paper and then quantitatively transferred to a volumetric flask. Additional petroleum ether was used to rinse the separation burette to ensure complete recovery of the extracted pigments. The carotenoid concentration was subsequently measured by UV–Vis spectrophotometry using characteristic absorption wavelengths for each compound: 450 nm for β-carotene, 444 nm for α-carotene, 452 nm for β-cryptoxanthin, and 462 nm for λ-carotene. The final values were reported as µg of carotenoids per 100 g of sample.

Total Phenolic Compounds and Antioxidant Activity

The content of total phenolic compounds was estimated using the Folin–Ciocalteu spectrophotometric assay, based on the methodology proposed by (Singleton & Rossi, 1965), with slight modifications to the original procedure. The method relies on the reduction of the Folin–Ciocalteu reagent by phenolic substances in an alkaline medium, producing a bluish complex proportional to the concentration of these compounds. After preparation of the reaction mixture, samples were stored at room temperature in the dark for 90 min to allow complete chromophore formation. Subsequently, absorbance readings were obtained at 725 nm using a UV–Vis spectrophotometer (Shimadzu® UV-1800, Kyoto, Japan). Quantification was achieved through a calibration curve prepared with gallic acid, and the results were expressed as µM gallic acid equivalents per gram of sample (µM GAE/g).

The antioxidant potential of the requeijão samples was investigated using two distinct radical-scavenging assays, namely DPPH and ABTS•+, which are commonly used to evaluate different antioxidant mechanisms. The DPPH method, originally described by Brand-Williams et al. (1995), is based on the reduction of the stable radical 2,2-diphenyl-1-picrylhydrazyl by antioxidant molecules capable of donating electrons or hydrogen atoms. The reaction mixtures were incubated for 30 min at room temperature under light-protected conditions, followed by spectrophotometric measurement at 515 nm using a Shimadzu® UV–Vis spectrophotometer (Kyoto, Japan). Antioxidant activity was calculated from a Trolox standard curve and expressed as µM Trolox equivalent antioxidant capacity per gram of sample (µM TEAC/g).

Antioxidant activity was also assessed using the ABTS•+ radical cation assay [2,2′-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid)], according to the methodology reported by Re et al. (1999). This assay measures the capacity of antioxidant compounds to reduce the ABTS•+ radical, thereby decreasing absorbance intensity. The absorbance values were recorded at 734 nm with a UV–Vis spectrophotometer (Shimadzu®, Kyoto, Japan), and the antioxidant capacity was likewise expressed as µM TEAC/g.

Multi-element profile

Prior to elemental analysis, the requeijão samples were digested in a closed-vessel microwave system (Multiwave PRO, Anton Paar, Graz, Austria). The procedure was conducted under controlled conditions, with microwave power reaching 1200 W, operating temperature maintained at 200 ± 1 °C, and internal pressure of approximately 20 bar. Different sample preparation strategies were evaluated before analysis. Ultrasound-assisted extraction was performed using an ultrasonic bath (Nova Instruments, Piracicaba, SP, Brazil) operating at 50 Hz and ambient temperature (25 ± 1 °C). Alkaline solubilization procedures were carried out in a thermostatically controlled water bath coupled to a heating plate (IKA, Campinas, SP, Brazil). In addition, dry mineralization was performed in a muffle furnace (Jung, Blumenau, SC, Brazil) at 550 ± 1 °C, and the resulting ashes were solubilized with concentrated hydrochloric acid at 80 ± 1 °C. Following the preparation steps, aliquots equivalent to 2.218 g of sample were centrifuged using a bench centrifuge (Fanem, Guarulhos, SP, Brazil).

Mineral determination was performed by inductively coupled plasma optical emission spectrometry (ICP-OES) using an iCAP 6000 instrument from Thermo Scientific. Quantification of the elements was carried out at specific analytical wavelengths: 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), and Zn (213.856 nm). Scandium (Sc, 361.384 nm) was employed as the internal standard to improve analytical stability and precision. The selection of analytes considered both their nutritional importance in dairy matrices and the instrument's analytical performance. The ICP-OES configuration included a V-groove nebulizer coupled with a cyclonic spray chamber, which allowed accurate measurements in samples containing relatively high concentrations of dissolved solids after suitable pretreatment.

All determinations were obtained in radial plasma observation mode. Instrumental operating conditions included a pump rotation speed of 60 rpm, plasma gas flow rate of 12 L min^{-1}, auxiliary gas flow of 1 L min^{-1}, nebulizer gas flow of 0.4 L min^{-1}, and radiofrequency power set at 1300 W. Argon with purity equal to or higher than 99.95% (Air Liquide, Brazil) was employed both for plasma formation and aerosol transport. Quantitative analysis was performed using external calibration with multi-element standard solutions prepared over the concentration range of 0.1–10 mg L^{-1}. Ultrapure water produced by a Master System purification unit (Gehaka, Brazil) was used during all dilution and preparation procedures. Reagents included nitric acid and hydrochloric acid, supplied by Quimis (Brazil), and tetramethylammonium hydroxide (25% w/w), obtained from Sigma-Aldrich (Germany). Nitric acid was further purified through sub-boiling distillation using a Berghof system (Germany). Certified mono-element stock standards (1000 mg L^{-1}) were used to prepare the calibration curve and to conduct recovery studies.

Statistical analysis

The experimental results were expressed as mean ± standard deviation. Differences between the evaluated treatments were assessed using one-way analysis of variance (ANOVA), and when significant effects were observed, comparisons of means were performed using Tukey's multiple comparisons test at a significance threshold of 5% ($p < 0.05$). Statistical analyses were performed using STATISTICA developed by TIBCO Software Inc. All determinations were performed in triplicate to ensure analytical reliability and reproducibility.

Results and Discussion

Physicochemical parameters

The incorporation of 15% native yellow fruit pulps significantly affected the physicochemical and color characteristics of creamy Requeijão, demonstrating that the addition of these fruits altered both the nutritional profile and the product's visual attributes (Table 1). In general, the formulations containing fruit pulps exhibited lower pH values, changes in moisture and total solids, and more intense color attributes compared with the control sample. These changes are expected since native fruits naturally contain organic acids, fibers, sugars, minerals, and pigments that directly interact with the dairy matrix (Prestes et al., 2025).

Among the evaluated treatments, RU15 had the lowest pH, while the control formulation was less acidic. The reduction in pH observed after pulp incorporation is likely due to the presence of organic acids naturally present in fruits such as uvaia, araçá, guabiroba, and butiá. Similar behavior has been reported in fermented dairy products enriched with fruit preparations, where the fruit matrix contributes not only to acidification but also to flavor enhancement and microbiological stability (Bianchini et al., 2020; Prestes et al., 2023; Prestes et al., 2024). From a technological perspective, lower pH values may also influence protein interactions within the Requeijão structure, contributing to modifications in texture and water retention capacity.

Protein content decreased in all fruit-added samples compared with the control treatment. This behavior likely resulted from a dilution effect caused by the addition of fruit pulps, which naturally contain lower protein concentrations than dairy ingredients. RB15 had the lowest protein value among all formulations, suggesting that butiá pulp may have had a greater impact on the product's final solids balance. In dairy systems, the incorporation of fruit matrices commonly modifies the distribution of proteins and moisture, especially because fruit fibers and soluble compounds compete for water within the structure (Priyashantha et al., 2025; Waweru et al., 2024).

	Samples				
	Control	RA15	RU15	RG15	RB15
pH	5.03 ± 0.02[a]	4.63 ± 0.05[c]	4.57 ± 0.04[d]	4.79 ± 0.03[b]	4.65 ± 0.05[c]
Protein (g/100g)	8.20 ± 0.35[a]	7.41 ± 1.34[c]	7.40 ± 0.49[c]	7.45 ± 0.17[b]	5.69 ± 0.73[d]
Moisture (g/100g)	64.96 ± 1.19[d]	63.00 ± 0.65[e]	66.81 ± 0.63[a]	65.24 ± 0.33[c]	66.51 ± 2.61[bc]
Total Solids content (g/100g)	35.04 ± 1.19[b]	37.00 ± 0.65[a]	33.19 ± 0.63[e]	34.76 ± 0.33[c]	33.49 ± 2.61[d]
Ash (g/100g)	1.18 ± 0.27[d]	1.33 ± 0.19[b]	1.21 ± 0.20[c]	1.34 ± 0.12[a]	1.10 ± 0.12[e]
L*	85.64 ± 1.20[a]	80.29 ± 0.50[d]	82.30 ± 1.30[c]	77.90 ± 2.01[e]	84.02 ± 1.50[b]
a*	-0.45 1.45[e]	1.74 ± 0.75[b]	-0.35 ± 1.30[d]	4.85 ± 1.50[a]	1.05 ± 2.30[c]
b*	13.30 ± 1.50[e]	13.49 ± 2.10[d]	16.87 ± 1.55[c]	20.73 ± 2.50[a]	19.44 ± 1.20[b]

Table 1. Physicochemical and color parameters of creamy Requeijão added with 15% pulp from yellow native fruits

Notes: RG15 = 15% guabiroba pulp; RB15 = 15% butiá pulp; RA15 = 15% araçá pulp; RU15 = 15% uvaia pulp; Values with mean ± standard deviation; [a-c] Means accompanied by the same letters in the same column do not show a significant difference ($p < 0.05$).

Moisture values showed noticeable differences between treatments, with RU15 presenting the highest water content. Consequently, formulations with higher moisture tended to exhibit lower total solids. This inverse relationship is commonly observed in processed cheeses and spreadable dairy products. The higher water retention observed in some samples may be related to the presence of pectins and soluble fibers in the fruit pulps, which can bind water and increasing matrix hydration. On the other hand, RA15 showed the highest total solids content, indicating a lower amount of free water in the formulation. These results suggest that each native fruit interacts differently with the dairy matrix depending on its chemical composition and fiber profile (Lucera et al., 2018;Prestes et al., 2025).

Ash content also varied significantly among treatments. RG15 had the highest ash value, which may indicate a greater mineral contribution from guabiroba pulp. Native Brazilian fruits are frequently described as good sources of essential minerals and bioactive compounds, which may enhance the nutritional value of dairy products when incorporated into formulations (Cargnin et al., 2024; da Fonseca Antunes et al., 2024; Machado et al., 2025). Although the differences in ash content were relatively small, they demonstrate that fruit addition can subtly improve the mineral composition of creamy Requeijão.

The addition of fruit pulps had an even more evident effect on color parameters (Figure 1). The control sample exhibited the highest luminosity (L*), which is characteristic of conventional creamy dairy products. After pulp incorporation, luminosity decreased, especially in RG15, indicating darker samples with stronger pigmentation. This reduction in brightness is directly related to the natural pigments present in native fruits, particularly carotenoids and phenolic compounds (Cargnin et al., 2024; da Fonseca Antunes et al., 2024; Prestes et al., 2022).

The a* values indicated that RG15 developed a more reddish appearance than the other treatments, while the control sample remained close to neutral. At the same time, all fruit-added formulations showed an increase in b* values, especially RG15 and RB15, indicating a more pronounced yellow coloration. This behavior was expected, given that yellow native fruits are rich in carotenoids, which are responsible for yellow-to-orange color tones in foods. The increase in yellowness may also positively influence consumer perception, since yellow shades are often associated with creaminess, flavor intensity, and naturalness in dairy products (Jeong & Park, 2025; Prestes et al., 2023).

Phenolic compounds, Antioxidant activity, and Total Carotenoid content

The addition of 15% native fruit pulp markedly improved the bioactive profile of creamy Requeijão when compared with the control formulation (Table 2). All fruit-enriched samples showed higher carotenoid content, total phenolic content, and antioxidant activity as measured by DPPH and ABTS, indicating that incorporating yellow native fruits effectively increased the functional potential of the dairy matrix.

Among the formulations, RG15 stood out with the highest contents of α-carotene, β-carotene, cryptoxanthin, λ-carotene, and total phenolic compounds, followed by RB15, RA15, and RU15 for most carotenoids. This result is consistent with previous studies reporting guabiroba as a fruit rich in phenolic compounds and with strong antioxidant potential. Malta et al. reported that guabiroba presented high total phenolic content and antioxidant activity, while Prestes et al. (2023) showed that guabiroba pulp increased phenolic content and antioxidant activity in fermented lactic beverage systems, supporting its use in dairy-based functional products (Prestes et al., 2023).

The antioxidant results followed, in part, the same tendency observed for phenolic compounds. RG15 showed the highest DPPH and ABTS values, which agrees with its superior phenolic and carotenoid content. This relationship is expected because phenolic compounds and carotenoids can contribute to radical-scavenging capacity through distinct antioxidant mechanisms (Prestes et al., 2022). Denardin et al.(2015) also reported that Brazilian native fruits, including araçá and butiá, contain relevant levels of phenolics and carotenoids, which may contribute to antioxidant activity (Denardin et al., 2015).

Although RA15 and RU15 showed lower carotenoid and phenolic contents than RG15 and RB15, both formulations still exhibited considerably higher antioxidant activity than the control. This indicates that even fruits with intermediate bioactive contents can improve the antioxidant potential of Requeijão when incorporated into the formulation. For uvaia, studies have highlighted its phenolic composition and antioxidant potential, including extracts obtained from pulp and residues, reinforcing its relevance as a source of natural antioxidants (de Souza Lopes et al., 2025; Rodrigues et al., 2021).

RB15 exhibited the second-highest carotenoid and total phenolic contents, but its antioxidant activity was not consistently the second-highest, particularly for DPPH and ABTS. This suggests that the antioxidant response was determined not only by the total amounts of phenolics and carotenoids, but also by the specific profiles of compounds, their stability in the dairy matrix, and possible interactions with proteins and lipids (Divya Priya & Martin, 2025).

	Samples				
	Control	**RA15**	**RU15**	**RG15**	**RB15**
α-caroten (µg/100g)	10.13 ± 2.00[e]	163.69 ± 41.96[c]	118.89 ± 61.50[d]	818.04 ± 171.43[a]	256.96 ± 31.70[b]
β-caroten (µg/100g)	56.56 ± 9.00[e]	176.83 ± 35.40[c]	128.43 ± 28.20[d]	883.69 ± 150.00[a]	277.59 ± 40.00[b]
Criptoxantin (µg/100g)	5.25 ± 1.26[e]	147.85 ± 32.00[c]	107.39 ± 25.00[d]	738.88 ± 140.00[a]	231.80 ± 38.00[b]
λ-caroten (µg/100g)	< 0.01	192.10 ± 38.00[c]	139.52 ± 30.00[d]	772.49 ± 160.00[a]	301.55 ± 45.00[b]
Total phenolic content (mg/100g)	7.00 ± 0.02[e]	14.00 ± 0.05[d]	15.00 ± 0.03[c]	59.00 ± 0.02[a]	27.00 ± 0.01[b]
DPPH (µmolTE/g*)	10.06 ± 3.67[e]	25.95 ± 1.97[c]	30.37± 2.45[b]	35.30 ± 6.37[a]	23.37 ± 2.07[d]
ABTS (µmolTE/g*)	5.28 ± 0.54[e]	17.24 ± 1.51[b]	15.85 ± 0.50[c]	22.29 ± 1.61[a]	14.42 ± 1.95[d]

Table 2. Total carotenoid content, phenolic compounds, and antioxidant activity of creamy Requeijão with 15% yellow native fruit pulp.

Notes: RG15 = 15% guabiroba pulp; RB15 = 15% butiá pulp; RA15 = 15% araçá pulp; RU15 = 15% uvaia pulp; Values with mean ± standard deviation; [a-e] Means accompanied by the same letters in the same column do not show a significant difference ($p < 0.05$). *TE= Trolox Equivalent

Elements (mg g^{-1})	Control	RU15	RG15	RA15	RB15
Al	< LOD	< LOD	< LOD	< LOD	< LOD
As	< LOD	< LOD	< LOD	< LOD	< LOD
Ca	1.99±0.05[a]	1.78±0.11[b]	1.75±0.03[b]	1.69±0.06[c]	1.67±0.01[c]
Cd	< LOD	< LOD	< LOD	< LOD	< LOD
Co	< LOD	< LOD	< LOD	< LOD	< LOD
Cr	< LOD	< LOD	< LOD	< LOD	< LOD
Cu	< LOD	< LOD	< LOD	< LOD	< LOD
Fe	< LOD	< LOD	< LOD	< LOD	< LOD
K	0.937±0.01[c]	0.748±0.043[d]	1.17±0.03[b]	1.19±0.03[a]	1.16±0.01[b]
Mg	0.113±0.01[b]	0.098±0.01[e]	0.120±0.01[a]	0.109±0.01[c]	0.105±0.01[d]
Mn	< LOD	< LOD	< LOD	< LOD	< LOD
Na	2.54±0.02	1.88±0.11	2.21±0.07	2.15±0.06	2.28±0.03
P	1.30±0.05	1.21±0.08	1.17±0.03	1.19±0.01	1.16±0.03
Pb	< LOD	< LOD	< LOD	< LOD	< LOD
S	1.32±0.05	1.44±0.09	1.24±0.02	1.44±0.02	1.23±0.07
Se	< LOD	< LOD	< LOD	< LOD	< LOD
Sr	Present	Present	Present	Present	Present
Zn	0.0056±0.01	0.0061±0.01	0.0053±0.01	0.0059±0.01	0.0052±0.0004

Table 3. Multi-element profile of creamy Requeijão with 15% pulp of yellow native fruits.

Notes: RG15 = 15% guabiroba pulp; RB15 = 15% butiá pulp; RA15 = 15% araçá pulp; RU15 = 15% uvaia pulp; Values with mean ± standard deviation; a-c Means accompanied by the same letters in the same column do not show a significant difference ($p < 0.05$). LOD = limit of detection.

The results indicate that guabiroba pulp was the most effective ingredient for enhancing the bioactive profile of creamy Requeijão, while butiá, araçá, and uvaia also contributed positively to the development of a dairy product with improved antioxidant properties.

Multi-element profile

The results of the multi-element profile of creamy Requeijão formulations enriched with native Brazilian fruit pulps are presented in Table 3. The major minerals identified in the formulations were calcium (Ca), sodium (Na), phosphorus (P), sulfur (S), potassium (K), and magnesium (Mg), which is expected for products based on dairy matrices, since these minerals are naturally associated with milk proteins and the mineral fractions of whey.

Calcium was the mineral present at the highest concentration across all formulations, with the control sample showing the highest value (1.99 mg/g). The addition of fruit pulps promoted a significant reduction in Ca content, with values of (1.78 mg/g) for RU15, (1.75 mg/g) for RG15, (1.69 mg/g) for RA15, and (1.67 mg/g) for RB15. This behavior may be associated with the dilution effect caused by the incorporation of the pulps into the dairy matrix. Since dairy ingredients are the main source of calcium in this type of product, partially replacing these components with fruit pulps tends to proportionally reduce the concentration of this mineral in the formulations. Similar results were reported by (A. A. Prestes et al., 2025), who observed a reduction in Ca content in Requeijão enriched with guabiroba pulp. Likewise, de Oliveira Mindelo et al., (2025) also reported a decrease in calcium concentration in cheese samples enriched with higher proportions of native fruit pulps. These findings indicate that incorporating plant-based ingredients into dairy matrices can significantly alter the mineral profile of the products, particularly for minerals traditionally associated with milk.

For potassium (K), an increase was observed in the formulations containing fruit pulps, with values of (1.17 mg/g) for RG15, (1.19 mg/g) for RA15, and (1.16 mg/g) for RB15, compared to the control formulation (0.937 mg/g). The only exception was RU15, which presented a lower K concentration (0.748 mg/g) than the control sample. Overall, the results indicate that incorporating fruit pulps increased this mineral in the formulations, as expected, given that tropical and native Brazilian fruits generally exhibit high potassium content. The behavior observed for RU15 may be associated with natural differences in the mineral profile of uvaia compared to the other fruits used in the formulations (Araujo et al., 2017; Bianchini et al., 2020; de Oliveira Raphaelli et al., 2021). Studies on the mineral characterization of Brazilian fruits report K as one of the main minerals found in these plant matrices, highlighting their potential for the nutritional enrichment of processed foods (de Oliveira Mindelo et al., 2025; Prestes et al., 2024). Furthermore, increases in K content in fruit-enriched dairy products have also been reported in dairy derivatives containing fruit pulps, indicating a direct contribution of the fruits to the final mineral profile of the product (de Oliveira Mindelo et al., 2025; Prestes et al., 2024).

Magnesium (Mg) showed significant differences among the formulations, with the highest concentration observed in RG15 (0.120 mg/g), followed by the control sample (0.113 mg/g), RA15 (0.109 mg/g), and RB15 (0.105 mg/g). The lowest value was identified in RU15 (0.098 mg/g). These results demonstrate that the type of fruit used directly influenced the Mg content of the formulations. In addition to the intrinsic mineral composition of the fruit pulps, the incorporation of plant-based ingredients may modify the distribution and retention of minerals within the food matrix, as interactions among milk proteins, fruit compounds, and water can affect the mobility and availability of these elements. From a technological perspective, Mg plays an important role in processed dairy products by contributing to the matrix's ionic balance and influencing properties such as water retention, structural stability, and protein interactions. Nutritionally, magnesium is considered an essential mineral due to its involvement in several metabolic and enzymatic functions in the human body (de Assis et al., 2022; de Oliveira Mindelo et al., 2025; Prestes et al., 2025; Salehi, 2021).

For sodium (Na), all formulations containing fruit pulps showed lower levels than the control sample (2.54 mg/g). The lowest concentration was observed in RU15 (1.88 mg/g), followed by RA15 (2.15 mg/g), RG15 (2.21 mg/g), and RB15 (2.28 mg/g). This behavior suggests a possible dilution effect due to the incorporation of fruit pulps into the dairy matrix, which proportionally reduces the contribution of ingredients traditionally associated with higher sodium content in the product. A similar result was reported by Prestes et al. (2025) for a creamy Requeijão enriched with guabiroba pulp, in which increasing pulp concentration also promoted a gradual reduction in Na levels compared to the standard formulation. This aspect is nutritionally relevant considering the growing interest from both industry and consumers in dairy products with reduced sodium content.

Phosphorus (P) and sulfur (S) contents remained relatively stable among the formulations, ranging from (1.16 to 1.30 mg/g) for P and from (1.23 to 1.44 mg/g) for S. The low variation observed suggests that the addition of fruit pulps did not promote expressive changes in these minerals. The presence of P is directly related to casein micelles and phosphates naturally present in the dairy matrix, while S is mainly associated with sulfur-containing amino acids from milk proteins (Salehi, 2021). Therefore, even with the incorporation of the fruits, the dairy matrix remained the primary source of these elements in the formulations. Studies on mineral distribution in dairy products also report greater stability of P and S when compared to minerals more strongly influenced by the incorporation of plant-based ingredients, such as K and Mg (Bianchini et al., 2020; de Oliveira Mindelo et al., 2025; A. A. Prestes et al., 2024; Salehi, 2021)

Sr was identified as present in the formulations, although at concentrations below the quantitative detection limit. Zinc (Zn), in turn, was detected at low concentrations, ranging from 0.0052 to 0.0061 mg/g. Studies involving enriched dairy products also report low Zn contents, generally showing less variation than major minerals such as Ca and K. This behavior may be associated with the strong interaction of Zn with milk proteins and the lower contribution of fruit pulps to this trace element. Although detected at low concentrations, Zn has important nutritional relevance due to its participation in essential metabolic and enzymatic functions in the human body (de Assis et al., 2022; Kahraman & Ustunol, 2012; Salehi, 2021).

Elements such as Al, As, Cd, and Pb are frequently classified as potentially toxic due to the adverse effects associated with prolonged exposure, including neurological disorders, kidney damage, and carcinogenic effects(de Assis et al., 2022; de Oliveira Mindelo et al., 2025). In this context, the absence of these elements in the evaluated formulations is an important result from a food safety perspective, indicating that incorporating native fruit pulps did not lead to detectable contamination in the final product. Therefore, the results reinforce the mineral quality and safety of the developed formulations, especially due to the absence of potentially toxic metals in the analyzed samples (Salehi, 2021; Zahid et al., 2022) . The incorporation of native fruit pulps, such as uvaia, guabiroba, butiá, and araçá, led to changes in the mineral profile of the Requeijão formulations, mainly through reductions in Ca and Na contents and increases in K in some samples. The differences observed among the formulations also demonstrate that the mineral composition was directly influenced by the type of fruit used, highlighting the potential of these raw materials to contribute to both the nutritional value and the development of dairy products with differentiated characteristics and higher added value.

Conclusion

The results obtained in this study demonstrate the potential of combining cheese whey with native Brazilian yellow fruit pulps to develop creamy Requeijão with improved functional and nutritional characteristics. The incorporation of 15% fruit pulp was sufficient to significantly modify the physicochemical properties, mineral composition, carotenoid content, total phenolic compounds, and antioxidant activity of the formulations, confirming the strong influence of the fruit matrix on the final product characteristics.

Among the evaluated fruits, guabiroba pulp stood out as the most promising ingredient, promoting the highest levels of carotenoids, phenolic compounds, antioxidant activity, and important mineral contributions. In addition, all fruit-enriched formulations exhibited more intense and attractive color characteristics than the control sample, reinforcing the potential of these native fruits to enhance both the technological and sensory appeal of dairy products.

Beyond its functional advantages, the use of cheese whey is an important strategy for the valorization of dairy by-products, contributing to waste reduction and the development of products aligned with sustainability and circular economy principles. At the same time, incorporating underexplored native fruits fosters appreciation of Brazilian biodiversity and creates opportunities to develop innovative foods with regional identity and added market value.

Overall, the findings indicate that creamy Requeijão enriched with native yellow fruit pulps is a promising alternative for the dairy industry, combining technological feasibility, nutritional enhancement, antioxidant potential, and sustainable innovation in a single product. Furthermore, this study reinforces the potential of Brazilian native fruits as strategic ingredients for developing next-generation functional dairy products that combine health benefits, sustainability, and the valorization of Brazil's rich biodiversity within innovative food systems.

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