






**Influence of Edible Coatings on the Physicochemical Quality and Fatty Acid Profile of Brazil Nut Almonds During Storage**


***Influência de Revestimentos Comestíveis na Qualidade Físico-Química e Perfil de Ácidos Graxos de Amêndoas de Castanha-do-Brasil Durante o Armazenamento***

**Received:** October 23, 2025  
**Accepted:** November 24, 2025


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**Abstract**

The objective of this study was to evaluate the physicochemical quality and fatty acid profile of Brazil nut almonds stored at room temperature under different edible coatings. The almonds were sanitized and coated with three formulations containing whey protein, xanthan gum, and essential oils of basil, thyme, and mint, compared to an uncoated control group. After 120 days of storage, physicochemical analyses, texture measurements, and fatty acid profile assessments were performed. The treatments showed no significant differences compared to the control in moisture content, protein, lipids, carbohydrates, energy value, pH, and soluble solids, indicating that the coatings did not influence these basic quality parameters. However, changes

were observed in ash content, titratable acidity, texture, and luminosity of the coated almonds, suggesting that coatings can modify specific characteristics related to physicochemical stability and appearance of the product. The fatty acid profile exhibited modifications in both the treatments and the control, possibly associated with natural lipid oxidation occurring during storage, which is common in high-lipid foods. Most of the evaluated coatings did not outperform the control in preserving the analyzed characteristics. Nonetheless, the incorporation of essential oils shows potential for application in Brazil nut almonds, although further studies are needed to improve their efficacy and understand their interactions with the lipid compounds present in the product.

**Keywords:** Edible Coating. Storage. Rancidity.

### Resumo

O objetivo deste trabalho foi avaliar a qualidade físico-química e o perfil de ácidos graxos de amêndoas de castanha-do-Brasil armazenadas em temperatura ambiente sob diferentes revestimentos comestíveis. As amêndoas foram higienizadas e revestidas com três formulações contendo proteína do soro do leite, goma xantana e óleos essenciais de manjeriço, tomilho e hortelã, comparadas a um grupo controle sem revestimento. Após 120 dias de armazenamento, foram realizadas análises físico-químicas, de dureza e de perfil de ácidos graxos. Os tratamentos não apresentaram diferenças significativas em relação ao controle para teor de água, proteína, lipídios, carboidratos, valor energético, pH e sólidos solúveis, indicando que os revestimentos não influenciaram esses parâmetros básicos de qualidade. Contudo, verificaram-se alterações nos teores de cinzas, na acidez titulável, na textura e na luminosidade das amêndoas revestidas, evidenciando que os revestimentos podem modificar características específicas relacionadas à estabilidade físico-química e à aparência do produto. O perfil de ácidos graxos apresentou modificações tanto nos tratamentos quanto no controle, possivelmente associadas à oxidação lipídica natural ao longo do armazenamento, comum em alimentos com elevado teor de lipídios. A maioria dos revestimentos avaliados não demonstrou desempenho superior ao controle na preservação das características analisadas. Apesar disso, a incorporação de óleos essenciais revela potencial para aplicação em amêndoas de castanha-do-Brasil, embora sejam necessários estudos adicionais para aprimorar sua eficácia e compreender suas interações com os compostos lipídicos presentes no produto.

**Palavras-chave:** Revestimento Comestível. Armazenamento. Rancidez.

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## 1 Introduction

The Brazil nut production in the Amazon is essentially extractive and plays a significant role in social sustainability and biodiversity preservation (Polmann *et al.*, 2021). Brazil nut is an important source of nutrients. It is harvested manually in indigenous regions by farmers during the rainy season. However, exposure of pods and nuts to the soil can increase the risk of fungal infection. In addition to minerals, Brazil nut also contains fibers, folate, and antioxidant compounds, being notable for its high selenium content (Brito; Pereira Junior; Dantas, 2019; Luo *et al.*, 2014; Silva Junior *et al.*, 2017;).

The quality of Brazil nuts reaching the final consumer is influenced by appropriate practices at all the production chain stages (Maroccolo *et al.*, 2021). To ensure consumer health and product nutritional quality, some countries have established strict limits for aflatoxins, which results in stricter criteria for the importation of Brazil nuts (Oliveira *et al.*, 2020).

Edible films and coatings have a promising potential in the protection of food products. They play an important role in slowing down lipid oxidation, the action of microorganisms, and the effects

of moisture (Bittencourt *et al.*, 2020). Furthermore, these materials can help minimize unwanted physical changes in food (Erdem; Diblan; Kaya, 2019).

Edible films and coatings based on proteins are widely used in the food industry due to their properties, such as water solubility, emulsifying capacity, and high nutritional value (Çakmak *et al.*, 2020). Whey protein isolate is used to create films and coatings that are transparent, flexible, and without noticeable odor or flavor, making them well accepted by consumers (Bourtoom, 2008; Ramos *et al.*, 2013).

Coatings using polysaccharide gums, such as xanthan gum, create a semipermeable barrier (Kumar; Saini, 2021). This helps maintain the product nutritional value, reduce weight loss, and decrease the respiration rate on the product surface (Salehi, 2020).

A trend in food technology is the creation of edible films and coatings enriched with bioactive ingredients to enhance their functional properties (Karača *et al.*, 2019). Natural essential oils have been used to extend the shelf life of minimally processed foods, due to their antimicrobial properties (Çakmak *et al.*, 2020).

Studies on the preservation of strawberries applying chitosan and thyme (*Thymus vulgaris*)/rosemary (*Rosmarinus officinalis* L.) oil coatings showed higher stability in soluble solids values compared to control groups (Quintana *et al.*, 2021). Tomatoes coated with whey protein isolate, xanthan gum, and clove oil showed potential to maintain quality characteristics of tomatoes after fifteen days of storage (Kumar; Saini, 2021).

Based on the above, the aim of this study was to evaluate the physicochemical quality and fatty acid profile of food stored at room temperature under different edible coating.

## **2 Material and Methods**

### **2.1 Material and Methods**

The materials used in the formulation of the coating emulsion in this study were whey protein (batch 201312105, Nestle Brasil Ltda, Arara, São Paulo, Brazil), glycerol monostearate (Batch 2022040665, Allimentari, São Paulo, São Paulo, Brazil), xanthan gum (Xanthan Gum 1Kg - 100% Pure Imported - Soldiers Nutrition), peppermint essential oil *Mentha x piperita* (LASZLO, Belo Horizonte, Minas Gerais, Brazil), green basil essential oil *Ocimum basilicum* (Herbia Joinville, Santa Catarina, Brazil), thyme essential oil *Thymus vulgaris* (Phytoterapica, São Paulo, São Paulo, Brazil). All the solvents and reagents used were of PA grade.

The cashew nuts were collected in a rural property in the municipality of Alta Floresta, Mato Grosso, and transported to Coxim, Mato Grosso do Sul (Brazil). The cashew nuts were opened at the Fruit and Vegetable Technology laboratory of the Instituto Federal do Mato Grosso do Sul. The nuts were manually shelled, sanitized, and the almonds were pre-selected (discarding almonds with

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biological contamination, or with the odor of deterioration or damaged), then placed in trays. All the utensils and laboratory benches were previously sanitized.

## 2.2 Formulation of the coating emulsion and application on Brazil nuts

The procedure was according to Kumar and Saini, (2021) and the formulations of isolated whey protein coating solution (WPI) were used in the ratio of 5% w/v (or 5g/100 mL) prepared in distilled water, with pH adjusted to 9. The whey protein isolate solution was prepared according to the method employed by Duan *et al.* (2011). Denaturation was carried out at 65 °C for 20 min on a magnetic stirrer and then cooled to 25 °C. The highly viscous solution in either hot or cold water at low concentrations with excellent stability over a range of temperatures and pH. Glycerol Monostearate (GMS) (based on protein 2% w/v or 2g/100 mL) was added to all solutions as a plasticizing agent, mint oil, basil oil, thyme oil 2 mL was incorporated into the solutions separately.

There were three coating formulations, and one control sample (uncoated) (Frame 1). After preparing different combinations, the solution was stirred in a magnetic stirrer for 30 min for a uniform mixture. The ratio of whey protein and xanthan gum was 1:1.

**Table 1** – Brazil nut coating formulation

Coating	Formulation
Control (No coating)	0
Treatment 1 (T1)	Whey protein, xanthan gum, and peppermint essential oil
Treatment 2 (T2)	Whey protein, xanthan gum, and basil essential oil
Treatment 3 (T3)	Whey protein, xanthan gum, and thyme essential oil

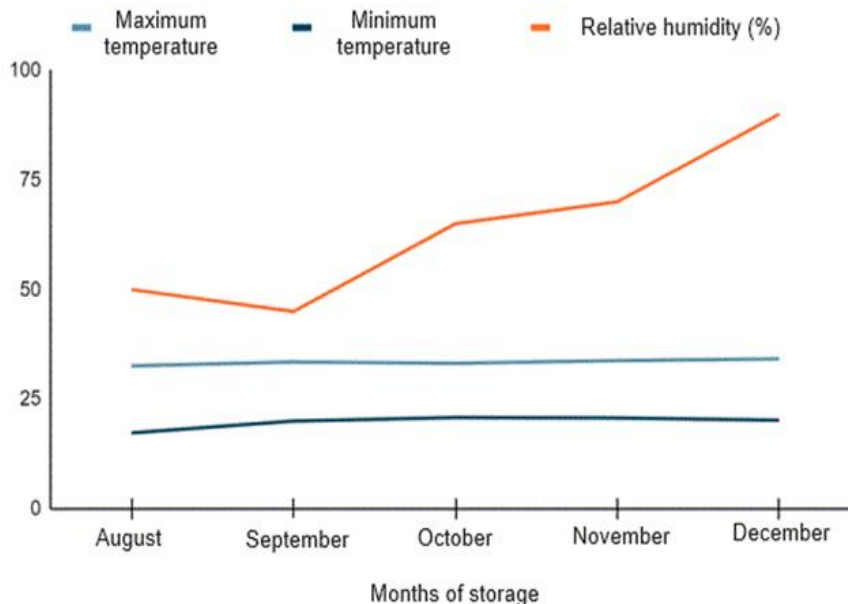
Source: research data.

The almonds were coated with four different formulations: one with whey protein and peppermint essential oil, another with whey protein and basil essential oil, and another with whey protein and thyme essential oil. Additionally, there was a control group (C) in which the almonds were stored without any coating on expanded polystyrene trays. The almonds underwent immersion, draining, and drying processes before storage.

## 2.3 Storage

The almonds and the control were stored for 120 days. During this period, analyses of proximate composition and physicochemical characteristics were carried out, starting from the beginning and continuing until the completion of the 120-day storage period. In Figure 1, the environmental conditions in Coxim, Mato Grosso do Sul are presented. The maximum temperature ranged from 32.6 °C to 34.2 °C, while the minimum temperature fluctuated between 17.3 °C and 20.8 °C. The relative humidity also varied, ranging from 45% to 90% throughout this period.

**Figure 1** – Average temperature (°C) and Relative Humidity (%) of the storage environment of Brazil nuts almonds with and without coating



**Source:** Center for Weather Forecasting and Climate Studies/National Institute for Space Research, 2022.

## 2.4 Determination of proximal composition

Proximate composition analysis was carried initially on the control on day 0 and after 120 days of storage in the treatments. Moisture content was determined by oven-drying, following Association of Official Analytical Chemists (AOAC) Method n° 968.11 (2019). Crude protein was assessed by the Kjeldahl method with the measurement of total nitrogen content using AOAC Method n° 960.52 (2019). The quantified nitrogen content was converted to protein content by multiplying by the appropriate conversion factor, which was 5.46 in the case of Brazil nuts. Ash was identified using AOAC Method n° 923.03 (2019). Lipid determination followed the Bligh DYER method (1959). Carbohydrate content was calculated according to AOAC Method n° 926.08 (2019). Finally, the energy value was determined using the Atwater conversion factors (AOAC, 2019).

## 2.5 Physicochemical analysis

pH was measured using the AOAC method no. 943.02 (2006). In addition, the titratable acidity and total soluble solids analysis followed the Adolfo Lutz Institute (2008) methodology.

## 2.6 Texture analysis

Texture analysis was carried out in accordance with Silva and Junior (2006).

## 2.7 Color

In the study of the color of the samples, a colorimeter was used to determine the parameters L\*, a\* and b\*. The value of L\* represents luminosity, ranging from 0 (black) to 100 (white), following the AOAC method n°14-22 (2006).

## 2.8 Vegetable oil extraction

The crude oil is derived from Brazil nut kernels, without the woody endocarp, and is stored in different coating formulations. The vegetable oil was determined by direct method using hexane, weighing 17 g of powdered sample in an Erlenmeyer flask. Then, 75 mL of hexane was added immediately after homogenization for 24 h. The solution was filtered and then the separation solvent was used. The extracted oil was then taken to a Rotavapor, heated to 60 °C, with a rotary pressure of 90", and then placed in an oven at a temperature of 40 to 50 °C for 4 hours to reach a constant weight (Silva, 2021).

## 2.9 Gas chromatography coupled with mass spectrometry (GC-MS)

The oils obtained from nuts were characterized by their fatty acid profile using gas chromatography (GC Shimadzu 2010 Plus) coupled to a mass spectrometer (MS Shimadzu TQ8040) (GC/MS). Sample preparation was carried out according to Ichihara and Fukubayashi (2010), to convert oils into fatty acid methyl esters. The injection volume was 1 $\mu$ L of the previously esterified samples. During operation, the detector was maintained at 280°C and the injector at 250°C. The injection was performed in split mode (1:100) and separation was carried out on an SH-Rtx-5MS column (Shimadzu) (30 m x 0.25 mm x 0.25  $\mu$ m). The oven was set at 50°C for 1 min, then heated at 25 °C/min to 175 °C, and finally at 4 °C/min to 260 °C. The final temperature was held for 12 min. The carrier gas was Helium at 150 cm<sup>3</sup>/min.

Compounds were identified using the NIST-11 library database, considering their retention indices and comparing them with MS data presented in the literature. Data were processed using the GCMS Postrun Analysis and GCMS Real Time Analysis solution software, both from GCMS solution version 4.20 (Shimadzu Corporation) and NIST Mass Spectral Library. The chart was plotted using Origin software version 9.1 (OriginLab Corporation, Massachusetts, USA). Fatty acid quantification was performed using the area normalization procedure. Results were expressed as the percentage of each fatty acid present in the samples.

## 2.10 Statistical analysis

Proximal and physicochemical analyzes were performed in triplicate in both the control group and the treatments. To assess the significance of the results, analysis of variance (ANOVA) was used, *Ensaio e Ciências*, v.29, n.4, p.1058-1073, 2025.

and the Tukey's multiple range test was applied, with a significance level of  $p < 0.05$ . These analyzes were conducted using the statistical software SISVAR for Windows.

### 3 Results and Discussion

The proximate composition of Brazil nut almonds is crucial for applications in the food and cosmetic industries. The proximal composition and physicochemical analysis of uncoated Brazil nut kernels(control) of this study presented a water content 4.11 (g 100 g<sup>-1</sup>); ashes 3.41(g 100 g<sup>-1</sup>); protein 9.90 (g 100 g<sup>-1</sup>); lipid 61.94 (g 100 g<sup>-1</sup>); carbohydrate 20.63 (g 100 g<sup>-1</sup>); Energy value 679.62 (Kcal 100 g<sup>-1</sup>); pH 7.15. Regarding the parameters total soluble solids 0.36 (°Brix), titratable acidity 1.64 and Hardness 0.4871(N), these findings corroborate previous studies of Lima *et al.* (2021), Silva *et al.* (2021), Botelho *et al.* (2019) and Schons *et al.* (2017).

Regarding the water content, after 120 days of storage, no significant differences were observed between the control group and the treatments (Table 1). The results are consistent with the study by Fernandes *et al.*, (2020) who did not identify variations in the water content of Portuguese chestnuts (*Castanea sativa*) over the storage period. However, in a study by Gull *et al.* (2023), the nuts (*Juglans regia* L.) in the control group showed a significant reduction in water content during storage, while the coated samples maintained higher levels of moisture. Due to its strong barrier potential against carbon dioxide, oxygen, and lipids, whey protein produces superior coatings and exhibits unique properties, such as protection against moisture and aroma loss (Kumar; Saini, 2021).

**Table 1** – Analysis of variance with mean square values for proximal and physicochemical parameters, uncoated almonds, and different treatments after 120 days of storage

	After 120 Days of Storage at Room Temperature						
	Control	T 1	T 2	T 3	CV%	Average	GL
Proximal Analysis							
Water content	3.05a	2.76a	2.07a	2.91a	16.05	2.70	3
Ashes	3.89a	3.38ab	3.26b	3.24b	6.24	3.44	3
Protein	6.18a	6.35a	5.97a	5.97a	6.09	6.11	3
Lipid	55.79a	53.47a	49.40a	56.71a	7.99	53.84	3
Carbohydrate	31.07a	34.03a	39.28a	31.16a	14.64	33.88	3
Energy value	651.16a	642.75a	625.66a	658.96a	3.08	644.63	3
Ph	6.33a	6.65a	6.56a	6.18a	4.31	6.43	3
Physical-Chemical Analysis							
Total soluble solids (°Brix)	0.76a	0.80a	0.83a	0.73a	6.02	0.78	3
Titratable acidity	1.85b	3.45a	3.44a	2.12b	17.08	2.71	3
Hardness (N)	0.2813a	0.1806b	0.1597b	0.1732b	4.93	0.1987	3

Control (No coating); Treatment 1 (T1) with whey protein, xanthan gum, and peppermint essential oil. Treatment 2 (T2) with whey protein, xanthan gum, and basil essential oil. Treatment 3 (T3) with whey protein, xanthan gum, and thyme essential oil. Lowercase letters differ in the lines indicates a difference by the Tukey test ( $P < 0.05$ ); Equal letters do not differ significantly from each other.

**Source:** research data.

The Brazil nut, due to its hygroscopic nature, has a water content that varies according to the climate (Silva, 2021), being rich in lipids. The water content is crucial for the shelf life of the nut kernels, with low humidity being essential to prevent microbial contamination (Gull *et al.*, 2023). Food products with low moisture content must be microbiologically safe for consumption (Gull *et al.*, 2023). Relative humidity influences the mechanical properties and gas permeability in edible films (Grosso *et al.*, 2020).

Regarding the ash content, it is noted that after storage, the control showed similarity with treatment 1 (Table 1). Treatment 2 and 3 differed from the control. Concerning this change in the ash content of treatment 2 (3.26%) and 3 (3.24%) after storage, Silva (2021) observed that there was variation in ash content over the storage periods due to the different packaging materials used, there was interaction between different packaging materials and storage time. Lorini *et al.* (2018) found variation in ash content when stored in vacuum packaging of polypropylene with nylon and PET packaging with aluminized polyethylene (PE) used for storing Brazil nuts during a 9-month period, which is similar to the data from this study.

In the protein values (Table 1), there was no significant difference throughout storage despite the reduction in protein content values between control and treatments. Bitencourt (2020) obtained protein contents of dried Brazil nut almonds at 40°C of 9.38 g 100 g<sup>-1</sup>, indicating that factors such as drying time and temperature interfered in the results obtained.

Regarding the carbohydrate content, an increase was observed in the treatments compared to the control, but there was no difference after storage. Similar results were found in studies with three edible coatings (whey protein isolate, chitosan, and alginate) on the quality of coated *Castanea sativa*, where reducing sugars in the chestnuts were detected in low quantities initially and an increase in reducing sugars was observed during storage in the alginate treatment (Fernandes *et al.*, 2020).

In terms of energy value, the control did not differ from treatments 1, 2, and 3 after the storage period. Similarly, a study by Silva (2021) on Brazil nut almonds stored in different packaging found that they did not differ in energy value during storage, but when almonds and nuts were stored in the same packaging, there were differences from time four onwards.

Regarding the total soluble solids (TSS), there was no difference between the control and treatments after the storage period (Table 1), despite a slight increase in treatments 1 and 2. Similarities in a study with coatings (xanthan gum, whey protein isolate, and clove essential oil) applied to tomatoes by Kumar and Saini (2021) observed that there was a gradual increase in total soluble solids in the tomato samples with and without coating. In chitosan-based coating on strawberries, it was observed that after storage, the TSS of all strawberries was lower than the initial TSS value and the TSS values did not show significant differences between the treatments (Yan *et al.*


2019). Bitencourt (2020) highlights that the content of soluble solids is related to flavor and sugars, being a complex of volatile substances that are stored during the food development.








Regarding titratable acidity, resolution no. 481 of the National Health Surveillance Agency (Brasil, 2021) establishes a maximum limit of 4 mgKOH/g as an indicative parameter of acidity for cold-pressed and unrefined oils. In the study with Brazil nut almonds applied in coatings, an increase in acidity values was observed after storage compared to the control and treatments 1, 2, and 3, although these values remained within the limits allowed by Brazilian legislation. Similar results were obtained in previous studies, such as Fernandes *et al.* (2020), who used nuts coated with whey protein isolate, chitosan, and alginate during storage. Furthermore, in studies with umbu fruit treated with starch, titratable acidity differed only based on storage time (Dos Santos *et al.*, 2021).

Regarding the hardness of almonds, the control of coated almonds differed after the storage period (Table 1). It can be observed in the uncoated almond that the hardness had values of greater force than the coated ones, in both treatments, and it was evidenced that the application of the coating caused a loss of hardness, related to the values of water content and the storage environment. Similarities were found with strawberries coated with chitosan, rice bran, and cassava starch, showing a decrease in firmness at the end of storage compared to the initial hardness (Turquett *et al.*, 2021). The firmness of umbu with biofilm decreased with storage days and remained stable after 9 days. The fruits treated with 1% cassava starch biofilm were 67.66% higher than the untreated fruits (Dos Santos *et al.*, 2021). Ananey-Obiri *et al.* (2018) highlights that protein-based coatings exhibit better moisture barrier properties and superior mechanical characteristics compared to polysaccharide-based coatings.

Color is a visual indicator of quality for minimally processed ready-to-eat products (Torun; Ozdemir, 2022). In the study of Pará nut kernels (Table 2), it was observed that treatments 1, 2, and 3 caused changes in the luminosity (L\*) of the kernels, resulting in a darker color compared to the control group, which did not receive any treatment at time 0. This is consistent with previous findings by Wang *et al.* (2023), who also reported a significant decrease on the fruits surface luminosity after the application of coating, indicating a color darkening. Studies by Wen *et al.* (2022) demonstrated that a composition of sodium alginate and xanthan gum improved the gloss of coated areca nuts.

**Table 2** – Color parameters of uncoated (control) and coated Brazil nuts during storage

Period (Months)		Luminosity L*	Picture
Time 0	Control	53.09a	

	T 1	23.80c	
	T 2	43.73b	
	T 3	36.75c	
Time 4	Control	50.39a	
	T 1	50.51a	
	T 2	53.73a	
	T 3	54.65a	

Control (No coating); Treatment 1 (T1) with whey protein, xanthan gum, and peppermint essential oil. Treatment 2 (T2) with whey protein, xanthan gum, and basil essential oil. Treatment 3 (T3) with whey protein, xanthan gum, and thyme essential oil. Means followed by the same letter in the row for each packaging and different letters in the columns for each storage period do not differ from each other at 5% significance level (Tukey,  $p < 0.05$ ).

**Source:** research data.

In this study, at the final storage time, the control almonds and the treatments showed no difference compared to the initial control group. During this storage period, the coated almonds increased in brightness. In the literature, researchers applied coatings to chestnuts (*Castanea sativa*) and found that after one month, all the coated samples increased in brightness, justifying that after the application of edible coatings, the chestnuts became shinier and clearer (Fernandes *et al.*, 2020). In conventional packaging, Brazil nuts almonds were stored and showed an increase in brightness values (Silva, 2021).

There were significant variations due to the interaction between the packaging and coating used when analyzing the free fatty acids (Table 4). According to the study by Bechlin *et al.* (2019), it was found that storage for golden flaxseed affected the fatty acid index, which increased after storage. Similar effects were observed in the storage of coffee, as there was oxidation of free fatty acids during the storage (Toci *et al.*, 2013). The development of undesirable compounds resulting from lipid oxidation is a major issue that must be addressed to prolong the shelf life of oils, fats, and high-fat foods. To minimize the damage caused by oxidation and to preserve the oxidative stability of oils, the oilseed industry uses antioxidants (Costa *et al.*, 2014).

**Table 4** – Fatty acid composition of uncoated and coated Brazil nut oil after storage period

Fatty Acids	Area (%)*			
	Control	Treatment 1	Treatment 2	Treatment 3
Palmitic acid (C16:0)	14.32c	14.57a	14.20d	14.55b
Palmitoleic acid (C 16:1)	0.28b	0.28b	0.29ab	0.30a
Stearic acid (C18:0)	15.66b	15.59c	16.33a	15.32d
Oleic acid (C 18:1)	29.23d	29.85b	29.33c	29.99a
Linoleic acid (C18:2)	40.19a	39.43d	39.48b	39.45c
Saturated	29.98c	30.16b	30.53a	29.87d
Unsaturated	69.70a	69.56a	69.11a	69.74a
Total Identified	99.68	99.72	99.64	99.61

\*Quantification of fatty acids was performed by the area normalization procedure. Different lowercase letters in the lines indicate a difference according to the Tukey test ( $P < 0.05$ ); Identical letters do not differ from each other significantly.

**Source:** research data.

Control and coated almonds showed difference throughout the storage, as moisture can cause alteration of fatty acids. Roasting of almond led to an increase in fatty acid content, depending on the walnut varieties, due to the removal of relative humidity during the walnut roasting (Ghafoor *et al.*, 2020).

The manual walnut shelling method induced higher concentration of unsaturated fatty acids content compared to the natural piling method, method using a solid ethylene releasing agent or immersion method in ethephon (Wei *et al.*, 2020).

The changes in fatty acids were different between the control and treatment groups (Table 4). Studies with peanuts at different concentrations of edible coatings found alterations in the composition of fatty acids during the storage, significantly affecting the polyunsaturated fatty acids, monounsaturated fatty acids, and saturated fatty acids of all the samples. Coating peanuts with chitosan and  $\gamma$ -glucan significantly affected the changes in saturated fatty acids during the autoxidation, and coated samples, especially chitosan at 1%/ $\gamma$ -glucan, showed lower quantities of saturated fatty acids than the control samples (Kazemian-Bazkiaee *et al.*, 2020).

Among the unsaturated fatty acids, it can be observed that linoleic acid had the highest loss after treatment with the coating. This loss of fatty acids occurred in research with Brazil nuts coated with zein and essential oils in relation to storage time at high temperature is justified by the oxidation process (Gibelli, 2017). Due to the concentration of linoleic acid, Brazil nut oil tends to undergo oxidative reactions, thus acquiring off-flavor characteristics that impact the consumer approval (Carvalho *et al.*, 2022). Studies on the processing of Brazil nuts have shown significant losses of unsaturated fatty acids, such as oleic and linoleic acids, as well as essential amino acids, especially lysine. These losses may lead to a reduction in the biological value and sensory quality of the nut

kernels (Silva; Ascheri; Souza, 2010).

Unsaturated fatty acids can undergo oxidation due to prolonged exposure to oxygen (Gibelli, 2017). The amount of lipids in food influences the oxidation speed, making the product more susceptible (Baron; Pazinato; Baron, 2020). Additionally, fatty acids play a crucial role in the shelf life, nutritional value, and taste of seeds and nuts (Tian *et al.*, 2023). One of the drawbacks of food with a high lipid content is the presence of triglycerides, phospholipids, and free unsaturated fatty acids, as these compounds trigger lipid oxidation problems (Nascimento *et al.*, 2022).

Bitencourt (2020) observes that the temperature and drying time can affect the lipid content in samples, food rich in fat can trigger lipid oxidation problems. This oxidation can occur during storage, especially when factors such as humidity, temperature, and exposure to ultraviolet rays are not controlled according to the sanitary standards of oilseeds presenting reduced shelf life (Nascimento *et al.*, 2022).

Treatment 2 showed a lower alteration in the fatty acid profile of Brazil nuts after 120 days of storage. This difference may be attributed to the presence of basil essential oil (Alves *et al.*, 2015), which has antioxidant properties that combat oxidation in the  $\beta$ -carotene/linoleic acid system (Kulisic *et al.*, 2004). A study using an edible coating of cassava starch/carboxymethylcellulose with added tocopherol on Brazil nut kernels found that the fatty acids present in their composition contributed significantly to the nuts oxidative state (Da Costa *et al.*, 2024).

#### **4 Conclusion**

The results of the 120-day study revealed that the combination of coatings based on whey protein isolate, xanthan gum, and mint, basil, and thyme oils did not significantly influence most of the quality characteristics of Brazil nuts, indicating that this coating was not effective for the kernels postharvest preservation. Only ash content, titratable acidity, texture, and fatty acid profile showed differences compared to the uncoated samples. In summary, further studies on coatings for Brazil nuts are needed, considering their high lipid content, which makes them susceptible to rancidity and microbial contamination during the postharvest period.

#### **Acknowledgements**

The authors would like to thank CAPES (Coordination for the Improvement of Higher Education Personnel) for supporting this study, as well as to Mato Grosso do Sul Federal Institute (IFMS) and Goiano Federal Institute (IFGOIANO), and the Federal University of Paraná (UFPR).

#### **References**

ALVES, L.S. *et al.* Teor, rendimento e composição química do óleo essencial de plantas de manjeriço submetidas ao estresse salino com NaCl. *Rev Bras. Plantas Med.* 2015;17(4):807-13. doi: [https://doi.org/10.1590/1983-084X/14\\_031](https://doi.org/10.1590/1983-084X/14_031)

ANANEY-OBIRI, D. *et al.* Application of protein-based edible coatings for fat uptake reduction in deep-fat fried foods with an emphasis on muscle food proteins. *Trends Food Sci. Technol.*, v.80, p.167-174, 2018. doi: <https://doi.org/10.1016/j.tifs.2018.08.012>

AOAC - Association of Official Analytical Chemists. Official Methods of Analysis of Association of AOAC International. Maryland, USA. 2019.

BARON L.F; PAZINATTO R.; BARON, C.P. Oxidação de lipídeos e as implicações na nutrição e saúde de animais de produção. *Cad. Ciênc. Tecnol.*, v.37, n.1, p.e26597-e26597, 2020. doi: <http://dx.doi.org/10.35977/0104-1096.cct2020.v37.26597>

BECHLIN, T.R. *et al.* Evaluation of grain and oil quality of packaged and ozonized flaxseed. *J. Stored Prod. Res.*, v.83, p.311-316, 2019. doi: <https://doi.org/10.1016/j.jspr.2019.07.014>

BITENCOURT, M.A.F. Isotermas de dessecção, secagem e caracterização nutricional das amêndoas das castanha-do-Brasil da região amazônica. 2020. Dissertação (Mestrado Tecnologia de Alimentos) apresentado ao Instituto Federal Goiano – Campus Rio Verde, 25 a 34 f,

BITTENCOURT, V.R. *et al.* Embalagens ativas como novas abordagens sustentáveis e ambientalmente corretas: uma revisão da literatura. In: AVANÇOS EM CIÊNCIA E TECNOLOGIA DE ALIMENTOS. Editora Científica Digital. 2020. p.217-232.

BLIGH, E.G; DYER W.J. A rapid method of total lipid extraction and purification. *Can. J. Biochem. Physiol.*, v.37, n.8, p.911-917, 1959.

BOTELHO, S.C.C *et al.* Fruits, Seeds and Oil of Brazil Nuts Produced in Mato Grosso State. *Floresta Amb.* 2019;26(2):e20170660. doi: <https://doi.org/10.1590/2179-8087.066017>

BOURTOOM, T. Edible films and coatings: characteristics and properties. *Int. Food Res. J.*, v.15, n.3, p.237-248, 2008.

BRASIL Ministério da Saúde. Agência Nacional de Vigilância Sanitária. Resolução RDC nº 481, de 15 de março de 2021. Dispoe sobre os requisitos sanitários para óleos e gorduras vegetais. Brasília: Anvisa; 2021

BRITO, R.C.M.; PEREIRA JUNIOR, J.B.; DANTAS, K.G.F. Quantification of inorganic constituents in Brazil nuts and their products by inductively coupled plasma optical emission spectrometry. *LWT*, v.116, p.108383, 2019. doi: <https://doi.org/10.1016/j.lwt.2019.108383>

ÇAKMAK, H. *et al.* Whey protein isolate edible films incorporated with essential oils: Antimicrobial activity and barrier properties. *Polymer Degrad. Stabil.*, v.179, p.109285, 2020. doi: <https://doi.org/10.1016/j.polymdegradstab.2020.109285>

CARVALHO, A.L.S. *et al.* Óleo de Castanha-do-Brasil: métodos de extração e aplicações na indústria. *Res. Soc. Develop.*, v.11, n.4, p.e29511427256-e29511427256, 2022. doi: <https://doi.org/10.33448/rsd-v11i4.27256>

COSTA, M.N.F.S. *et al.* Characterization of Pentaclethra macroloba oil: Thermal stability, gas chromatography and Rancimat. *J. Thermal Anal. Calorimetry*, v.115, n.3, p.2269-2275, 2014.

DA COSTA, D.S. *et al.* Cassava Starch/Carboxymethyl Cellulose Edible Coating Added of Ensaio e Ciências, v.29, n.4, p.1058-1073, 2025.

Tocopherol: A Strategy to Preserve the Oxidative Stability of Brazil Nuts. *Foods*, v.13, n.17, p.2732, 2024. doi: <https://doi.org/10.3390/foods13172732>

DOS SANTOS, E.F. *et al.* Extension of umbu (*Spondias tuberosa* Arruda) postharvest life using a cassava starch-based coating. *Agron. Colomb.*, v.39, n.2, p.293-299, 2021. doi: <https://doi.org/10.15446/agron.colomb.v39n2.94028>

DUAN, J. *et al.* Effect of edible coatings on the quality of fresh blueberries (Duke and Elliott) under commercial storage conditions. *Postharvest Biol. Technol.*, v.59, n.1, p.71-79, 2011. doi: <https://doi.org/10.1016/j.postharvbio.2010.08.006>

ERDEM, B.G.; DIBLAN, S.; KAYA, S. Development and structural assessment of whey protein isolate/sunflower seed oil biocomposite film. *Food Bioprod. Proc.*, v.118, p.270-280, 2019. doi: <https://doi.org/10.1016/j.fbp.2019.09.015>

FERNANDES, L. *et al.* Physicochemical properties and microbial control of chestnuts (*Castanea sativa*) coated with whey protein isolate, chitosan and alginate during storage. *Scie. Horticul.*, v.263, p.109105, 2020. doi: <https://doi.org/10.1016/j.scienta.2019.109105>

GHAFOOR, K. *et al.* Influence of roasting on oil content, bioactive components of different walnut kernel. *J. Oleo Sci.*, v.69, n.5, p.423-428, 2020. doi: <https://doi.org/10.5650/jos.ess19205>

GIBELLI, I.C. Filmes de Zeína e óleos essenciais para revestimento e conservação de Castanha-do-Brasil. 2017. Tese (Doutorado em Biotecnologia) – Universidade Federal de São Carlos, São Carlos, 2017.

GROSSO, A.L. *et al.* Increase of walnuts' shelf life using a walnut flour protein-based edible coating. *LWT*, v. 118, p.108712, 2020. doi: <https://doi.org/10.1016/j.lwt.2019.108712>

GULL, A. *et al.* Effect of sodium alginate coatings enriched with  $\alpha$ -tocopherol on quality of fresh walnut kernels. *Food Chemistry Advances*, v.2, p.100169, 2023. doi: <https://doi.org/10.1016/j.focha.2022.100169>

HORWITZ, W.; LATIMER, G.J.R. Association of Official Analytical Chemists–AOAC. Official Methods of Analysis of AOAC International, 18th ed.; AOAC International: Gaithersburg, MD, USA, 2006.

ICHIHARA, K.; FUKUBAYASHI, Y. Preparation of fatty acid methyl esters for gas-liquid chromatography [S]. *J. Lipid Res.*, v.51, n.3, p.635-640, 2010.

INSTITUTO ADOLFO LUTZ. Métodos físico-químicos para análise de alimentos. São Paulo: Instituto Adolfo Lutz, 2008.

KARAČA, S. *et al.* The functional potential of immortelle (*Helichrysum italicum*) based edible films reinforced with proteins and hydrogel particles. *LWT*, v.99, p.387-395, 2019. doi: <https://doi.org/10.1016/j.lwt.2018.09.039>

KAZEMIAN-BAZKIAEE, F. *et al.* Evaluating the protective effect of edible coatings on lipid oxidation, fatty acid composition, aflatoxins levels of roasted peanut kernels. *J. Food Measur. Charact.*, v.14, n.2, p.1025-1038, 2020. doi: <https://doi.org/10.1007/s11694-019-00352-9>

KULISIC, T. *et al.* Use of different methods for testing antioxidative activity of oregano essential oil. *Ensaios e Ciências*, v.29, n.4, p.1058-1073, 2025.

Food Chem., v.85, n.4, p.633-640, 2004.

KUMAR, A.; SAINI, C.S. Edible composite bi-layer coating based on whey protein isolate, xanthan gum and clove oil for prolonging shelf life of tomatoes. *Measurement* 2021;2. doi: <https://doi.org/10.1016/j.measfoo.2021.100005>

LIMA, D.S. *et al.* Technological quality and sensory acceptability of nutritive bars produced with Brazil nut and baru almond coproducts. *LWT*, v.137, p.110467, 2021. doi: <https://doi.org/10.1016/j.lwt.2020.110467>

LORINI, A. *et al.* Influence of packaging on the quality of Brazil nuts. *Acta Amaz.*, v.48, p.368-372, 2018.

LUO, J. *et al.* Application of loop-mediated isothermal amplification assays for direct identification of pure cultures of *Aspergillus flavus*, *A. nomius*, and *A. caelatus* and for their rapid detection in shelled Brazil nuts. *Int. J. Food Microbiol.*, v.172, p.5-12, 2014.

MAROCCOLO, J.F. *et al.* O protagonismo de organizações indígenas na estruturação da cadeia produtiva da castanha-da-amazônia no estado de Roraima, Amazônia brasileira. *Interações*, v.22, n.1, p.1935, 2021. doi: <http://dx.doi.org/10.20435/inter.v22i1.2816>

NASCIMENTO, D.R. *et al.* Importância dos revestimentos comestíveis ativos como estratégia para proteção das oleaginosas contra processos de oxidação lipídica encontrados na literatura. *Res. Soc. Develop.*, v. 1, n.6, p.e21911629080-e21911629080, 2022.

OLIVEIRA, J.M. *et al.* Ozonation of Brazil nuts: Decomposition kinetics, control of *Aspergillus flavus* and the effect on color and on raw oil quality. *LWT*, v. 123, p. 109106, 2020.

POLMANN, G. *et al.* Non-conventional nuts: an overview of reported composition and bioactivity and new approaches for its consumption and valorization of co-products. *Future Foods*, v.4, p.100099, 2021. doi: <https://doi.org/10.1016/j.fufo.2021.100099>

QUINTANA, S.E. *et al.* Comparison between essential oils and supercritical extracts into chitosan-based edible coatings on strawberry quality during cold storage. *J. Supercr. Fluids*, v.171, p.105198, 2021. doi: <https://doi.org/10.1016/j.supflu.2021.105198>

RAMOS, Ó.L. *et al.* Effect of whey protein purity and glycerol content upon physical properties of edible films manufactured therefrom. *Food hydrocol.*, v.30, n.1, p.110-122, 2013.

SALEHI F. Edible Coating of Fruits and Vegetables Using Natural Gums: a review. *Int. J. Fruit Sci.*. v.6, 2020. doi: <https://doi.org/10.1080/15538362.2020.1746730>

SCHONS, J. I. *et al.* Extração assistida por ultrassom e caracterização do óleo da castanha-do-brasil (*Bertholletia excelsa* HBK). *Interiencia*, v.42, n.9, p.586-590, 2017.

SILVA, F.A.; JUNIOR, A.M. Perfil de textura de amêndoas de noz macadâmia (*Macadamia integrifolia*) secas com aplicação de energia de microondas e ar quente. 2006. *RECEN*, v.8, n.2, p.189-199, 2006.

SILVA JUNIOR E.C. *et al.* Natural variation of selenium in Brazil nuts and soils from the Amazon region. *Chemosphere*, v. 188, p. 650-658, 2017. doi: <https://doi.org/j.chemosphere.2017.08.158>

SILVA, S.D.R. Caracterização química e perfil de ácidos graxos da castanha-do-brasil (*Bertholletia excelsa* h.b.k) durante o armazenamento em diferentes embalagens. Dissertação (Tecnologia de Alimentos) Instituto Federal Goiano – Rio Verde Goiás, 2021.

SILVA, B. P. P. C. *et al.* Avaliação das características físico-químicas da castanha do Brasil (*Bertholletia excelsa*) e da castanha portuguesa (*Castanea sativa* mill.). *Revista Brasileira de Tecnologia Agroindustrial*, v. 15, n. 2, 2021.

SILVA, R.F.; ASCHERI, J.L.R.; SOUZA, J.M. L. Influência do processo de beneficiamento na qualidade de amêndoas de castanha-do-brasil. *Ciênc. Agrotecnol.*, v.34, p. 45-450, 2010.

SOUZA, A.L.S.; MIRANDA, J.S.; SOUSA, R.C.S. Caracterização físico-química da amêndoa e do óleo de baru submetido à extração sólido-líquido com solventes alternativos. *Braz. J. Develop.*, v. 5, n. 11, p. 26548-26556, 2019.

TIAN, T. *et al.* Studies on the lipid oxidation and oleosomes behavior in raw pecan kernels during storage. *Food Chem.*, v.405, p.134867, 2023. doi: <https://doi.org/10.1016/j.foodchem.2022.134867>

TOCI, A.T. *et al.* Changes in triacylglycerols and free fatty acids composition during storage of roasted coffee. *LWT*, v.50, n.2, p.581-590, 2013. doi: <https://doi.org/10.1016/j.lwt.2012.08.007>

TORUN, M.; OZDEMIR, F. Milk protein and zein coatings over peeled garlic cloves to extend their shelf life. *Sci. Horticult.*, v.291, p.110571, 2022. doi: <https://doi.org/10.1016/j.scienta.2021.110571>

TURQUETT, L.C.G.B. *et al.* Avaliação da cobertura comestível elaborada a partir de quitosana, farelo de arroz e fécula de mandioca na conservação pós-colheita de morangos. *Braz. J. Develop.*, v.7, n.3, p.33153-33171, 2021.

WANG, L. *et al.* Effect of chitosan-ascorbic acid composite coating on postharvest quality of Custard apple (*Annona squamosa*). *Process Biochem.*, v.129, p.76-85, 2023. doi: <https://doi.org/10.1016/j.procbio.2023.03.013>

WEN, Q. *et al.* Effect of synergism between sodium alginate and xanthan gum on characteristics of composite film and gloss of areca nut coating. *Food Biosc.*, v.50, p.102113, 2022. doi: <https://doi.org/10.1016/j.fbio.2022.102113>

WEI, F. *et al.* Effects of hulling methods on the odor, taste, nutritional compounds, and antioxidant activity of walnut fruit. *LWT*, v. 120, p. 108938, 2020. doi: <https://doi.org/10.1016/j.lwt.2019.108938>

YAN, J. *et al.* The effect of the layer-by-layer (LBL) edible coating on strawberry quality and metabolites during storage. *Posthar. Biol. Technol.*, v.147, p.29-38, 2019. doi: <https://doi.org/10.1016/j.postharvbio.2018.09.002>