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IMPACT OF DRYING CONDITIONS ON COMPOSITION AND STABILITY OF BRAZIL NUT KERNELS DURING

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KEYWORDS

ashes, lipids, minerals, proteins.

ABSTRACT

This study aimed to evaluate the effect of different drying temperatures on the physicochemical characteristics of Brazil nut kernels during storage. Nuts were dried at five temperatures (40, 50, 60, 70, and 80 °C) until reaching a moisture content of about 4.0% (wb). Kernels were then stored under laboratory conditions (27.77 ± 1.77 °C and 58.27 ± 8.57% RH) for 0, 2, 4, 6, 8, and 10 months. At each storage period, water, protein, ash, lipid, mineral, pH, titratable acidity, total soluble solids, and colorimetric parameters were analyzed. Results showed that protein content remained constant throughout storage, with values of 13.7 and 14.4% at 40 and 80 °C, respectively. Higher ash content was recorded at 70 and 80 °C (3.6 and 3.8%). Lipid content was the lowest at 60 °C (65.3%). The highest macro- and micromineral concentrations were observed for nitrogen (24.5 g kg^{-1}), iron (62.4 g kg^{-1}), and zinc (48.64 g kg^{-1}). Based on physicochemical characteristics, Brazil nut kernels remained viable for consumption throughout ten months of storage.

INTRODUCTION

Bertholletia excelsa is one of the most important extractive species in the Amazon and Brazil, supporting the socioeconomic sustainability of many communities and increasingly regarded as a crop of commercial interest (Martins et al., 2021). The Brazil nut tree, native to the Amazon rainforest, is high in protein and calories and also rich in fiber, calcium, and iron. Its seeds provide selenium, a mineral essential for combating free radicals. Despite their high caloric value, Brazil nuts help reduce cardiovascular and respiratory diseases, diabetes, and infections due to their essential fatty acids, high antioxidant levels, vitamins, amino acids, and minerals (Lima et al., 2021). Although widely recognized as a Brazilian product and internationally known as “Brazil nut,” Bolivia is the world’s largest exporter, accounting for about 50% of global production, followed by Brazil (Ribeiro et al., 2022).

Brazil nuts are oil-rich and nutrient-dense. Although native to the Amazon, they are marketed worldwide (Silva et al., 2017). Beyond raw consumption, they are processed into oils, flours, beverages, and nutrition bars (Cardoso et al., 2017). However, post-harvest handling presents critical challenges. Inadequate processing conditions, particularly under high temperature and optimal relative humidity, favor the growth of aflatoxin-producing fungi, rendering nuts unsuitable for consumption (Kluczkovski et al., 2020).

The high lipid content of Brazil nuts also creates technological challenges during storage, including susceptibility to oxidation and limited lipid solubility in food formulations (Lemos & Feltes, 2025). Lipid oxidation leads to rancidity, compromising both sensory and nutritional quality (Zhou et al., 2025). Maintaining quality and food safety therefore requires strict post-harvest practices. Delays in processing, particularly during drying, increase the risk of contamination by aflatoxin-producing fungi such as Aspergillus pseudonomius (Massi et al., 2014).

Drying, a critical stage in Brazil nut processing, is essential given the high moisture-content of the seeds. Efficient drying is necessary to inhibit fungal growth (Takeuchi & Egea, 2020). Consequently, research aimed at

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improving drying and storage practices is vital to maintain quality and extend post-harvest shelf life. Inadequate preservation conditions compromise product quality, with mycotoxin contamination representing one of the most significant threats.

Accordingly, this study aimed to evaluate the effect of different drying temperatures on the physical and chemical characteristics of Brazil nut kernels during storage.

MATERIAL AND METHODS

Raw material

The experiment was conducted at the Federal Institute of Education, Science, and Technology Goiano, Rio Verde Campus, in the Post-Harvest Laboratory for Plant Products. Brazil nuts were collected in Manaus, Amazonas, and transported in wooden containers to the laboratory. The fruits were manually opened with metal knives, and kernels were extracted. Visibly damaged kernels were discarded, and the remaining ones were homogenized and analyzed for initial moisture content, determined according to Silva et al. (2021). Moisture was measured in a forced-air oven at 105 °C for 31 hours until constant mass was achieved.

Drying

Samples were dried in a forced-air oven at 40, 50, 60, 70, and 80 °C. Kernels were evenly distributed on rectangular aluminum trays (0.25 × 0.10 m), each containing 0.20 kg of sample, in four replicates. Drying was continued until equilibrium moisture content was reached, defined as constant mass over three consecutive weighings.

Storage

The kernels were removed from the woody endocarp and stored in polypropylene (PP) containers at room temperature (~28 °C). Temperature and relative humidity were recorded every two months over ten months using a data logger (LOGBOX-RHT-LCD). During storage, kernels were analyzed for water, protein, ash, lipid, and mineral contents (at 0 and 10 months), pH (0, 2, 4, 6, and 8 months), titratable acidity, total soluble solids, and colorimetric parameters.

PROXIMATE COMPOSITION OF KERNELS

Moisture content

Moisture content was determined by oven-drying with air circulation according to AOAC method 968.11 (2010). Three grams of sample were weighed into porcelain crucibles, dried at 105 °C until constant mass, cooled in a desiccator, and weighed.

Crude protein content

Protein content was determined by the Kjeldahl method, measuring total organic nitrogen according to AOAC (2010).

Ash

Ash content (fixed mineral residue) was measured by gravimetric incineration following AOAC method 923.03 (2010). Three grams of sample were weighed into porcelain crucibles and placed in a muffle furnace (MAGNUS N480D) at 550 °C for 4 hours. Samples were cooled in a desiccator and weighed.

Lipids

Lipid content was analyzed by the Soxhlet method (AOAC 920.39, 2010). Three grams of sample were weighed onto filter paper and placed in the apparatus. Flasks were pre-dried in a forced-air oven at 105 °C, cooled in a desiccator, and weighed. Hexane PA was used as solvent for 8 hours. After extraction, solvent was evaporated in a rotary evaporator. Residues were oven-dried at 105 °C for 1 hour, cooled under room temperature, and weighed. Heating and weighing were repeated every 30 minutes until constant mass was reached.

Minerals

Selenium was determined by atomic absorption spectrometry in initial samples and after ten months of storage. A 0.5 g sample was digested with 10 mL of nitric acid (HNO_3) in an Alfa Mare AM 348 block digester and analyzed by ICP-MS at Exata Laboratory. Results were expressed as mg kg^{-1}. Analyses were performed in triplicate. Macronutrients (N, P, K, Ca, Mg, and S-SO_4) and micronutrients (Fe, Mn, Cu, Zn, and B) were quantified in initial and final samples using atomic absorption spectrophotometry (AAS), following AOAC method 985.35 (2010).

PHYSICOCHEMICAL ANALYSIS

pH

The pH was determined according to AOAC method 943.02 (2010). Five grams of sample were weighed into Erlenmeyer flasks with 50 mL of distilled water. Suspensions were stirred on a magnetic stirrer, rested for 10 minutes, and measured using a calibrated digital pH meter (LUCA-210). Analyses were performed up to eight months of storage.

Titratable acidity

Titratable acidity was measured using the IAL method (2008). Three drops of phenolphthalein were added as an indicator to the solution prepared for pH analysis. Titration was carried out with 0.1 N NaOH until the endpoint. Results were expressed as meq NaOH 100 g^{-1}.

Total soluble solids (TSS)

Total soluble solids were determined following the IAL method (2008). Ten grams of sample were weighed, dissolved in distilled water, stirred, and filtered. One milliliter of each sample was analyzed using a digital refractometer (Atago Hand Refractometer, QUIMIS). Results were expressed in °Brix.

Color

Color was measured at room temperature with a Color Flex EZ/HunterLab colorimeter. Results were expressed in color coordinates L*, a*, and b*. L* values represent brightness, ranging from black (0) to white (100). a* values range from green (–a) to red (+a), and b* values from blue (–b) to yellow (+b). Chromaticity (C*) and Hue angle (°Hue) were also calculated according to AACC method 14-22 (2006). All measurements were performed in triplicate.

Statistical analysis

The experiment followed a completely randomized design in a 5 × 6 factorial arrangement, with five drying temperatures (40, 50, 60, 70, and 80 °C) and six storage periods (0, 2, 4, 6, 8, and 10 months). Three replicates were used. Physicochemical analyses were performed in triplicate, and means were compared by Tukey's test at the 5% significance level. Mineral contents were assessed at 0 and 10 months of storage.

RESULTS AND DISCUSSION

Figure 1 presents the mean temperature and relative humidity (RH) recorded during the ten-month storage period, which averaged 27.77 ± 1.77 °C and 58.27 ± 8.57%, respectively.

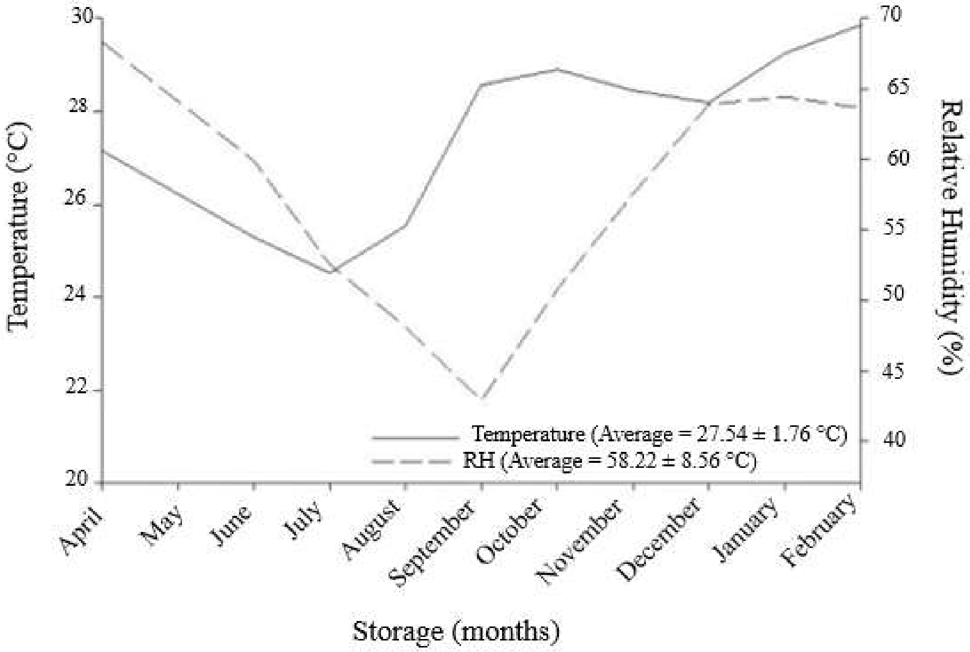

FIGURE 1. Mean temperature (ºC) and relative humidity (%) in the storage environment of Brazil-nut kernels.

The parameters presented in Table 1 showed an isolated effect ($p > 0.05$) of drying temperature and storage time. For moisture content, significant differences were observed between 40 and 60 °C. Drying at 60 °C promoted greater water removal from Brazil nut kernels than at 40 °C.

TABLE 1. Values of water, protein, and ash contents in Brazil nut kernels subjected to different drying temperatures and storage times.

Drying temperature (°C)	Moisture content (% sb)	Protein (%)	Ash (%)
40	3.10 a	13.70 ab	3.40 b
50	2.90 ab	12.90 b	3.20 b
60	2.60 b	12.90 b	3.30 b
70	2.90 ab	13.50 b	3.60 ab
80	2.9 ab	14.4 a	3.8 a
Time (months)	**Moisture content (% sb)**	**Protein (%)**	**Ash (%)**
0	2.70 ab	13.60	3.40 ab
2	3.00 ab	13.60	3.00 b
4	3.00 ab	13.30	3.50 ab
6	2.60 b	13.70	3.70 a
8	3.00ab	13.60	3.70 a
10	3.00 ab	13.00	3.50 ab

Means followed by the same lowercase letter within columns do not differ significantly according to Tukey's test at the 5% level.

All Brazil nut moisture contents remained below 8.2% db. According to Botelho et al. (2019), in evaluating sorption isotherms of Brazil nuts at different temperatures, moisture content should be maintained below 8.2% on a dry basis in storage environments below 55 °C to prevent fungal development.

For protein, no significant differences were observed at 40 °C compared with other drying temperatures. However, at 80 °C protein values differed from those at other temperatures, except 40 °C. Both 40 and 80 °C presented the highest protein contents. This effect may be related to drying with the woody endocarp, which may have provided some protection to the proteins. Protein content remained stable throughout storage, averaging 13.5%.

Ash content at 80 °C was higher than at 40, 50, and 60 °C, and did not differ from 70 °C. The mean ash value obtained in this study was 3.46%. Similar results were reported by Costa et al. (2012), who observed ash contents averaging 3.65% in Brazil nut kernels across storage periods. Silva et al. (2021) also reported values ranging from 3.22% to 3.86% for Brazil nuts and kernels of the same species. Consistently, Bitencourt et al. (2020) found an average of 3.53% in Brazil nut samples.

Drying temperature and storage time influenced lipid content (Table 2). Differences were observed among drying temperatures, with the highest values recorded at 50 and 80 °C at 0, 2, and 8 months of storage.

TABLE 2. Average lipid content (%) of Brazil nut kernels at different drying temperatures across varying storage times.

Drying temperature (°C)	Storage time (months)					
	0	2	4	6	8	10
40	70.90bB	70.80bB	70.60 bB	75.90 aA	64.00 bC	69.20 bB
50	78.30aA	77.3 aA	71.00 aB	70.00 bB	69.90 aB	68.70 bB
60	65.30cC	69.50 bB	69.90 aB	66.50 bcBC	65.10 bC	78.40 aA
70	72.40bA	72.50bA	71.70 aA	63.10 cB	63.80 bB	70.00 bA
80	77.90aA	78.30 aA	70.00 aB	65.10 cC	67.40abBC	69.40 bB

Means followed by the same lowercase letter within columns and uppercase letter within rows do not differ significantly according to Tukey's test at the 5% level.

An increase in drying temperature influenced the parameters analyzed in Brazil nut kernels. In general, faster water release during drying, promoted by higher air temperatures, reduces the quality of plant products (Costa et al., 2012). However, this effect was not evident for lipid content. Possible explanations include the heterogeneity of nuts, which vary in size, diameter, and proximate composition. Lipid content declined over storage compared with the initial period.

Table 3 presents macro- and micromineral values in Brazil nut kernels at 0 and 10 months of storage at different temperatures. Brazil nuts are rich in minerals and serve as sources of Fe, K, Mg, Mn, N, P, Ca, S-SO_4, Zn, B, and Cu, all of which play important physiological roles in the human body. Among macrominerals, nitrogen showed the highest mean value (25.9 g kg^{-1}), followed by potassium (6.2 g kg^{-1}). Among microminerals, zinc was highest (81.2 g kg^{-1}), followed by iron (46.9 g kg^{-1}). After ten months of storage, the values for N, K, Fe, and Zn (24.5, 6.3, 48.69, and 62.4 g kg^{-1}, respectively) remained similar to those at time 0, indicating that Brazil nut kernels exhibited excellent storage stability in terms of macro- and micromineral composition.

TABLE 3. Mineral composition of Brazil nut kernels at different drying temperatures during 10 months of storage.

Time (month)	Temperature (°C)	Macromineral (g kg^{-1})						Micromineral (mg kg^{-1})				
		N	P	K	Ca	Mg	S	Fe	Mn	Cu	Zn	B
00	40	34.3	5.3	6.5	0.5	2.9	0.82	63.7	6.0	13.6	93.9	34.5
	50	22.4	5.5	5.5	2.3	3.0	0.69	42.8	10.6	14.0	90.1	29.6
	60	31.9	5.1	4.5	0.8	2.5	0.77	47.3	4.9	6.9	79.1	18.1
	70	19.3	4.7	6.0	0.7	2.2	0.75	45.5	5.8	6.2	70.0	12.6
	80	21.7	6.3	8.5	0.9	3.0	0.84	35.1	7.1	24.2	72.9	10.4
Average		25.9	5.4	6.2	1.0	2.7	0.8	46.9	6.9	13	81.2	21.0
10	40	24.6	5.9	7.0	1.1	3.0	1.01	42.3	5.6	10.0	0.4	15.3
	50	23.9	6.4	5.5	0.4	3.0	0.79	33.4	8.6	8.2	62.9	22.5
	60	14.4	5.6	6.0	1.0	2.8	0.84	81.7	6.4	8.5	62.8	20.8
	70	31.4	6.2	6.0	0.7	3.1	0.64	39.1	5.9	6.7	62.0	17.0
	80	28.0	6.0	7.0	0.8	2.8	0.90	46.7	5.3	10.9	53.8	19.7
Average		24.5	6.0	6.3	0.8	3.0	0.84	48.6	6.4	8.9	62.4	19.1

Camargo & Lima (2019) reported that Brazil nuts can complement the human diet due to their potential health benefits, including the prevention of cancer, cardiovascular disease, diabetes, immune disorders, and neurodegenerative conditions.

Table 4 shows the pH values of Brazil nut kernels subjected to different drying temperatures and evaluated over eight months of storage. Drying temperatures of 40, 50, 60, 70, and 80 °C did not significantly affect pH, which averaged 6.38. This value characterizes the product as slightly acidic and close to neutrality. After eight months of storage, kernel pH decreased to 6.34 compared with the initial value of 6.65. Cândido et al. (2014) reported pH values of 6.64, 6.65, and 6.87 for Brasil Nuts dried for 72 hours to a moisture content of 2.8 g 100 g^{-1}, results slightly higher than those found in this study.

TABLE 4. Average pH values of Brazil nuts dried at different temperatures depending on storage.

Drying temperature (°C)	pH	Time (meses)	pH
40	6.45 a	0	6.65 a
50	6.39 a	2	6.46 bc
60	6.44 a	4	6.55 ab
70	6.32 a	6	6.27 cd
80	6.36 a	8	6.34 c

Means followed by the same lowercase letter within columns do not differ significantly according to Tukey's test at the 5% level.

According to Machado et al. (2019), food pH significantly influences microbial growth and development and is considered a key factor in food microbiology, acting as a limiting parameter for different microbial groups. Fiorda & Siqueira (2009) classified foods into three categories based on pH: low-acidity foods (pH > 4.5), which favor the growth of pathogenic and spoilage microorganisms; acidic foods (pH 4.0–4.4), in which yeasts, molds, and lactic acid bacteria predominate; and very acidic foods (pH < 4.0), where microbial growth is restricted mainly to molds and yeasts. Brazil nuts are classified as low-acidity foods, with pH values close to neutrality, which compromises microbiological stability during storage and demands specific preservation measures.

Table 5 shows the mean titratable acidity values. After drying, kernels did not differ at 0, 4, and 8 months across drying temperatures. However, acidity did not exhibit a consistent trend during storage. The initial mean value was 0.58 meq NaOH 100 g^{-1} and increased to 6.35 meq NaOH 100 g^{-1} after 12 months of storage. This increase reflects product quality changes associated with fatty acid degradation. Acidity is therefore directly related to raw material quality, processing, and particularly storage conditions of vegetable oils, and is a useful indicator of conservation status.

TABLE 5. Average titratable acidity (meq NaOH 100 g^{-1}) of Brazil nut kernels dried at different air temperatures during storage.

Drying temperature (°C)	**Storage time (months)**					
	0	2	4	6	8	10
40	0.33 aD	0.57 bD	1.97 aBC	1.63 bC	2.87 aB	6.90 aA
50	0.53 aC	1.20 abBC	1.57 aBC	1.33 bBC	1.97 aB	7.00 aA
60	0.60 aC	1.30 abBC	1.57 aBC	1.40 bBC	2.10 aB	6.37 abA
70	0.73 aC	2.13 aB	2.10 aB	2.70 aB	2.63 aB	5.83 bA
80	0.70 aC	2.00 aB	2.33 aB	2.63 aB	2.47 aB	5.67 bA

Means followed by the same lowercase letter in columns and uppercase letter in rows do not differ significantly according to Tukey's test at 5% level.

The acidity index observed was higher than that reported for commercial soybean oil studied by Santos et al. (2016), in which the maximum value was 0.8 mg KOH g^{-1}, and also higher than that of Brazil nut oil (0.207 mg KOH g^{-1}). Determining total acidity in foods is important for evaluating processing efficiency and preservation status.

Table 6 presents soluble solids values for different drying temperatures at each storage period. Soluble solids increased at the end of storage for all drying temperatures. This behavior reflects a biochemical process in which starch is converted into sugars during the ripening of plant products; higher total soluble solids content is associated with greater sweetness. However, no consistent trend was observed with increasing drying temperature. According to Santiago et al. (2022), the increase in total soluble solids may be related to the conversion of reserve tissues into soluble sugars.

TABLE 6. Soluble solids content (°Brix) of Brazil nut kernels dried at different temperatures during storage.

Drying temperature (°C)	Storage time (months)					
	0	2	4	6	8	10
40	0.40 aB	0.57 cB	1.17 aA	1.30 aA	1.40 aA	1.50 aA
50	0.53 aC	1.20 bA	1.00 aAB	0.57 bcBC	0.73 bBC	0.77 bABC
60	0.40 aB	1.10 bA	1.13 aA	0.50 cB	0.70 bAB	0.77 bAB
70	0.76 aC	2.13 aA	1.07 aC	0.93 abC	1.53 aB	1.57 aB
80	0.70 aB	2.00 aA	0.80 aB	0.53 bcB	0.83 bB	0.90 bB

Means followed by the same lowercase letter in columns and uppercase letter in rows do not differ significantly according to Tukey's test at 5% level.

Tables 7, 8, and 9 present the results of colorimetric analyses of Brazil nut kernels. For luminosity, both storage time and drying temperature influenced kernel color during storage. According to Francisquini et al. (2017), the Maillard reaction, a non-enzymatic browning process, is affected by several factors, including temperature. The reaction rate is slow at lower temperatures but can double with every 10 °C increase between 40 and 70 °C.

TABLE 7. Average L* values of Brazil nut kernels dried at different temperatures during storage.

Drying temperature (°C)	Storage time (months)					
	0	2	4	6	8	10
40	60.20 cBC	61.70aAB	62.60 bA	53.90 cE	56.40 bD	58.90 bcC
50	70.10 aA	60.80 aB	55.00 dE	59.50 bBC	57.60 abD	58.40 cCD
60	69.30 abA	60.30 aC	64.70 aB	58.50 bD	58.90 aCD	59.60 abcCD
70	68.40 bA	61.40 aBC	61.70 bB	62.90 aB	57.90 abD	60.00 abC
80	70.50 aA	61.70 aBC	57.80 cD	62.80aB	54.50 cE	60.50 aC

Means followed by the same lowercase letter in columns and uppercase letter in rows do not differ significantly according to Tukey's test at 5% level.

Table 8 shows the hue angle values of Brazil nut kernels dried at different temperatures during storage. The hue angle (°Hue) can range from 0° to 360°, where 0° corresponds to red, 90° to yellow, 180° to green, and 270° to blue (HunterLab, 2008). At 0 months of storage, kernels dried at 40 °C had the lowest hue angle (77.3°). From this temperature onward, hue values increased. Across storage periods, kernels showed variations in hue without a clear trend. The final average value after storage was 81°Hue, indicating a yellowish coloration.

TABLE 8. Average hue angle (°Hue) of Brazil nut kernels dried at different air temperatures during storage.

Drying temperature (°C)	Storage time (months)					
	0	2	4	6	8	10
40	77.30cD	78.90aC	80.50cB	76.60dE	81.50bA	80.80bAB
50	83.10aA	78.10bD	78.20eD	80.90bB	79.80dC	80.00cC
60	82.80abA	78.50abC	82.10bA	79.80cB	82.80aA	82.20aA
70	82.50bB	78.50abD	83.50aA	82.20aB	81.00bcC	81.40bC
80	80.90bA	78.90aC	79.60dB	80.40bcA	80.70cA	79.40cBC

Means followed by the same lowercase letter in columns and uppercase letter in rows do not differ significantly according to Tukey's test at 5% level.

For chroma, increasing drying temperature did not reveal a clear trend. At 0 months, kernels dried at 40 and 60 °C showed the same chromaticity (17.6), the lowest value in the initial period. At 2 months, kernels dried at 80 °C behaved similarly to those at 40 °C. From the fourth month onward, chroma values increased, with 80 °C presenting the highest saturation levels. Chroma reflects color saturation, where values near 0 indicate grayish tones, while values near 60 represent more vivid and intense colors.

TABLE 9. Average chroma values of Brazil nut kernels dried at different air temperatures during storage.

Drying temperature (°C)	Storage time (months)					
	0	2	4	6	8	10
40	17.60cB	21.80 aA	16.10 dD	16.30 dC	15.30 dD	15.48 dD
50	19.10bA	17.80 cBC	17.30 cBC	18.0 cB	17.10 cC	17.50 cBC
60	17.60cAB	17.30cABC	18.00 cA	16.40 dD	16.60 cCD	16.97 cBCD
70	19.30bE	20.30 bCD	20.20 bDE	21.0 bBC	22.20 bA	21.69 bAB
80	25.30aA	21.80 aA	23.00aC	24.90 aAB	25.20 aA	24.38 aB

Means followed by the same lowercase letter in columns and uppercase letter in rows do not differ significantly according to Tukey's test at 5% level.

CONCLUSIONS

To maintain the quality and preservation of Brazil nut kernels, drying temperatures up to 60 °C are recommended. Over the ten-month storage period, kernels remained suitable for consumption based on their physical and chemical characteristics.

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DATA AVAILABILITY STATEMENT

Data available on request due to restrictions, e.g. privacy or ethics.

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