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Chemical characterization of baru oil and its by-product from the northwest region of Minas Gerais, Brazil

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SUMMARY: This study investigated baru oil and partially defatted baru flour from the northwest region of Minas Gerais, Brazil. The physicochemical characterization of the oil was made by determining the fatty acid profile using gas chromatography, lutein, and α- and β- carotenes by means of high-performance liquid chromatography, and total carotenoids by spectrophotometry. The flour was analyzed for its chemical composition, fiber, and mineral contents. Baru oil presented excellent quality parameters and high contents in unsaturated fatty acids and carotenoids. The flour showed relevant levels of proteins, lipids, and dietary fiber, in addition to having representative mineral contents for food such as manganese, magnesium, and copper. Thus, baru oil and the by-product of its extraction offer a rich chemical composition, and their application may add nutritional value to foods in addition to reducing negative environmental impacts.

KEYWORDS: *Agricultural waste valorization; Brazilian Cerrado; Carotenoids; Fatty acid composition*

RESUMEN: ***Caracterización química del aceite de barú y su subproducto de la región noroeste de Minas Gerais, Brasil.*** En este estudio se investigó el aceite de barú y la harina de barú parcialmente desengrasada de la región noroeste de Minas Gerais, Brasil. La caracterización físico-química del aceite se realizó mediante la determinación del perfil de ácidos grasos mediante cromatografía de gases, luteína y α- y β- carotenos mediante cromatografía líquida de alta resolución y carotenoides totales mediante espectrofotometría. En la harina se analizó su composición química, fibra y contenido mineral. El aceite de barú tiene excelentes parámetros de calidad, un buen contenido de ácidos grasos insaturados y carotenoides. La harina presentó niveles relevantes de proteínas, lípidos y fibra dietética, además de tener un contenido representativo de minerales para la alimentación, como manganeso, magnesio y cobre. Así, el aceite de baru y el subproducto de su extracción tienen riqueza en su composición química y su aplicación puede agregar valor nutricional a los alimentos, además de reducir los impactos ambientales.

PALABRAS CLAVE: *Carotenoides; Cerrado Brasileño; Composición de ácidos grasos; Valorización de residuos agrícolas*

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1. INTRODUCTION

The Brazilian savanna or Cerrado is the second largest biome in Brazil and is considered one of the richest savannas in the world and is recognized for its biodiversity due to its great plant diversity (Oliveira-Alves *et al*., 2020). However, a large number of endemic fruit species remain unexplored despite their high nutritional and economic potential (Schiassi *et al*., 2018). Because of the area's rich biodiversity, it is important to investigate the nutritional composition and technological and commercial potential of exotic fruits in order to contribute to the preservation of native biomes and the diversification of the human diet.

The baru (*Dipteryx alata* Vog.) is an oleaginous which is native to the Cerrado that deserves to be considered. It produces a light brown drupoid fruit that contains an elliptical dark brown edible seed called the baru almond (Bento *et al*., 2014). Studies have reported that baru almonds are rich in high-quality proteins, lipids, unsaturated fatty acids (especially oleic and linoleic acids), dietary fibers, phenolic compounds (e.g., gallic acid, caffeic acid, rutin, vanillin, and catechin), tocopherols, and minerals (such as iron, zinc, and magnesium) (Campidelli *et al*., 2020; Lima *et al*., 2020; Oliveira-Alves *et al*., 2020). Among the constituents present in the baru almond, the oily fraction has quality characteristics and a good balance of fatty acids, especially those of highly unsaturated fatty acids which are required by the food industry (Pineli *et al*., 2015a).

In addition, the extraction of baru oil by mechanical pressing generates processing residues, known as partially defatted bran. This by-product contains a large amount of unsaturated fatty acids, dietary fibers, proteins, and minerals such as iron (Caetano *et al*., 2017). Thus, baru bran has nutritional relevance as human food, and prevents the improper disposal of large amounts of waste into the environment. In addition, it contributes to the preservation of native species and sustainable regional development. Lima *et al*. (2020) developed and evaluated the technological quality and sensory profile of a nutritive bar produced from baru almond by-products, and reported that the product maintained the nutritional characteristics and bioactive compounds. Formulations with 75 and 100% baru almond obtained favorable results in sensorial tests. Caetano *et al*. (2017) prepared oat cookies by replacing 100% soy oil with baru oil and 30% wheat flour with partially defatted baru flour. They reported that the cookies offered high protein and dietary fiber contents, along with substantial concentrations of oleic acid and iron. Therefore, the results from these studies reinforce the possibility of using this residue in human nutrition.

It is worthwhile to consider the applicability of baru bran and oil in food formulations and to study the nutritional potential of these alternative vegetable sources. Prior to this study, there were no studies on these raw materials from the Brazilian Savanna in the northwest of Minas Gerais, which strengthens the originality of this study. This study aimed to investigate the quality, carotenoid content, and fatty acid profile of baru almond oil from the northwest region of Minas Gerais, and to evaluate the chemical composition and nutritional potential of partially defatted baru flour.

2. MATERIALS AND METHODS

2.1. Plant material

The baru (*Dipteryx alata* Vog.) used to carry out the experiments was donated by an agro-industry located in the north of Minas Gerais, Brazil. The samples were obtained during the harvest season (between August and September 2017) from the Brazilian Savanna, in Arinos Town located in the northwest of the Minas Gerais State (coordinates: 15° 55' 01" S and 46° 06' 21" W, and altitude of 927 m). The procedure described below was carried according to the processes used for extraction in communities where the collection and sustainable management of baru are common practices.

The fruits that fall to the ground were collected and only ripe fruits of uniform size and without injuries were selected. In other words, when the baru fruit is at its proper ripening point, the plants are practically leafless; the fruits detach from the trees and fall naturally to the ground. After harvesting, the fruits were dried naturally in the sun for 1–3 days (28 ± 2 °C). The producers had already established the practice of collecting baru for extraction, by observing whether the fruits were properly dry and suitable for the removal of the almond. Otherwise, the fruits were left a little longer in sun to dry, the time for this may vary.

The almonds were then removed with a manual breaker consisting of a handmade guillotine with a blade fitted to a wooden structure. The baru fruit was

placed under this structure and was broken with the aid of the blade to remove the almond. Subsequently, the almonds were packed in low-density polyethylene bags and immediately sent for oil extraction.

2.2. Extraction of oil and obtaining partially defatted baru flour

The oil was extracted and the partially defatted baru flour (PDBF) was obtained at the Cooperativa dos Agricultores Familiares e Agroextrativistas Grande Sertão Ltda, Brazil. The almonds were subjected to a drying process, which was carried out in an industrial machine called grain conditioner (SMR 610, Scott Tech, São Paulo, Brazil), built specifically used to promote the pre-heating of oily matrices to facilitate oil extraction. The samples were kept at 55 °C for 15 min. After that, the baru oil was extracted by cold mechanical pressing using a continuous press type "Expeller" (Scott Tech) with an extraction capacity of 200 mL of oil/min, at the nominal power of 1.5 kW, and electrical voltage of 220 V. Pressing was performed with 5 kg of almonds and the oil extraction yield was calculated based on the total mass of almonds in relation to the mass of oil obtained. The final yield of the process was 22% crude oil. After pressing, the crude oil was submitted to decantation (3 h) and then filtered through filter press (Ecirtec, São Paulo, Brazil). The baru oil was packed in hermetically sealed bottles of 250 mL and stored (7 ± 1 °C) until analysis. The partially defatted baru bran was ground, packed in low-density polyethylene bags and frozen (- 18 ± 1 °C) until use.

2.3. Oil quality

The oil quality parameters were determined according to the Official Methods of the American Oil Chemist's Society (AOCS, 2009): acid value (mg $KOH \cdot g^{-1}$), saponification value (mg $KOH \cdot g^{-1}$), peroxide value (meq $O_2 \cdot kg^{-1}$), iodine value (g $I_2 \cdot 100\, g^{-1}$) and colors (yellow, red and blue).

2.4. Determination of the fatty acid profile in baru almond oil

The analysis of fatty acid methyl esters (FAME) (tetradecanoic, palmitic, heptadecanoic, stearic, arachidic, behenic, lignoceric, palmitoleic, *cis*-10-heptadecenoic, oleic, linoleic, linolenic and eicosenoic acids) was conducted using a gas chromatograph Agilent 68650 with plus detector (quadrupole, electron impact) and autoinjector. Briefly, chromatographic analyses were performed using a column DB-23 Agilent (cyanopropil-methylsiloxane) of 60 m in length, 0.25 mm internal diameter and 0.25 mm film thickness. Identification of the peaks was performed by comparison with the retention time of standards (Supelco 37 component FAME Mix, Sigma-Aldrich) of known concentrations of each and mass spectra (ratio m/z) and compared to the internal database. The fatty acids were quantified by peak areas correlated to the response factors of the detector. These factors were determined for each FAME in the internal standard mix by comparing the unit area of each peak to the unit area of the fatty acid methyl ester peak investigated.

2.5. Determination of the carotenoids and vitamin A content in baru almond oil

Carotenoids were extracted according to the methodology proposed by Rodriguez-Amaya (2001) and the analysis followed the chromatographic condition developed by Pinheiro-Sant'ana *et al*. (1998). The analysis were performed by High Performance Liquid Chromatografy (HPLC), using a Phenomenex Gemini RP-18 chromatography column (250 mm × 4.6 mm, 5 μm i.d.), fitted with a Phenomenex ODS guard column (C18) (4 mm × 3 mm), at room temperature and the injection volume varied from 5 to 100 μL, according to the sample. The mobile phase consisted of methanol:ethyl acetate:acetonitrile (80:10:10, v/v). The mobile phase flow rate was 2.0 mL/min, isocratic, during 12 min. The quantification was performed by comparing peak areas to those obtained from the analytical curve constructed from the injection, in duplicate, of six different concentrations of standard solutions (lutein, α-carotene and β-carotene).

The total carotenoids in the oil samples were determined according to the procedure described by Rodriguez-Amaya (2001). The spectrophotometer used was Thermo Scientific (Evolution 60S, USA) and the absorbance of extracts was measured at 449 nm using n-hexane as blank.

The vitamin A content in baru oil was determined from each precursor carotenoid, considering the conversion rate of 6 μg β-carotene to 1 μg retinol and 12 μg α-carotene to 1 μg retinol, as advised by the Codex Alimentarius (FAO, 1985). The results were expressed in μg Retinol Equivalent – $RE \cdot 100\ g^{-1}$.

2.6. Centesimal composition and total phenolics of the partially defatted baru flour

The centesimal composition of the PDBF was obtained based on the methods recommended by the Association of Official Analytical Chemists (AOAC, 2016). The moisture analysis was performed by drying in an oven at 105 ºC until constant weight. Protein content was determined using the Kjeldahl method with a correction factor of 6.25. The lipids were quantified by direct extraction in a Soxhlet apparatus for 6 h, using petroleum ether as solvent. The ash analysis was done by muffle incineration at 550 °C. Soluble and insoluble dietary fibers were determined according to the gravimetric-enzymatic method using enzymes (α-amylase, protease and amyloglucosidase). Digestible carbohydrates were obtained by difference. The determination of the energy value was performed using the Atwater conversion factors for carbohydrates (4.0 kcal·g^{-1}), proteins (4.0 kcal·g^{-1}) and lipids (9.0 kcal·g^{-1}) (FAO, 1985). Food components and energy values were expressed in % and kcal·g^{-1}, respectively.

Total phenolics were determined by the Folin–Ciocalteau reagent method (Waterhouse, 2002), using gallic acid (0.2–1.4 mg·ml^{-1}) as the standard for the calibration curve. The absorbance was measured at 750 nm with a spectrophotometer, and the results were expressed in mg of gallic acid equivalent (GAE)·100 g^{-1}.

2.7. Mineral characterization of the partially defatted baru flour

The methodology used to quantify the minerals was based on acidic digestion overnight according to Kumari and Platel (2017). For that, 5 mL of nitric acid were added to 0.5 g of each ground sample for pre-digestion overnight. The following day, the samples were heated to 90-120 ºC on a heating plate for complete digestion. The obtained products were filtered with ultrapure water in a volumetric flask and the separated extract was analyzed in an atomic absorption spectrophotometer (Varian AA 240 FS), as well as the standard solutions of each element. The minerals evaluated were Calcium (Ca), Copper (Cu), Iron (Fe), Magnesium (Mg), Manganese (Mn) and Zinc (Zn), and the results were expressed in mg·100 g^{-1} of sample.

2.8. Statistical analysis

The results were expressed as a mean value ± standard deviation (SD) for three measurements (n = 3), and calculated using SISVAR Software, version 5.6 (Lavras, Minas Gerais, Brazil).

3. RESULTS AND DISCUSSION

3.1. Physicochemical characteristics of baru almond oil

The results for the acidity and peroxide index obtained in this study (Table 1) comply with the standards established by Codex Alimentarius (FAO, 2019) for cold-pressed oils, giving values lower than the recommended maximum limits (4.0 mg KOH·g^{-1} for acidity and 15 meq O_2·kg^{-1} for peroxide). According to Siqueira *et al*. (2016), a low acidity index indicates that a high-quality raw material and processing method were used. In addition, the peroxide content expresses the presence of hydroperoxides, the primary oil oxidation products formed during the initial stages of oxidation that are toxic to humans. According to the Codex Alimentarius (FAO, 2019), the saponification values are 168–181, 186–198, and 188–194 mg KOH·g^{-1} for rapeseed, safflower, and sunflower oils, respectively, which have similar degrees of unsaturation to that of baru oil. The iodine index measures the degree of unsaturated fatty acids (Siqueira *et al*., 2016); the value for baru oil in this study (92.50 g·100 g^{-1}) was lower than that of rapeseed (94–120 g·100 g^{-1}), safflower (136–148 g·100 g^{-1}), and sunflower (118–141 g·100 g^{-1}) oils (FAO, 2019).

Table 1. Physicochemical properties of baru almond oil

Analysis	Baru almond oil[a]
Acidity (mg KOH·g^{-1})	0.39 ± 0.42
Saponification value (mg KOH·g^{-1})	187.27 ± 0.64
Peroxide value (meq O2·kg^{-1})	4.78 ± 0.08
Iodine value (g·100 g^{-1})	92.50 ± 0.05
Color yellow	70.6 ± 0.12
Color red	4.4 ± 0.10
Color blue	0.7 ± 0.06

[a]Mean value ± standard deviation (n = 3).

Although physicochemical characteristics vary according to the plant variety and environmental and post-harvest conditions (Soares *et al*., 2021), the iodine, acidity, and peroxide index values for baru oil

were similar to those reported in other studies. Pineli *et al*. (2015a) and Siqueira *et al*. (2016) extracted baru oil by cold pressing and obtained values ranging from 72.90 to 97.68 g $I_2 \cdot 100\ g^{-1}$, 0.28 to 0.44 mg $KOH \cdot g^{-1}$, and 1.61 to 4.33 meq $O_2 \cdot kg^{-1}$, for iodine, acidity, and peroxide indices, respectively. The results obtained in our study demonstrate that baru fit in with the quality standards; this can be mainly attributed to post-harvest conditions.

Crude vegetable oils generally have different colors compared to commercial and refined oils, mainly because of the presence of unremoved pigments like carotenoids (Sulihatimarsyila *et al*., 2020). This is likely because of the carotenoid content in baru oil, as these are the main source of the yellow/red color in oils.

3.2. Fatty acids profile of baru almond oil

Baru almond oil mainly contained monounsaturated fatty acids (MUFA), followed by polyunsaturated fatty acids (PUFA) and a significant amount of saturated fatty acids (SFA), with values of 48.77, 29.09, and 21.84%, respectively (Table 2). The high degree of unsaturation was due to the predominance of oleic (45.83%) and linoleic (28.93%) acids. This result was expected, considering that unsaturated fatty acids are most commonly found in vegetable oils. The considerable PUFA content may cause lipid oxidation due to the presence of double bonds which affect oil stability. However, the presence of tocopherol (vitamin E) in the oil acts as an antioxidant because this molecule donates its phenolic hydrogens to free radicals, thus mitigating the oxidation process in the product (Lemos *et al*., 2016). Palmitic acid was the SFA with the highest concentration (6.37%) in baru oil, followed by stearic acid (5.28%). The values found in this study are in line with the range applied by Codex standards for peanut oil: palmitic acid (5–14%), oleic acid (35–80%), and linoleic acid (4–43.0%) (FAO, 2019).

The levels of most of the fatty acids in this study corroborate with the range reported for baru oil from other regions of the Brazilian savanna: palmitic (5.51–6.40%), stearic (3.59–6.66%), oleic (37.48–49.20%), linoleic (25.59–39.40%), and linolenic (0.15–4.2%) (Pineli *et al*., 2015a; Siqueira *et al*., 2016; Caetano *et al*., 2017). The growing region, soil type, cultural practices, and climatic conditions may affect fatty acid biosynthesis (Kaseke *et al*., 2020), thus explaining these differences.

Among the fatty acids found in baru oil, the percentage of oleic acid (ω-9) was the highest. According to Pereira *et al*. (2018), oils that have monounsaturated fatty acids in the carbon chain have received increasing interest because they help preserve the characteristics of the oil and provide high stability, making them less prone to oxidative reactions. A high consumption of oleic acid decreases the con-

Table 2. Fatty acids profile of baru almond oil

Common and systematic names	Carbon numbers	Chemical formula	Baru almond oil[a] (%)
Tetradecanoic acid	C14:0	$C_{14}H_{28}O_2$	0.04 ± 0.01
Palmitic acid	C16:0	$C_{16}H_{32}O_2$	6.37 ± 0.06
Heptadecanoic acid	C17:0	$C_{17}H_{34}O_2$	0.08 ± 0.01
Stearic acid	C18:0	$C_{18}H_{36}O_2$	5.28 ± 0.04
Arachidic acid	C20:0	$C_{20}H_{40}O_2$	1.38 ± 0.02
Behenic acid	C22:0	$C_{22}H_{44}O_2$	3.90 ± 0.17
Lignoceric acid	C24:0	$C_{24}H_{48}O_2$	4.79 ± 0.19
Palmitoleic acid	C16:1	$C_{16}H_{30}O_2$	0.04 ± 0.01
Cis-10-heptadecenoic acid	C17:1	$C_{17}H_{32}O_2$	0.21 ± 0.14
Oleic acid	C18:1	$C_{18}H_{34}O_2$	45.83 ± 0.36
Linoleic acid	C18:2	$C_{18}H_{32}O_2$	28.93 ± 0.12
Linolenic acid	C18:3	$C_{18}H_{30}O_2$	0.16 ± 0.01
Eicosenoic acid	C20:1	$C_{20}H_{38}O_2$	2.69 ± 0.02
Unidentified acids			0.37 ± 0.03
Total saturated fatty acids			21.84
Total monounsaturated fatty acids			48.77
Total polyunsaturated fatty acids			29.09

[a]Mean value ± standard deviation (n = 3).

centrations of plasma triglycerides and low-density lipoprotein cholesterol (LDL-c) and is a protective factor against the development of cardiovascular diseases (Marcelino *et al*., 2019).

Linoleic acid is considered to be essential since it cannot be synthesized by the human body. In this study, the percentage of linoleic acid was significantly higher than that recommended by the Food and Agriculture Organization (FAO). This, in association with presence of fibers and bioactive compounds, may contribute to reducing the risk of cardiovascular disease (Bento *et al*., 2014). The essential fatty acids, linoleic (ω-6) and linolenic (ω-3) acids, affect various physiological processes and act in the prevention and treatment of cardiovascular disease, reducing atherosclerotic plaque and thrombosis, and consequently, the risk of stroke (CVA) (Lemos *et al*., 2016). Thus, baru oil can be added to other commercial oils in food preparation to provide health benefits.

3.3. Carotenoids and vitamin A content in baru almond oil

As shown in Table 3, the sum of carotenoid values did not correspond to the total carotenoids. This can be explained by the use of different analytical techniques, e.g., the greater HPLC method sensitivity, and by the possible presence of other carotenoids than lutein, and α- and β-carotenes in baru oil. The total carotenoid content was lower in baru almond oil (15.68 mg·100 g^{-1}) than in virgin palm oil (55.34 mg·100 g^{-1}) but higher than in refined canola oil (0.0084 mg·100 g^{-1}) (Mba *et al*., 2017). Differences in cultivar type, climatic and growing conditions, maturation degree, oil processing, extraction and quantification methods, storage conditions, and other factors might explain these variations in total carotenoid values.

The lutein value (0.91 µg·100 g^{-1}) in this work was higher only in comparison to commercial canola and sunflower oils that exhibit nondetectable levels of lutein (Flakelar *et al*., 2017). However, the lutein content of baru oil was much lower than that of crude canola oil (3160 µg·100 g^{-1}) and commercial olive oil (976 µg·100 g^{-1}) (Flakelar *et al*., 2017). The β-carotene content in baru oil was higher (0.24 mg 100 g^{-1}) than in commercial sunflower (0.14 mg·100 g^{-1}) and canola oils (not detected) (Flakelar *et al*., 2017). However, the β-carotene content was slightly lower compared to crude canola oil (0.41 mg·100 g^{-1}) and commercial olive oil (0.31 mg·100 g^{-1}) (Flakelar *et al*., 2017). The α-carotene content of 1.05 mg·100 g^{-1} was observed in the present study. This fraction was not detected in the research conducted by Soares *et al*. (2021) in the oil extracted from buriti, which is another fruit commonly found in the Cerrado.

The quantification of carotenoids is necessary because these compounds have antioxidant properties, and provide photoprotection and provitamin A activity (Resende and Franca, 2019). Furthermore, studies suggest an essential role of dietary intake and nutritional supplementation of carotenoids in the protection against eye diseases including macular degeneration (Arunkumar *et al*., 2020). Campidelli *et al*. (2020) reported high levels of antioxidants (measured by the β-carotene/linoleic acid system) in baru almonds; this is an important result for the attenuation of oxidative reactions. The vitamin A content found in the baru oil of the present study was 127.5 µg RE·100 g^{-1}. According to the Codex Alimentarius (FAO, 1985) this value supplies approximately 16% of the Reference Daily Intake (RDI) for individuals older than 36 months. It is important to highlight that this content may be higher, considering that baru oil may contain other provitamin-A carotenoids that were not quantified in this study. Added to food, baru oil can increase vitamin A intake in the diet.

Table 3. Carotenoid and vitamin A content in baru almond oil

Analytical Determinations	Baru almond oil[a]
Total carotenoids (mg·100g^{-1})	15.68 ± 6.78
Lutein (µg·100g^{-1})	0.91 ± 0.81
α-carotene (mg·100g^{-1})	1.05 ± 0.35
β-carotene (mg·100g^{-1})	0.24 ± 0.01
Vitamin A (µg RE·100g^{-1})	127.5 ± 0.41

[a]Mean value ± standard deviation (n = 3). Data are represented in fresh weight.

3.4. Centesimal composition and total phenolics of the partially defatted baru flour

As seen in Table 4, the moisture content in PDBF (5.10%) is close to that found (6.53%) by Caetano *et al*. (2017) in baru bran from Goiás State, an area in the Cerrado. This variation is probably associated with the differences in the processes used to obtain flour. The dehydration process applied to baru almonds to remove excess free water can increase flour preservation by disfavoring microbial growth. The ash content (4.12%) was higher than that of

Table 4. Centesimal composition and total phenolics of partially defatted baru flour (PDBF)

Component	PDBF[a]
Moisture (%)	5.10 ± 0.10
Ash (%)	4.12 ± 0.04
Lipids (%)	25.12 ± 0.50
Proteins (%)	34.42 ± 0.68
Total dietary fiber (%)	18.31 ± 5.09
Soluble dietary fiber (%)	4.07 ± 0.05
Insoluble dietary fiber (%)	14.24 ± 0.08
Digestible carbohydrates (%)	12.93
Energy value (kcal·100g^{-1})	415.49
Total phenolics (mg GAE·100 g^{-1})	28.09 ± 5.61

[a]Mean value ± standard deviation (n = 3).
Except for moisture, data are expressed on a dry basis.

nuts such as Brazil nuts (3.4%), cashew nuts (2.6%), roasted, salted almonds (1.5%), and walnuts (2.1%) (NEPA, 2011). The ash percentage reflects the total amount of minerals present in the PDBF. The details of the most important minerals in this fraction are discussed below.

The percentage of lipids determined in this study (25.12%) was higher than the value (12.59%) reported by Siqueira *et al*. (2015) but lower than the value (56.12%) reported by Caetano *et al*. (2017) for baru bran obtained from Goiás. Although baru almonds were subjected to oil extraction, the lipid content in PDBF was not low because mechanical pressing was unable to remove all the oily content from this product. The mechanical pressing, considered a "clean technology," is an interesting alternative because it does not use toxic chemicals and does not alter the structure of the extracted oil. The lipid content found in this study can be interesting from a nutritional point of view because according to the Food and Drug Administration (FDA, 2020), 100 g of PDBF can supply 32.2% of RDI for adults and children aged 4 years and older, and for pregnant and lactating women. However, high-fat levels can favor hydrolytic and oxidative rancidity that can cause sensory changes in flour. Owing to its large amount of lipids, PDBF can become more susceptible to rancidification if improperly stored. Therefore, efficient conservation techniques must be implemented.

The protein content in PDBF (34.42%) detected in this study was higher than the value (22.96%) verified by Campidelli *et al*. (2020) in baru almond obtained from Mato Grosso, another region of the Cerrado. Moreover, the results of the present study indicate much higher protein levels than those found for other fruit by-products of the Cerrado such as pequi peel (5.30%) (Bemfeito *et al*., 2020). In addition, the flour obtained in this study showed a higher protein content than other commercial flour such as wheat (9.8%), corn (7.2%), and rye (12.5%) (NEPA, 2011). It should also be noted that the protein content in 100 g of PDBF supplies 68.84% of RDI (FDA, 2020). Thus, PDBF has great potential in food preparation as a partial replacement for cereal flour because of its high protein content.

The total dietary fiber value (18.31%) present in PDBF in this study was close to that (16.12%) reported by Siqueira *et al*. (2015) in baru bran but significantly lower than those found for other fruit residues such as banana (40.94%), mango (39.25%), and watermelon (46.20%) peels (Garcia-Amezquita *et al*., 2018). However, PDBF showed a higher fiber content than cashew nuts (3.7%) and Brazil nuts (7.9%) (NEPA, 2011). The dietary fiber content in 100 g of PDBF supplies 65.39% RDI (FDA, 2020), more than half of the recommended daily value. The percentage of soluble fiber (4.07%) was higher in PDBF than in fruit by-products such as orange (3.74%), tamarind (3.86%), and watermelon (3.17%) (Garcia-Amezquita *et al*., 2018). The value for insoluble fibers (14.24%) obtained in this study was higher than that observed in pumpkin pulp flour (11.25%) (Bemfeito *et al*., 2020). Thus, the dietary fiber content indicates that PDBF is a good source of fiber. It is important to mention that these components are associated with many benefits to human health including reduced risk of coronary heart diseases, type 2 diabetes, and cancer (Resende and Franca, 2019), reduction in glycemic response, and improvements in intestinal functions, among others.

As shown in Table 4, PDBF had a digestible carbohydrate content (12.93%) higher than the value (11.59%) reported by Caetano *et al*. (2017) for baru bran. This variation in the carbohydrate profile is probably due to the different origins of the raw material and its maturation degree (Caetano *et al*., 2017). Being a flour with a high lipid, protein, and carbohydrate contents, it also has a high energy value (415.49 kcal·100 g^{-1}). This value is higher than those found by Santiago *et al*. (2018) for baru peel (240 kcal·100 g^{-1}) and pulp (276 kcal·100 g^{-1}). Notably, 100 g of PDBF supplies approximately 21% of RDI (FDA, 2020). Thus, when marketed at a low

cost, PDBF can be part of fiber-rich products, making a positive impact on the human diet.

For phenolic compounds, PDBF showed low levels in this study (Table 4) compared to those reported by Siqueira *et al*. (2015), with a value of 588.11 mg GAE·100 g^{-1}. However, the value found in the present work is close to the range (11.52–44.53 mg GAE·100 g^{-1}) reported by Cangussu *et al*. (2021) for pequi peel flours. The low phenolic compound content can be attributed to the fact that many phenolics are found in the exocarp of the fruit as a defense mechanism of plants against aggressors such as bacteria and insects (Cangussu *et al*., 2021). Although PDBF contains a small number of phenolics, the content is interesting to increase these bioactive compounds when associated with other flours. According to Oliveira-Alves *et al*. (2020), baru is an important source of these compounds, especially gallic acid and its derivatives (such as gallic acid esters and gallotannins), which are responsible for the high antioxidant activity. These authors also reported that the baru nut has the potential to inhibit colorectal cancer cell proliferation. Thus, PDBF, when used as an ingredient, can provide health benefits.

3.5. Mineral profile in partially defatted baru flour

Table 5 shows the mineral content of PDBF together with the recommended daily intake (RDI) for each mineral. Except for calcium, all the minerals evaluated in this study are present in amounts which meet the nutritional needs of an adult person. In addition, PDBF can be considered to contain high levels of Cu, Fe, Mg, and Mn, because its values supply at least 30% of the nutrient reference values (NRVs) (FAO, 1997). Pineli *et al*. (2015b) found much higher values in baru bran for calcium (200.91 mg·100 g^{-1}), copper (2.04 mg·100 g^{-1}), iron (13.29 mg·100 g^{-1}), and zinc (7.62 mg·100 g^{-1}) than reported in the present study. In contrast, PDBF showed higher levels of minerals than those reported by Schiassi *et al*. (2018) when investigating fruits from the Brazilian Savanna such as araça (42.29 mg Ca·100 g^{-1}, 0.18 mg Fe·100 g^{-1}, and 15.28 mg Mg 100 g^{-1}), cagaita (22.50 mg Ca·100 g^{-1}, 0.33 mg Fe·100 g^{-1}, and 5.79 mg Mg·100 g^{-1}), and mangaba (31.01 mg Ca·100 g^{-1}, 0.50 mg Fe·100 g^{-1}, and 12.80 mg Mg·100 g^{-1}). Moreover, as shown in the Brazilian Table of Food Composition (NEPA, 2011), wheat flour has amounts of Mn, Mg, Fe, and Ca at approximately thirty-, six-, five-, and three-fold less than the PDBF, respectively. The comparison of these results suggests that the by-product from the extraction of baru almond oil has relevant mineral content and has great potential to fortify food formulations and prevent micronutrient deficiency.

Table 5. Mineral composition of partially defatted baru flour (PDBF) and the Reference Daily Intake (RDI) contribution per 100 g of PDBF

Mineral	PDBF[a] (mg·100g^{-1})	RDI[b] % in 100 g (PDBF)
Manganese (Mn)	14.00 ± 0.44	608.70
Copper (Cu)	1.54 ± 0.05	171.11
Magnesium (Mg)	194.20 ± 8.66	46.24
Iron (Fe)	5.50 ± 1.16	30.60
Calcium (Ca)	47.20 ± 9.22	3.63
Zinc (Zn)	2.75 ± 0.07	25

[a]Mean value ± standard deviation (n = 3).
Data are represented in fresh weight. [b]FDA (2020).

The intake of minerals is crucial to a healthy diet because they are a part of well-functioning biological mechanisms (Weyh *et al*., 2022). For example, iron is essential for transporting oxygen to the tissues from the lungs by red blood cell hemoglobin (Gupta and Gupta, 2014). Magnesium is involved in energy metabolism, protein synthesis, RNA, and DNA synthesis (Weyh *et al*., 2022). Calcium is associated with bone maintenance, helping to prevent osteoporosis in women, and zinc acts as a cofactor of several enzymes (Gupta and Gupta, 2014; Weyh *et al*., 2022).

4. CONCLUSIONS

Baru oil from the northwest region of Minas Gerais offers quality that meets the required standards because it has a high content in unsaturated fatty acids (mainly oleic acid), and total carotenoids, confirming the possibility of using it as a partial replacement for other oils. Partially defatted baru flour has high levels of proteins, lipids, and dietary fiber, in addition to the mineral contents, especially manganese, magnesium, and copper. Therefore, the addition of this flour to food formulations may produce nutritionally valuable products. Thus, baru may be used as an alternative source of oil together with offering an advantage of an agro-industrial by-product such as baru bran that can be transformed into flour. These products may be beneficial to human health, the environment, and the food industry.

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6. REFERENCES

AOAC. 2016. *Official Methods of Analysis of AOAC International*. Rockville, 20th ed. MD: AOAC International.

AOCS. 2009. *Official methods and recommended practices of the American Oil Chemists' Society.* 6th ed., Urbana, IL: USA.

Arunkumar R, Gorusupudi A, Bernstein PS. 2020. The macular carotenoids: A biochemical overview. *BBA-Mol. Cell Biol. L.* **1865**, 158617. https://doi.org/10.1016/j.bbalip.2020.158617

Bemfeito CM, Carneiro JDS, Carvalho EEN, Coli PC, Pereira RC, Vilas Boas EVB. 2020. Nutritional and functional potential of pumpkin (*Cucurbita moschata*) pulp and pequi (*Caryocar brasiliense* Camb.) peel flours. *J. Food Sci. Technol*. **57**, 3920–3925. https://doi.org/10.1007/s13197-020-04590-4

Bento APN, Cominetti C, Simões Filho A, Naves MMV. 2014. Baru almond improves lipid profile in mildly hypercholesterolemic subjects: A randomized, controlled, crossover study. *Nutr Metab Cardiovasc Dis*. **24**, 1330–1336. https://10.1016/j.numecd.2014.07.002

Caetano KA, Ceotto JM, Ribeiro APB, Morais FPR, Ferrari RA, Pacheco MTB, Capitani CD. 2017. Effect of baru (*Dipteryx alata* Vog.) addition on the composition and nutritional quality of cookies. *Food Sci. Technol.* **37**, 239–245. https://doi.org/10.1590/1678-457x.19616

Campidelli MLL, Carneiro JDS, Souza EC, Magalhães ML, Nunes EEC, Faria BP, Franco M, Vilas Boas EVB. 2020. Effects of the drying process on the fatty acid content, phenolic profile, tocopherols and antioxidant activity of baru almonds (*Dipteryx alata* Vog.). *Grasas Aceites* **71,** e343. https://doi.org/10.3989/gya.1170182

Cangussu LB, Leão DP, Oliveira LS, Franca AS. 2021. Profile of bioactive compounds in pequi (*Caryocar brasiliense Camb*.) peel flours. *Food Chem*. **350**, 129221. https://doi.org/10.1016/j.foodchem.2021.129221

FAO. 1985. *Guidelines on Nutrition Labelling*. Food and Agriculture Organization of the United Nations. Codex Alimentarius (CAC/GL 2-1985).

FAO. 1997. *Guidelines for Use of Nutrition and Health Claims*. Food and Agriculture Organization of the United Nations. Codex Alimentarius (CAC/GL 23-1997).

FAO. 2019. *Codex standard for named vegetable oils*. World Health Organization, Food and Agriculture Organization of the United Nations, Rome: Italy. Codex Stan 210-1999 (Revised in 2001, 2003, 2009, 2017 and 2019).

FDA. 2020. *Nutrition labeling of food*. Food and Drug Administration. Code of Federal Regulations. Title 21, volume 2 (Section 101.9).

Flakelar CL, Prenzler PD, Luckett DJ, Howitt JA, Doran G. 2017. A rapid method for the simultaneous quantification of the major tocopherols, carotenoids, free and esterified sterols in canola (*Brassica napus*) oil using normal phase liquid chromatography. *Food Chem*. **214**, 147–155. https://dx.doi.org/10.1016/j.foodchem.2016.07.059

Garcia-Amezquita LE, Tejada-Ortigoza V, Heredia-Olea E, Serna-Saldívar SO, Welti-Chanes J. 2018. Differences in the dietary fiber content of fruits and their by-products quantified by conventional and integrated AOAC official methodologies. *J. Food Compos. Anal*. **67**, 77–85. https://doi.org/10.1016/j.jfca.2018.01.004

Gupta UC, Gupta SC. 2014. Sources and deficiency diseases of mineral nutrients in human health and nutrition: a review. *Pedosphere* **24**, 13–38. https://doi.org/10.1016/S1002-0160(13)60077-6

Kaseke T, Opara UL, Fawole OA. 2020. Fatty acid composition, bioactive phytochemicals, antioxidant properties and oxidative stability of edible fruit seed oil: effect of preharvest and processing factors. *Heliyon* **6**, e04962. https://doi:10.1016/j.heliyon.2020.e04962

Kumari M, Platel K. 2017. Effect of sulfur-containing spices on the bioaccessibility of trace minerals from selected cereals and pulses. *J. Sci. Food Agric*. **97**, 2842–2848. https://doi:10.1002/jsfa.8113.

Lemos MRB, Zambiazi RC, Almeida EMS, Alencar ER. 2016. Tocopherols and fatty acid pro-

file in baru nuts (*Dipteryx alata* Vog.), raw and roasted: important sources in nature that can prevent diseases. *Food Sci. Nutr. Technol*. **1**, 000107. https://doi.org/10.23880/fsnt-16000107

Lima DS, Egea MB, Cabassa ICC, Almeida AB, Sousa TL, Lima TM, Loss RA, Volp ACP, Vasconcelos LG, Dall'Oglio EL, Hernandes T, Takeuchi KP. 2020. Technological quality and sensory acceptability of nutritive bars produced with Bazil nut and baru almond coproducts. *LWT-Food Sci. Technol.* 110467. https://doi.org/10.1016/j.lwt.2020.110467

Marcelino G, Hiane PA, Freitas KC, Santana LF, Pott A, Donadon JR, Guimarães RCA. 2019. Effects of olive oil and its minor components on cardiovascular diseases, inflammation, and gut microbiota. *Nutrients* **11**, 1826. https://doi.org/10.3390/nu11081826

Mba OI, Dumont MJ, Ngadi M. 2017. Thermostability and degradation kinetics of tocochromanols and carotenoids in palm oil, canola oil and their blends during deep-fat frying. *LWT--Food Sci. Technol.* **82**, 131–138. https://doi.org/10.1016/j.lwt.2017.04.027

NEPA. 2011. *Tabela Brasileira de Composição de Alimentos (TACO)*. 4th ed. Campinas, SP: NEPA – UNICAMP.

Oliveira-Alves SC, Pereira RS, Pereira AB, Ferreira A, Mecha E, Silva AB, Serra AT, Bronze MR. 2020. Identification of functional compounds in baru (*Dipteryx alata* Vog.) nuts: nutritional value, volatile and phenolic composition, antioxidant activity and antiproliferative effect. *Food Res. Int*. **131**, 109026. https://doi.org/10.1016/j.foodres.2020.109026

Pereira GS, Freitas PM, Basso SL, Araújo PM, Santos RR, Araújo PM, Conde CF, Pereira EFD, Haverroth M, Amaral AMF. 2018. Quality control of the buriti oil (*Mauritia flexuosa* L. f.) for use in 3-phase oil formulation for skin hydration. *Int. J. Phytocosmet. Nat. Ingred*. **5**, 1–5. https://doi.org/10.15171/ijpni.2018.01

Pineli L, Oliveira G, Mendonça M, Borgo L, Freire E, Celestino S, Chiarello M, Botelho R. 2015a. Tracing chemical and sensory characteristics of baru oil during storage under nitrogen. *LWT-Food Sci. Technol.* **62**, 976–982. http://dx.doi.org/10.1016/j.lwt.2015.02.015

Pineli LLO, Carvalho MV, Aguiar LA, Oliveira GT, Celestino SMC, Botelho RBA, Chiarello MD. 2015b. Use of baru (Brazilian almond) waste from physical extraction of oil to produce flour and cookies. *LWT-Food Sci. Technol*. **60**, 50–55. https://doi.org/10.1016/j.lwt.2014.09.035

Pinheiro-Sant'ana HM, Stringheta PC, Brandão SCC, Páez HH, Queiróz VMV. 1998. Evaluation of total carotenoids, alpha- and beta-carotene in carrots (*Daucuscarota* L.) during home processing. *Food Sci. Technol.* **18**, 39–44. http://dx.doi.org/10.1590/S0101-20611998000100009

Resende LM, Franca AS. 2019. Flours Based on Exotic Fruits and Their Processing Residues – Features and Potential Applications to Health and Disease Prevention, 2nd ed. *Flour and Breads and their Fortification in Health and Disease Prevention*. Academic Press, 387–401. https://doi.org/10.1016/B978-0-12-814639-2.00030-7

Rodriguez-Amaya DB. 2001. *A guide to carotenoid analysis in foods*. International Life Sciences Institute.

Santiago GL, Oliveira IG, Horst MA, Naves MMV, Silva MR. 2018. Peel and pulp of baru (*Dipteryx Alata Vog.*) provide high fiber, phenolic content and antioxidant capacity. *Food Sci. Technol.* **38**, 244–249. https://doi.org/10.1590/1678-457X.36416

Schiassi MCEV, Souza VR, Lago AMT, Campos LG, Queiroz F. 2018. Fruits from the Brazilian Cerrado region: Physico-chemical characterization, bioactive compounds, antioxidant activities, and sensory evaluation. *Food Chem*. **245**, 305–311. http://dx.doi.org/10.1016/j.foodchem.2017.10.104

Siqueira APS, Castro CFS, Silveira EV, Lourenço MFC. 2016. Chemical quality of Baru almond (*Dipteryx alata* oil). *Cienc. Rural* **46**, 1865–1867. https://doi.org/10.1590/0103-8478cr20150468

Siqueira APS, Pacheco MTB, Naves MMV. 2015. Nutritional quality and bioactive compounds of partially defatted baru almond flour. *Food Sci. Technol.* **35**, 127–132. https://doi.org/10.1590/1678-457X.6532

Soares JF, Borges LA, Brandi IV, Santos SHS, Lima JP. 2021. Characterization of buriti oil produced in northern region of Minas Gerais: quality parameters, fatty acid profile and carotenoids con-

tent. *Res. Soc. Dev*. **10**, e58010313734. https://doi.org/10.33448/rsd-v10i3.13734

Sulihatimarsyila AWN, Lau HLN, Nabilah KM, Azreena IN. 2020. Production of refined red palm-pressed fibre oil from physical refining pilot plant. *CSCEE* **2**, 100035. https://doi.org/10.1016/j.cscee.2020.100035

Waterhouse, AL. 2002. Determination of total phenolics. *Curr. Protoc. Food Anal. Chem*. **6**, I1.1.1–I1.1.8. https://doi.org/10.1002/0471142913.fai0101s06

Weyh C, Krüger K, Peeling P, Castell L. 2022. The Role of Minerals in the Optimal Functioning of the Immune System. *Nutrients* **14**, 644. https://doi.org/10.3390/nu14030644