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The potential of baru (*Dipteryx alata* Vog.) and its fractions for the alternative protein market

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The baru is a native fruit of the Brazilian Cerrado and its processing generates by-products that are normally undervalued and are not included in human food. Among the by-products of baru almond processing–the economically valued part for human consumption–are the broken almond, the partially defatted baru almond cake (DBC) and the pulp [composed of epicarp (peel) plus mesocarp]. Thus, this mini-review presents the potential use of baru (*Dipteryx alata* Vog.) and its fractions for the alternative protein market. Baru almond and its fractions (DBC and compounds obtained by different extraction methods) stand out for their high protein content (23–30g/100g) and, in particular, the by-products can be used as raw material for extraction, separation, hydrolysis, isolation, and concentration of the protein molecules to produce plant-based ingredients. Although it has great potential, including sensory, nutritional, and techno-functional properties, these by-products are still few studied for this purpose.

KEYWORDS

plant-based ingredient, baru pulp, baru defatted meal, baru by-products, meat analogs

1. Introduction

Proteins are important components for health, influencing the growth, development, and prevention of various disorders, such as anemia, physical weakness, edema, vascular dysfunction, and impaired immunity, in addition to contributing positively to the increase in lean body mass, increased muscle strength, improve bone density, among other benefits (Wu, 2016; Hertzler et al., 2020).

In food development, in addition to the nutritional role, proteins play important technological properties, contributing to texture, color, flavor, emulsifying, gelling, and water and oil absorption properties in formulation matrices. In addition, proteins act as agents to reduce syneresis and loss of solids during the storage and preparation of some products (Lemes et al., 2016a; Loveday, 2019), which increases the demand in different sectors.

Currently, great emphasis has been given to the offer of proteins and plant-based products for vegans and vegetarians. The profile of the vegan and vegetarian public is focused on the consumption and use of plant-based products (Aleixo et al., 2020). While vegetarians refrain from consuming meat, vegans–often considered to be a group among vegetarians–have a total restriction of products of animal origin in all their needs since this label is more than just a set of dietary preferences (Rosenfeld, 2019; Nezlek and Forestell, 2020). The factors that motivate adherence to this lifestyle can include health, nutrition, environmental impact, and ethics (Bryant, 2019).

Traditionally, plant-based ingredients and products for this target group are produced from cereals, leguminous plants, nuts, seeds, pseudocereals, and mushrooms, which present different sensory characteristics, stability, and nutritional composition, and can be used for the production of various food products, including vegetable milk and meat substitutes, for example (Silva et al., 2020, 2022; Franca et al., 2022).

Additionally, it is necessary to offer proteins to a population that does not stop growing in an increasingly complex scenario (Wu, 2016; Van Dijk et al., 2021), highlighting proteins from alternative sources due to their numerous advantages. Alternative proteins are new protein sources, including plant-based and microorganism technology created as alternatives to conventional ones (animal origin) and that can be applied in the development of the most diverse foods and beverages. This type of protein requires fewer inputs, such as land and water, and generates low negative effects, such as greenhouse gas emissions and pollution (Hertzler et al., 2020; GFI, 2022). In addition, alternative proteins can be obtained and/or produced from various sources, including vegetables (for example, grains, legumes, and nuts), microbial fermentation (fungi and bacteria) (GFI, 2022), and also by extraction from agro-industrial by-products (Lemes et al., 2022).

Plants are considered a suitable system for the bioproduction of proteins (Langyan et al., 2022) and stand out for not containing some of the less-healthy compounds found in meat, including saturated fat and cholesterol (Craig et al., 2021); provide high levels of protein without the high-fat content (Ahnen et al., 2019); improve the environmental sustainability of food production; and also, the ethical issues regarding the treatment of animals (Hertzler et al., 2020).

Obtaining proteins from plants by-products has gained great prominence due to environmental issues and circular economic (Sharma et al., 2022). In this context, it is important to highlight the large amount of by-products generated during baru processing. The baru (*Dipteryx alata* Vog.) is a fruit species that stands out among the native flora of the Brazilian Cerrado, and its almond is considered the edible part due to its nutritional composition (Takemoto et al., 2001; Alves-Santos et al., 2021).

The global baru almond market was estimated at US$5.1 million in 2022 and could reach up to US$47 million in 2032, due to the compound annual growth rate of ~25% until 2032 driven by the worldwide demand for the almond and the growing number of people looking for more and more healthy products (Fact.MR, 2022). Brazil has more than half of the baru almond cultivation in the world and alone produced about 117 tons of the almond, with the states of Goiás and Mato Grosso do Sul as the largest producers (IBGE, 2020).

Due to its composition–which includes the presence of proteins, minerals, amino acids, fatty acids, phenolic compounds, and others–baru almond and its fractions (oil, partially defatted baru almond cake–DBC, and compounds obtained by different extraction methods) have been the subject of several studies to assess the existence of possible beneficial effects of baru on health (Lima et al., 2022).The beneficial effects of baru almond consumption includes its potential effect to improve metabolic diseases (Souza et al., 2018), serum lipid parameters (Bento et al., 2014), oxidative stress (Souza et al., 2019), colorectal cancer (Oliveira-Alves et al., 2020), microbial infections (Ribeiro et al., 2014), chronic kidney disease (Schincaglia et al., 2020, 2021), and even snake envenomation (Ferraz et al., 2012) as reviewed by Campos et al. (2023). Baru almond, its extracts and/or bioactive compounds, have demonstrated no or low cytotoxicity or genocity (Esteves-Pedro et al., 2012; Ribeiro et al., 2014) and can be used to improve general well-being and bringing benefits to communicable and non-communicable diseases (Egea and Takeuchi, 2020; Lima et al., 2022).

From the processing of the fruits, the almond is obtained, which has a high commercial value (up to US$ 27.00/kg) (CONAB, 2021), in addition to large amounts of peel and pulp, since the almond corresponds to only 5% of the fruit weight (Alves et al., 2010), with an estimated generation of 2,200 tons of by-products annually. Due to the baru composition, especially the high protein content (23–30 g/100 g), high levels of these residual components are found in the by-products, including the DBC, broken almond, among others, which make them an excellent alternative for the production of ingredients destined for the elaboration of plant-based products due to their nutritional and technological properties (Gautério et al., 2022).

Thus, this mini-review presents the potential use of baru almond (*Dipteryx alata* Vog.) and its fractions (DBC, pulp, and others compounds obtained by different extraction methods) for the alternative protein market.

2. Baru almond processing and generation of by-products

In the process of obtaining the baru almond, different stages are adopted during its processing and, consequently, the generation of several by-products occurs depending on the level of transformation and the technology used, which can be used to obtain components and in the transformation into ingredients, with subsequent application in plant-based foods and beverages (Figure 1).

After collecting the baru ripe fruits–when they fall to the ground or have loose seeds inside (Sano, 2016), they are transported to the processing unit, selected (Pinho et al., 2015), cleaned, sanitized with a solution of sodium hypochlorite (Sano, 2016), and dried in the sun, oven, wind tunnel (fans), etc. for further processing (Rocha, 2012; Pinho et al., 2015).

Optionally, the fruit hydration stage can be carried out, from submersion in hot water (96°C/20 min) (Pinho et al., 2015) and agitation, in order to facilitate the separation of the endocarp, mesocarp, and epicarp of the baru almond. However, this procedure can entail costs for the process, since there is the use of a large amount of water and electricity, in addition to the need for a greater number of operators. The pulping step has the advantage of reducing the breaking resistance of the endocarp, facilitating the extraction of the almond and is quite feasible when the fruit pulp is also used for other purposes. Because it is a process that is still not standardized and mostly carried out manually, many industries still carry out the separation through the use of knives or guillotines (Sano, 2016), but other options are verified including the use of hammers, sickles, vise, presses, electrical equipment, and other adapted methods (Rocha, 2012).

With pulping, the generation of a solid by-product is verified, consisting of epicarp, endocarp, and mesocarp (Figures 1A–C), in addition to broken almonds. The whole almond, intended for human consumption, are submitted to the roasting process (90–145°C for variable times depending on the heat source used) to reduce the antinutritional factors (Rocha, 2012), chilled to room temperature, packed in polyethylene bags (Pineli et al., 2015), the packages are

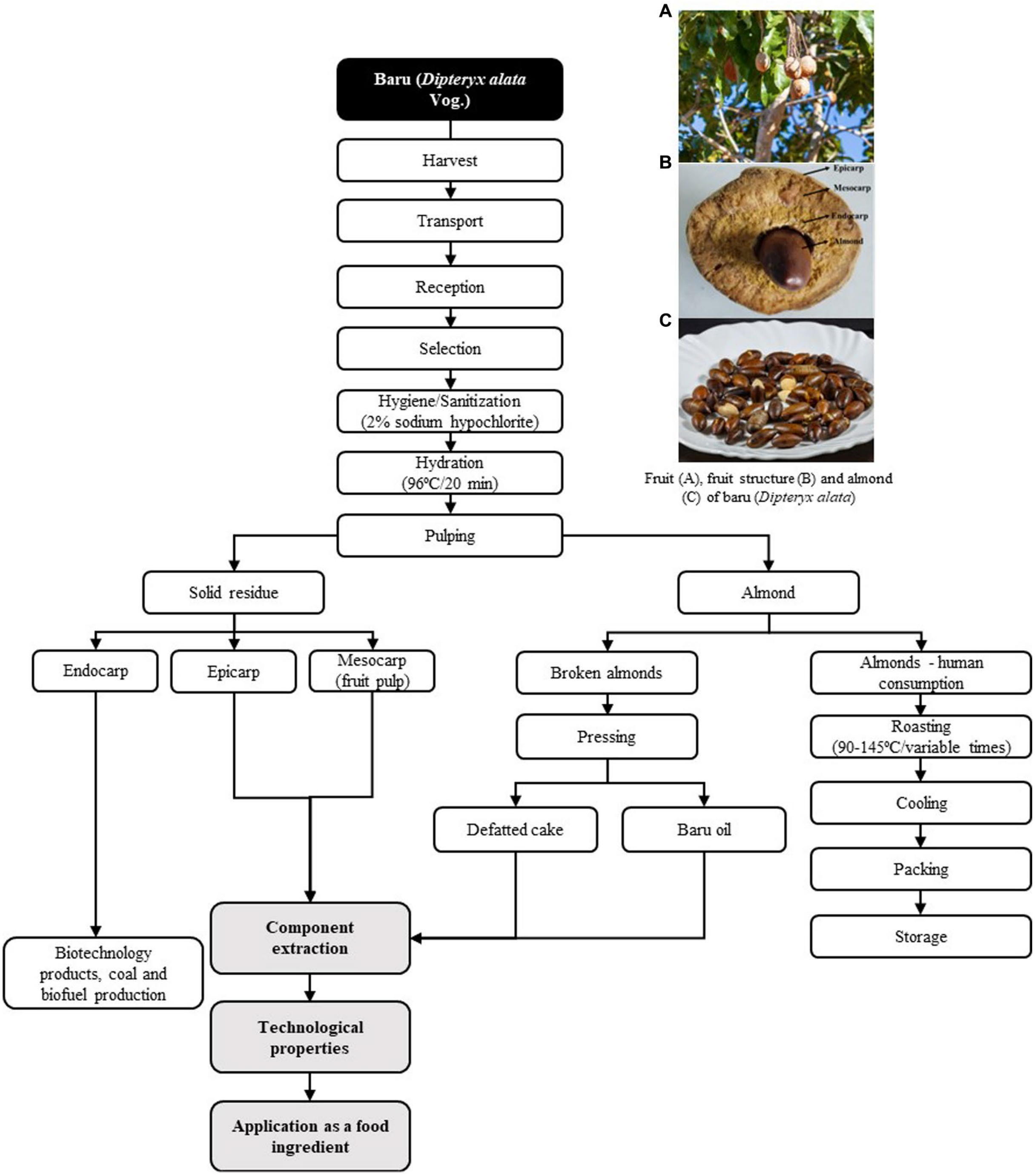

FIGURE 1
Baru almond production flowchart, generation of by-products and technological applications in plant-based food. **A** - baru fruit still on the trees, **B** - baru fruit and its parts being epicarp, mesocarp, endocarp and almond; and **C** - baru almond.

labeled, and stocked in a dry, airy environment, free of pests and rodents, as well as in the absence of light to avoid oxidative processes, a since it has high concentrations of polyunsaturated fatty acids (Mendes et al., 2013; Sano, 2016).

Almonds that present inadequacies or have been broken can be used in the production of crushed almond (flour) or oil (Rocha, 2012). For the extraction of baru oil, a cold pressing system is used, conventional processes using organic solvents, or using compressed solvents technology (Fetzer et al., 2018), among other processes, obtaining two fractions, baru oil, and partially defatted baru almond cake (Aracava et al., 2022), which can be used for extracting proteinaceous material.

All generated baru by-products–except for the endocarp which is used in the production of biotechnological products a such as biocoal and biofuels–are suitable for transformation into food ingredients or starting raw materials to obtain ingredients that can be used in plant-based products. The broken almonds and baru almond cake are the main sources of proteins and dietary fiber (baru pulp has high fiber content but lower protein content), as shown in item "3. Chemical characterization of baru almond and its fractions." In addition, they can also be used to obtain oil. The application can be carried out simply using appropriate treatments to obtain individual components and/or mixtures of components, which will be added in the new food product, provided they have the necessary properties for sensory, nutritional, functional, and technological purposes (Gautério et al., 2022).

3. Chemical characterization of baru almond and its fractions

The baru almond and its fractions present a diversity of components in their matrix and that can be conveniently explored. Although proteins are highlighted here and play an important role in the development of products, the applied process often results in proteins with different levels of purity, with the presence of other components being verified in smaller proportions. Among the components, the presence of minerals, carbohydrates, and bioactive compounds are verified, which can be isolated in additional processes or used as part of the protein ingredient, contributing to technological, nutritional, functional aspects and, consequently, influencing health (Santiago et al., 2018; Almeida et al., 2019; Egea and Takeuchi, 2020). In this topic we highlight the two main sources of baru proteins–baru almond and partially defatted baru almond cake–but we also present below the fractions with high lipid contents (baru oil with about 80% unsaturated fatty acids) and lower protein contents (baru pulp).

3.1. Baru almond

The baru almond, considered the edible and most economically important part of the baru fruit, has high levels of protein (23–30 g/100 g), dietary fiber (12.5–16.0 g/100 g), (Table 1) carbohydrates (12–37 g/100 g), and mineral (1.5–4.5 g/100 g; Souza et al., 2018; Campidelli et al., 2022), highlighting calcium (82–300 mg/100 g), iron (3.0–6.5 mg/100 g) and zinc (1.04–6.74 mg/100 g), in addition to a considerable amount of potassium (811–1810 mg/100 g) and magnesium (107 to 330 mg/100 g; Alves-Santos et al., 2021). The roasted baru almond has higher concentrations of all components, due to the difference in moisture content verified before and after the roasting process (Takemoto et al., 2001; Santiago et al., 2018).

Human health can be improved by the consumption of these minerals: potassium decreases systolic blood pressure; magnesium decreases problems related to hypertension and helps to prevent diabetes complications; zinc contributes to immune system; absence of iron has been associated with fatigue and with increased risk of cardiovascular/thromboembolic events; and calcium prevents osteoporosis and fractures in adulthood and old age (Guimarães et al., 2018).

In relation to the amino acid profile and protein quality, a good composition of essential (mg amino acid/g protein) of 23.4 His, 37.5 Ile, 77.8 Leu, 48.4 Lys, 22.0 Met+Cys, 77.2 Phe + Tyr, 44.9 Thr, 20.2 Trp, and 51.8 Val, as well as non-essential amino acids was verified (101.6 Asp., 216.8 Glu, 46.1 Ala, 85.6 Arg, 47.2 Gly, 55.3 Pro, and 44.1 Ser; Fernandes et al., 2010). The concentration of amino acids presents in baru almonds meet dietary recommendations and their amino acid score (AAS) can vary from 75 to 105% according to the native area of the fruit (Fernandes et al., 2010; Freitas and Naves, 2010) in contrast to the deficiency of the amino acids such as methionine + cysteine, valine, and lysine observed in several nuts such as peanuts, almonds, and cashew nuts (Freitas and Naves, 2010).

According to the protein digestibility-corrected amino acid score (PDCAAS)–a recommended method to estimate the nutritional quality of protein in foods and diets–baru almonds demonstrated proteins of good biological quality in their composition (Fernandes et al., 2010). The PDCAAS values of baru almonds (73%) are higher than those found in other oilseeds such as Brazil nuts (63%) (Freitas and Naves, 2010) and almonds (44 to 48%) (House et al., 2019). Cruz et al. (2011) reported that the total protein fraction and the globulin fraction presented *in vitro* digestibility values of 85.59 and 90.54%, respectively, in relation to casein.

In addition, baru almond has a high lipid content (40.2–48.6%) featuring 41.4–51.4 g/100 g of oleic acid, which is the most abundant monounsaturated fatty acid in this product such as 24.4–31.7 g/100 g of linoleic acid, 5.9–7.6 g/100 of palmitic acid, 3.12–5.4 g/100 g of stearic acid, among others in smaller quantities (Alves et al., 2016; Lemos et al., 2017; Alves-Santos et al., 2021). Baru almond presents a lipid concentration like cashew nut (44.10 g/100 g) and peanut (44.0 g/100 g), and higher concentrations when compared with other traditional oilseeds such as soybeans (20.0 g/100 g), cottonseed (16.0 g/100 g), and sorghum (4.32 g/100 g; Alves et al., 2016; Mailer, 2016; Prado et al., 2020).

Almonds can contribute by providing phenolic compounds (111.3–568.9 mg/100 g) with gallic acid (66.7–224.0 mg/100 g) being considered the main phenolic compound followed by catechin (13.6–87.2 mg/100 g), ferulic acid (3.6–45.4 mg/100 g), epicatechin (2.1–23.9 mg/100 g), and p-coumaric acid (0.3–14.3 mg/100 g; Lemos et al., 2012); carotenoids (11.40 μg/100 g) being α-carotene (19.5 μg/100 g), β-carotene (20.7 μg/100 g), and lycopene (15.1 μg/100 g; Oliveira-Gonçalves et al., 2020); anthocyanins (0.62–1.24 mg/100 g; Lemos et al., 2012); and tocopherol (~2.4 mg/100 g; Lemos et al., 2017). Phenolic compounds play a multiple functionalities and bioactivities such as antioxidant, antihypertensive, and antimicrobial activities, as well as inhibition of carcinogenesis and also are suggested for applications in food as active agents to control lipid oxidation and microbial growth in foods (Lemes et al., 2022).

In general, non-whole almonds that are not used for fresh consumption can be used in the production of oil or other products and have the same composition as the whole almond (Arruda-Silva et al., 2022). However, the issue of conservation of these broken almonds must be checked since they would be more exposed to oxygen and therefore more sensitive to the occurrence of lipid oxidation (Lima et al., 2021). In addition, another issue related to almonds is the skin that covers them, which in many cases ends up being removed. However, most of the available literature has recommended that the skin be an integral part of the almond because it contributes to the nutritional value of the almond (Silva P. N. et al., 2020).

3.2. Baru oil

The main composition of baru oil is the fatty acids, where (i) monounsaturated fatty acids such as oleic acid (45.7 g/100 g total lipids) and eicosenoic acid (2.7 g/100 g total lipids) were described (Borges et al., 2022; Moreira et al., 2022), and in lower concentrations palmitoleic and cis-10-heptadecenoic acids (0.21 g/100 g total lipids;

TABLE 1 Summarized mean values of protein, fibers, and lipids content: (as previously described in item 3) from the baru almond and baru by-products (DBC and pulp) and the potential applications in the development of food products.

Baru and baru by-products	Protein (g/100g)	Fiber (g/100g)	Lipids (g/100g)	Applications	Potential	Ref.
Almond and broken almond	23–30	12.5–16.0	40.2–48.6	"Paçocas": 25% baru almonds (↑ global acceptance, dietary fiber, and moisture; ↓ energetic density)	Possibility of substituting peanuts in formulations	Santos et al. (2012)
				Ice cream: 2.60% baru almonds (↑lipids, proteins, fibers, and caloric value)	Better nutritional value of added products and promotion of the trade of this Cerrado fruit	Pineli et al. (2015)
				Frozen: 9.8% baru almonds (↑proteins, carbohydrates, lipids, phenolic compounds, tannins, antioxidant activity, and sensory acceptability)	New food matrix to promote health care	Arelhano et al. (2019)
				Cupcakes: 30% baru almond flour (↑higher proteins, dietary fiber, minerals, lipids, and dough development time; ↓water absorption, stability, mixing tolerance index, and resistance to extension in the rheological analyzes)	Possibility of producing cupcakes with good technological, nutritional, and sensory properties	Paglarini et al. (2018)
				Synbiotic fermented beverages: Water-soluble extract of baru almonds (↑ bioactive compounds, anti-diabetic properties, acidity, and fatty acid profile; higher concentration of linoleic acid; and ↓ pH)	Possibility of producing synbiotic fermented beverages	Fernandes et al. (2021)
Defatted baru almond cake (DBC)	17.8–34.4	17.87–34.42	12.59–30.2	Bread: Replacing 100% of partially deffated baru flour (↑fiber, iron, zinc and copper contents, hardness, and adhesiveness; ↓cohesiveness, elasticity, and moisture)	Substitute wheat flour in gluten free cake, improving its nutritional quality	Pineli et al. (2015)
				Cookie: replacing 100% soy oil for baru oil and 30% wheat flour for partially defatted baru flour (↑moisture, protein, dietary fiber, phosphorus and iron, unsaturated fatty acids, and phenolic compound contents; and ↓ calorie content)	Interesting composition from a nutritional point of view and may be used as part of a healthy diet	Caetano et al. (2017)
Pulp	3.2–5.0	5.7–32.9	0.9–4.13	Pasta: Replacing 10 to 20% of wheat flour with baru pulp flour (↑ dietary fiber; ↓carbohydrates content)	Application of the baru pulp in the food industry	Antunes et al. (2021)

↑increased and ↓decreased.

Borges et al., 2022); (ii) polyunsaturated fatty acids such as linoleic (28.93 g/100 g total lipids) and linolenic acids (0.16 g/100 g total lipids); and (iii) saturated fatty acids such as palmitic (6.37 g/100 g total lipids), stearic (5.28 g/100 g total lipids), lignoceric (4.79 g/100 g total lipids), behenic (3.9 g/100 g total lipids), and arachidonic (1.10 g/100 g total lipids) acids (Borges et al., 2022; Moreira et al., 2022), and in lower concentrations tetradecanoic and heptadecanoic acids (0.04 and 0.08 g/100 g total lipids, respectively; Borges et al., 2022). In addition, baru oil also demonstrated the presence of carotenoids (15.68 mg/100 g), lutein (0.91 μg/100 g), α-carotene (1.05 mg/100 g), β-carotene (0.24 mg /100 g), and vitamin A (127.5 μg RE/100 g; Borges et al., 2022). The components found in baru oil are reported to help preserve the characteristics of the oil, provide high stability and also reported for contributing to the reduction the risk of cardiovascular disease (Borges et al., 2022).

3.3. Partially defatted baru almond cake

The DBC is considered a by-product of the cold pressing of the almond to extract the oil (Figure 1). This by-product consists of 12.59–30.2 g/100 g of lipids (Siqueira et al., 2015; Arruda-Silva et al., 2022; Borges et al., 2022), 17.8–34.4 g/100 g of protein, 17.87–34.42 g/100 g of dietary fiber, 3.04–4.12 g/100 g of ash, and 12.93–18.01 g/100 g of carbohydrates on a dry basis (Borges et al., 2022; Moreira et al., 2022). Furthermore, the DBC contains total phenolics of 28.1 mg GAE/100 g and the minerals such as magnesium (194.2 mg/100 g), calcium (47.2 mg/100 g), manganese (14.0 mg/100 g), iron (5.5 mg/100 g), and copper and zinc (1.54 and 2.75 mg/100 g, respectively; Borges et al., 2022).

3.4. Baru pulp

The baru pulp is composed of the epicarp (peel) plus mesocarp (pulp without peel; Alves et al., 2010; Lima et al., 2010; Togashi and Sgarbieri, 2010; Vallilo et al., 2010; Santiago et al., 2018; Almeida et al., 2019; Alves-Santos et al., 2021, 2022). Baru peel presents (g/100 g) 2.5 of proteins, 2.7 of lipids, 2.9 of ash, and 24.1 of dietary fiber. In addition, the peel shows 477 mg GAE/100 g of total phenolic compounds that result in antioxidant activity of 60, 45, and 50 μmol TE/g by ABTS, DPPH, and FRAP methods, respectively (Santiago et al., 2018).

In turn, baru pulp presents (g/100 g) 3.2–5.0 of protein, 0.9–4.13 of lipids, 1.7–3.1 of ash (Lima et al., 2010; Togashi and Sgarbieri, 2010; Vallilo et al., 2010; Santiago et al., 2018; Almeida et al., 2019; Alves-Santos et al., 2021), and 5.7–32.9 of dietary fiber depending on the processing applied (Lima et al., 2010; Togashi and Sgarbieri, 2010; Santiago et al., 2018; Alves-Santos et al., 2021, 2022). Also, was reported for the pulp 292 mg/100 g of total phenolic compounds, especially hesperidin (19 mg/100 g), which result in antioxidant activity of 49, 21.2, and 24.2 μmol TE/g by ABTS, DPPH, and FRAP methods, respectively (Santiago et al., 2018). Minerals such as (mg/100 g) potassium (572), phosphorus (82.2), calcium (75.2), iron (5.94), magnesium (3.9), manganese (3.84), copper (3.54), sodium (1.74), and zinc (1.08) were also reported for baru pulp (Vallilo et al., 2010). Due to its chemical composition, the pulp has shown potential as a prebiotic ingredient (Alves-Santos et al., 2022) being able to act as a non-digestible food ingredients that beneficially affect the host by selectively stimulating the growth and/or activity of one or a limited number of bacterial species already resident in the colon and thus attempt to improve host health (Connerton et al., 2011).

4. Protein extraction from baru almond residue and its fractions

As highlighted in item 3, in the chemical composition of baru and its fractions, the protein content stands out making baru and its fractions an excellent source for plant-based protein extraction (Lemes et al., 2016b). In general, protein extraction methods are based on the isoelectric point of the molecules, considering that the low protein solubility occurs there, which facilitates its separation from the raw material (Munialo et al., 2022). A variety of methods have been used to extract proteins, some methods were developed based on the type of solvent and procedures performed, using heat treatment or not (Mahatmanto et al., 2014; Prado et al., 2020).

The hydrolysis–which can be catalyzed using acids or bases solvents, as well as enzymes–is carried out with the aim of maximizing the biological properties of the encrypted protein molecules, cleaving the peptide bonds and releasing amino acid molecules, decreasing the molecular mass of the protein molecule, and consequently, increased its reactivity (Lemes et al., 2020; Oliveira Filho et al., 2021).

After the extraction and/or hydrolysis process, techniques to recover, concentrate, and purify the obtained biomolecules are carried out. These techniques must be selected considering the specificities of protein hydrolysates which include but are not limited to the physical properties and biological function of the protein (Lemes et al., 2021).

As for the application of these methods in baru and its fractions, only one study reached our knowledge. In this study, which used DBC of baru as raw material, protein extraction (pH 10), followed by precipitation at the isoelectric point, and drying of the isolate was performed. The protein concentrate showed a higher protein content than the DBC and a lower enthalpy, which may be associated with protein denaturation resulting from the isolation process. In general, the application of these techniques (extraction, separation, among others) results in the concentration of the protein content being able to increase by more than 70%, in the case of DBC (Guimarães et al., 2012a). This is still a pioneering study, and more efforts need to be made in this regard.

So far, there are no studies available that use other fractions from baru processing to obtain proteins and, therefore, a great effort must be made to use and take advantage of these by-products.

5. Application of protein from baru almond residue and its fractions

Over the years a substantial amount of knowledge has accumulated about plant protein sources such as soy, peas, lentils, and beans, and less information is available on emerging protein sources such as baru proteins (Munialo et al., 2022). The baru almond has currently been considered an emerging source of vegetable protein due to its protein content, which is higher than that found in some alternative protein sources such as Brazil nuts, cashews, pistachios, and macadamia (9–18 g/100 g; Fernandes et al., 2010; Souza et al., 2015).

In addition to good nutritional characteristics, in order to use alternative proteins in food formulation, it is necessary that baru protein be characterized in terms of their technological properties. Gelling ability, oil and water absorption, solubility, emulsification or foaming capacities are some of the technological properties of proteins that are important in food formulation (Alonso-Miravalles and O'Mahony, 2018). The proteins extracted from the baru almond have the potential for application in various foods and may confer water absorption (193.84%), oil absorption (199.80%), water solubility (~60%), as well as emulsifiers (95.00%) and foamability (50.00%) capacities (Guimarães et al., 2012b). High water absorption capacity and emulsifying property are desirable in analogs of meat products such as meat sausages, demonstrating the potential of baru proteins, which even without having gone through refining processes showed high values for these indices.

Another factor that corroborates its use is that baru almond, pulp, peel, oil, and water-soluble extract have already been properly applied in products (vegan and non-vegan) such as cereal bars (Lima et al., 2010, 2021), "paçoca"–Brazilian peanut candy (Santos et al., 2012), ice cream and frozen yogurt (Pinho et al., 2015; Arelhano et al., 2019), cupcakes (Paglarini et al., 2018), cookies (Pineli Pineli et al., 2015; Caetano et al., 2017), bread (Rocha and Santiago, 2009), pasta (Antunes et al., 2021), and to production of water-soluble extract of baru almond (Fernandes et al., 2021), with an increase in properties such as protein content, fibers, sensory aspects, bioactive properties such as antioxidants, among others nutritional, and techno-functional properties.

Although baru almond proteins are a promising source of good quality vegetable protein for application in the development of new plant-based foods, to our knowledge, no studies were found using baru proteins for the development of food products. Despite this, the results on the properties of baru proteins are encouraging and future studies should explore these proteins to contribute for plant protein supplying.

Table 1 summarizes and highlights the mean content of protein, fibers, and lipids presented in items 3.1 to 3.4. In addition, are presented the applications and potentialities of baru almond and baru by-products which should be considered for application in the development of food products.

Despite the techno-functional potential and low cost, obtaining plant proteins from by-products still presents difficulties related to seasonality, quantity generated, as well as the process of obtaining, geographic location, among other factors. Thus, issues such as the complexity of the chain and its logistical costs, the use of complex and costly processes, energy consumption, and regulatory issues, among others, must be overcome. In this sense, the processing of by-products must overcome several barriers before becoming economically viable, including the need to process large quantities of raw materials, the capacity to process heterogeneous raw materials, integrated logistics with different processing industries, the possibility of the integration process in the processing unit to allow the generation of high-value ingredients, among others (Pintado and Teixeira, 2015; Lemes et al., 2016b, 2022, 2023).

6. Conclusion and future directions

Large amounts of baru by-products are available from almond processing and can be properly converted into proteins and other ingredients for the food industry in addition to being a good protein alternative for vegans and vegetarians. The baru–almond and partially defatted baru almond cake–have been shown to be a significant source of plant-based protein produced from proper extraction and processing once they present high protein content (23–30 g/100 g). Additional studies are necessary to optimize the recovery, separation, and isolation of these molecules, as well as evaluation of the characteristics of the extracts produced.

In addition to nutritional properties, baru demonstrates good technological properties for food and beverage application, including its water absorption capacity, oil absorption, solubility, foaming ability and foam stability. Despite the techno-functional potential and low-cost, obtaining vegetable proteins from by-products is still verified difficulties related to seasonality, quantity generated, as well as the process used to obtain, geographic location, among other factors.

Author contributions

Conceptualization and methodology, MBE, JGOF, SBC, and ACL. Investigation, MBE, JGOF, SBC, and ACL writing—original draft preparation, MBE, JGOF, SBC, and ACL. Writing—review and editing, MBE, JGOF, SBC, and ACL. Funding acquisition, MBE and ACL. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2023.1148291/full#supplementary-material

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