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Baru (*Dipteryx alata Vog.*): Fruit or almond? A review on applicability in food science and technology ☆

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ABSTRACT

Considered harvest integrating products of socio-biodiversity, native fruits have gained prominence, particularly in the gastronomic media, for their exotic flavors; therefore, their exploitation, valuation, recognition, and acceptability have increased in recent years. Baru trees (*Dipteryx alata* Vog.) are native to the Brazilian Cerrado, and their popularity is primarily attributed to the unique almond, the nutritional and functional potential of which is associated with health-promoting benefits. Often erroneously referred "baru", the baru almond constitutes up to one-fourth of the fruit; other distinct fruit fractions include epicarp (peel), mesocarp (pulp), and endocarp (a woody material rich in cellulose, hemicellulose, and lignin that covers and protects the almond). Apparently, these fractions are as valuable as the almond and have thus garnered scientific interest. However, these fractions are often considered waste and remain unexploited in the structured production chain of baru almonds. Specifically, the epicarp is rich in fibers and phenolics. The mesocarp contains abundant carbohydrates—a sucrose source—from which granulated sugar can be obtained. The endocarp may be used as a source for generating biomass, biofuel, and activated charcoal-type biochar to reduce CO_2 emissions. Therefore, baru fruit, in its entirety, holds tremendous technological potential for application in the food and related industries.

1. Introduction

In the light of global movement to valorize biodiversity, the present review highlights the significance of baru (*Dipteryx alata* Vog.) fruits. The popularity of baru must be contextualized in its natural habitat, the Cerrado biome, which is the second-largest Brazilian ecosystem and considered the richest tropical savanna region in the world in terms of biodiversity (Oliveira-Alves et al., 2020; Sawyer et al., 2018). Considering its magnitude, the wide variety of species in Cerrado is unquestionable, albeit underutilized as yet by the local communities. Either lack of scientific knowledge or low incentives to develop innovative technologies and processes have prevented these communities from exploiting the productive potential of this biome to the fullest (Lima et al., 2021; Oliveira et al., 2020).

Baru fruits have a peculiar taste, which has been primarily explored by the gastronomic media, enhancing the recognition and acceptance of this fruit by the society that is increasingly judicious regarding the food they consume (Oliveira et al., 2020). Beyond their exotic sensory attributes, baru fruits, in addition to other Cerrado products, offer favorable nutritional potential and health-promoting benefits (Lima et al., 2021); hence, it has been regarded as a functional ingredient in the food industry (Gonçalves et al., 2020). Furthermore, baru fruits present a unique chemical composition in terms of proteins, lipids, vitamins, minerals, fibers, sugars, and bioactive compounds (Oliveira et al., 2020).

Although it is on the agenda of various research groups, baru fruit processing and commercialization profile remain typical extractivist activities, generally associated with family farming and agricultural production cooperatives (Gonçalves et al., 2020; Lima et al., 2021). Of note, scientific studies on baru fruit processing have produced a significant social impact on population groups that depend on Cerrado's resources to make their living, such as Indians, quilombolas, and ribeirinhos, who represent traditional communities of the Cerrado region. Furthermore, baru is one of the many species native to the Cerrado that find well-known uses in traditional medicine. Therefore, these fruits are regularly consumed by the native communities and sold in the local markets (Sawyer et al., 2018).

☆ MUFAs: monounsaturated fatty acids; SFAs: saturated fatty acids; SFE: supercritical fluid extraction; CMC: carboxymethylcellulose; LDPE: low-density polyethylene.

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In this context, the importance of native species extends beyond their health-promoting roles, since they also contribute to preserving the natural biomes. Furthermore, aggregating value to native species increases their commercial value, which, in addition to their nutritional potential, has attracted national and international interest (Gonçalves et al., 2020).

Food scientists have focused on developing products that promote raw material value (Lima et al., 2021), thus contributing to technological innovations and competitive development in the food industry (Oliveira et al., 2020).

To this end, the present review aimed at promoting and disseminating information regarding baru fruits, the production chain of which is based on regional extractivism. In particular, this supply chain is related to the promotion of coordinated actions to aggregate commercial value to derived products using sustainable and innovative technologies and generate income sources for the local communities. Therefore, the present article intends to stimulate the development of family farming and other productive areas related to the food, pharmaceutical, and cosmetic industries.

Given the environmental and nutritional relevance of baru fruits, the objective of the present study was to compile information from the literature regarding the technological potential of baru fruits and their applications in areas of food research.

2. Material and methods

The present descriptive review adopted a search strategy and eligibility criteria for screening scientific articles based on the following three search terms: *Dipteryx alata* Vog., baru, and Cerrado fruits. The first two terms are the scientific and popular names of the fruit recognized and cited in the literature, respectively. Meanwhile, the third term covers research devoted to all Cerrado fruits, including relevant information concerning baru. The study publication period delimited the quinquennial period ranging from July 2016 to July 2021.

Bibliographic research was conducted from January to July 2021 using the academic databases available through the CAPES (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior) [Coordination of Improvement of Higher Education Personnel] Platform (https://www.periodicos.capes.gov.br/) Brasil. Ministério da Educação (2021) which maintains cooperation with the Federal University of Goiás (UFG) via the Federated Academic Community (CAFe), providing remote access to a plethora of national and international academic databases. Furthermore to compile information on international publications, three specific databases of paramount importance to the area of food science and technology were selected: ScienceDirect (https://www.sciencedirect.com/); SCOPUS (https://www.scopus.com/), and SpringerLink (https://link.springer.com/). Finally, the selected terms (in Portuguese) were directly input to the database topic search field of the CAPES Platform to search for national publications.

The selected publications were classified according to the baru fruit fraction they dealt with, namely, nut, epicarp, mesocarp, and endocarp. Subsequently, the publications were evaluated for their relevance to the area of food science and technology.

3. Baru (*Dipteryx alata Vog.*)

To better comprehend the context of baru fruit applicability and recent studies, one must know the botanical, cultural, and ecological aspects that significantly impact the potential for commercial expansion of this product.

The name "baru" is often used laxly and erroneously to designate the fruit, tree, and nut, although the term should be reserved for fruit alone. Since the priority exploitation of the fruit is for the commercialization of the baru nut and other components are not much appreciated and valued as yet, "baru" has become a popular name for the nut.

Fig. 1. Baru tree (*Dipteryx alata* Vog.) from the northwestern region of the Brazilian state Minas Gerais.
Source: Authors.

The term "baruzeiro" is used to identify the baru tree. Its scientific name is *Dipteryx alata* Vog., and it is a fruit tree species belonging to the family Fabaceae (Egea & Takeuchi, 2020). It is distributed primarily in the Cerrado region and sporadically in the north, northeast, mid-west, and southeast of Brazil. In addition, baru trees grow in Venezuela, Costa Rica, and Panamá (Niedack, Souza, Alves, & Damiani, 2021). The popular name "baru" is common in the Brazilian states of Goiás, Tocantins, Minas Gerais, and Distrito Federal, although some variations exist, including cumaru or cumbaru in São Paulo, Mato Grosso, and Mato Grosso do Sul (Sano, Ribeiro, & Brito, 2004).

The baru tree (Fig. 1) can typically reach 5 to 10 m in height, although some individuals reach up to 20 m in their adult age (Carvalho, 2003). The trees blossom from November to May and produce fruits from July to October (Reis & Schmiele, 2019; Sano et al., 2004).

A single adult tree produces around 150 kg of fruit in each harvest period, typically presenting one productive harvest period every 2 years (Carrazza & Avila, 2010). Therefore, the species exhibits shows a biennial behavior—a common phenomenon among plants that use the subsequent year after the harvest to recover the energy spent during fruiting. Thus, seasonality represents the first challenge in the commercial use of baru fruits. This particular feature, stemming from an intermittent harvest, causes abrupt variations in fruit productivity from one year to the next.

Regarding botanical characteristics, the fruit is classified as a monospermic drupe, indehiscent, fibrous, typically oval and slightly flattened, and with opaque colors varying from light or dark brown to reddish-brown (Alves-Santos, Fernandes, & Naves, 2021; Sano et al., 2004). Its surface is irregular with depressions and has a rough texture, with a rounded peak that serves as the base for the attachment of a narrow petiole and slightly flattened sides (Carvalho, 2003; Silva et al., 2021). On average, the fruit measures 52 mm in length, 38 mm in width, and 29 mm in thickness, weighting from 26 to 40 g (Alves-Santos et al., 2021; Martins, Ferraz, & Schmidt, 2017).

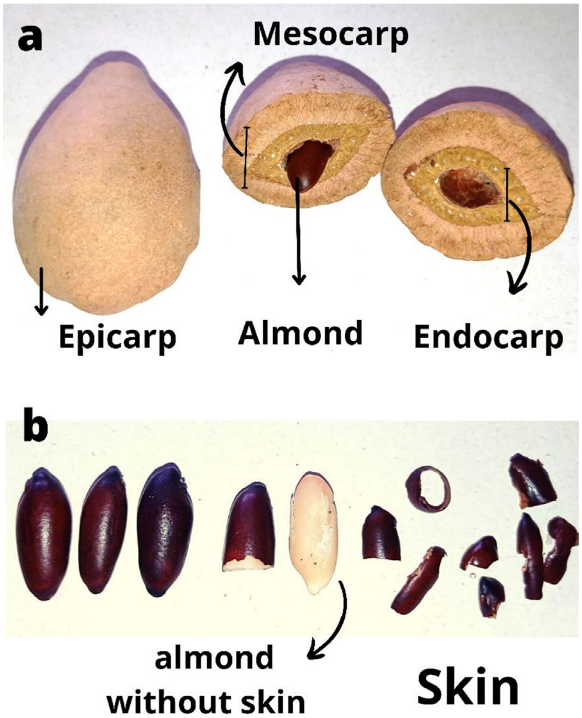

Fig. 2. Whole baru fruit and cross-section (a) and almonds with and without the skin (b).
Source: Authors.

The baru fruit contains an almond or seed, also called a true nut (Morais, Belisário, Favareto, Maia, & Carvalho, 2021; Oliveira-Alves et al., 2020). The almond is the primary commercial product obtained from the fruit (Egea & Takeuchi, 2020), representing only 5% of the total weight (Martins et al., 2017). The almond color varies from cream to white, and it is covered with a brownish skin (Silva, Ferreira, Asquieri, Damiani, & Asquieri, 2021a). Of note, this thin skin contains 10% of the total phenolic compounds of the fruit and presents potent antioxidant capacity when consumed along with the almond (Silva, Machado, Cardoso, Silva, & Freitas, 2020a).

Meanwhile, in recent years, the epicarp (peel), mesocarp (pulp), and endocarp have been attracting much scientific interest, particularly in research devoted to waste reuse and transformation into byproducts (Rambo, Nemet, Santana, Pedroza, & Rambo, 2021). In the environmental context, such products are beneficial for reducing food loss and wastage, as the almond represents only 5% of the total fruit mass.

The peel, or epicarp, comprises a thin layer in direct contact with the environment, which is responsible for the fruit's characteristic light brownish color and is rich in fibers (Santiago, Oliveira, Horst, Naves, & Silva, 2018). The pulp, or mesocarp, contains over 70% carbohydrates in its composition, most of which are sugars (23 $g{\cdot}100\ g^{-1}$) (Egea & Takeuchi, 2020). This fraction of the fruit is regarded as a fibrous layer (Alves-Santos et al., 2021), which is sweet (Santiago et al., 2018) and edible (Gadioli et al., 2021). The woody endocarp covers and protects the almond (Carrazza & Avila, 2010) because of its hardness. The endocarp is composed of cellulose, lignin, and hemicellulose and is darker than the mesocarp (Egea & Takeuchi, 2020). However, information on the physical properties of baru peel and pulp, such as mass and yield, is scarce in the literature (Alves-Santos et al., 2021). Fig. 2 illustrates the whole baru fruit (a), with fractions exposed by cross-sections and (b) the almond with and without the skin.

3.1. Baru in the spotlight among Cerrado fruits

Considered a hotspot of biodiversity globally, the Cerrado is the second largest Brazilian biome, following the Amazonian forest (Almeida et al., 2019). It hosts a wide diversity of fruits with exotic colors and tastes (Gadioli et al., 2021) and with high nutritional value and functional potential (Gonçalves et al., 2020), which are primarily attributed to their rich bioactive compounds, including antioxidants (Oliveira et al., 2020); therefore, these fruits offer irrefutable health benefits.

The nutritional, functional, and sensory potential of baru can satisfy the consumer demands and expectations of purchasing natural and functional products, bringing native fruits into the limelight (Oliveira et al., 2020). In addition to their traditional consumption by the local populations, baru fruits represent excellent potential for application in the food industry as an ingredient because of its sensory and technological attributes, which are interesting to both consumers and manufacturers (Almeida et al., 2019). Harmonizing the increasing consumer demand with the production capacity of the food industry is a real challenge for food product manufacturers, particularly research and development teams, who are responsible for turning these materials into pleasant, healthy, and durable products (Reis & Schmiele, 2019).

Notably, studies on native fruits are of great economic and social relevance to regional extractivism (Gonçalves et al., 2020). The scientific knowledge of new nutrient sources attributed to native fruits reinforces their use by the food and pharmaceutical industries (Leite et al., 2020). Such information encompasses the national and international exploratory potential, which calls consumer interest, contributes to the search for innovative products (Oliveira et al., 2020), and promotes new product formulation (Reis & Schmiele, 2019).

Baru, similarly to many Brazilian native fruits, has garnered the attention of scientists. These products play a central role in aggregating commercial value. In addition to their nutritional and functional potential (Oliveira et al., 2020), these products may promote the viability of diverse applications in the food industry, which seeking technological innovations. The relevance of this fruit in scientific research can be gauged by indexing the term "baru" along with other topics, such as "Brazilian Cerrado native fruit" (Almeida et al., 2019), "edible seed" (Egea & Takeuchi, 2020), "true nut" (Oliveira-Alves et al., 2020), and "reforesting tree" (Antunes et al., 2020), among many other, as discussed in the present review.

Moreover, baru is remarkable in terms of its economic potential and versatility, as evidenced by studies in diverse areas, such as nutrition, animal feeding, medicine, damaged area recovery, landscaping, and wood extraction (Antunes et al., 2020). Furthermore, baru fruit residues from the pulp and endocarp may be reused in many industries (Rambo et al., 2021).

3.2. Path of agroecology in the baru production chain

From the viewpoint of prospects and challenge of the production and exploitation of baru, this species, similar to many other Cerrado fruits, must overcome several obstacles—the major one being deforestation of the Cerrado (Schatz, 2019). With the intensification of anthropogenic activities accelerating the use and exploitation of natural resources, many ecosystems, including the Cerrado, have been fragmented or even lost, leading to tremendous biodiversity loss (Cardoso & Nogueira, 2021; Valadão et al., 2018).

In a biome characterized by the presence of extractive communities, indigenous, quilombola, and small agro-extractive producers and many others have been effectively conserving large natural areas over many generations. Therefore, we must realize and value small-scale family production and extractivism as allies of conservation and the Cerrado populations as its true guardians (Lobo & Sawyer, 2022). Therefore, when proposing the rational use of natural resources, including the exploitation of baru, we must understand and value economic activities that practice sustainability (Valadão et al., 2018), incorporating the actors involved in the process while seeking social equity and environmental protection (Hespanhol, 2008).

In this sense, agroecology stands out as an alternative to family farming based on the principles of sustainability. These principles, concepts, and methodologies enable planning of high-quality food production while maintaining land productivity, respecting the nature, increasing the diversity of products for family and market consumption, and generating more income for farmers (Copabase, 2022). Truly ecological agriculture cannot be restricted to environmental concerns alone, and other dimensions, such as the social, economic, cultural, political, and ethical aspects, must be incorporated (Hespanhol, 2008).

Agroecology encompasses the entire food system, from extractivism, production, and marketing to consumption. It creates self-sufficient, healthy, and pollution-free systems, offering safe, affordable, and diverse foods (Critical Ecosystem Partnership Fund, 2022).

The Regional Cooperative for Family Agriculture and Extractivism (https://www.copabase.org/) has presented optimistic productivity and innovation data in a report published by the non-governmental organization Critical Ecosystem Partnership Fund (CEPF) (https://www.cepf.net/). They used the highly regarded Social Return on Investment (SROI) analytical tool to elaborate the data. The promotion of agroecology in various agro-food chains, including the priority chain in the region, that is baru nuts, can offer competitive advantages when applied to the productive model of family farming based on agroecology (Critical Ecosystem Partnership Fund, 2022).

According to Critical Ecosystem Partnership Fund (2022), the results of this success story include the reduction of illiteracy, diversification of production, increase in producer income, inclusion of women in productive activities, recovery of springs, and increase in the number of native trees on various properties. Socio-environmental returns calculated from on the monetization of re-composing hectares of Cerrado and tons of CO_2 sequestered as a result of forest recovery, among other parameters, approached R$ 37,634,959.75 (ca. US$ 263,444,718.30). This value corresponds to the period between 2013 and 2021, characterized by the operation of the cooperative and active conversion from conventional agriculture to agroecology.

Baru nuts are commercially exploited by several communities throughout Brazil, with production that continuously evolves according to data released by the National Supply Company (CONAB)—the agency that is linked to the Ministry of Agriculture, Livestock and Supply (MAPA) and is responsible for the management of agricultural policies in Brazil.

Baru nuts have been officially listed in Brazil's socio-biodiversity products (Companhia Nacional de Abastecimento, 2022). According to data presented by CONAB regarding the historical series of production costs of baru nuts, only four enterprises marketing baru nuts were monitored during 2010–2021. Of these, three enterprises were from the Goiás (GO) region and one from the Mato Grosso (MT) region. The average production of baru nuts ranged from 375 kg to 1 ton per harvest per production cycle, depending on the production unit, corresponding to the production cost of R$ 5003.31–R$ 10,169.77. The price of the product fluctuated widely during the period; however, in 2022, the minimum price for commercialization was stipulated at R$26.68·kg^{-1}, as calculated on the basis of price established by Ordinance No. 376 (2021) according to the guidelines of the Policy for Guaranteeing Minimum Prices for Sociobiodiversity Products (PGPM-Bio).

Regarding baru by-products, to the best of our knowledge, only the pulp (mesocarp) is marketed and exported to the USA by Barùkas, a multinational company based in Carlsbad, California (Schatz, 2019). They exports a trail mix, which includes dehydrated strips of baru pulp (mesocarp). The co-founder of the company, Darin Olien, mentioned in his interview with the Forbes that he dreams of reforesting the regional ecosystem with baruzeiro trees and creating a source of livelihood for the local people who harvest and live off the product that bears his company's name.

3.3. Applications of baru nuts in food science and technology

Baru almond is the most valued portion of the fruit. It is highly appreciated in culinary preparations and has been extensively studied (Egea & Takeuchi, 2020). Moreover, its nutritional potential and functional appeal have been explored. It is considered a food source of proteins with a unique amino acid profile (Fernandes, Freitas, Czeder, & Naves, 2010) and is a rich source of monounsaturated fatty acids (MUFAs), which are associated with low atherogenicity and thrombogenicity indices (Campidelli et al., 2020). Furthermore, baru almonds contain significant amounts of calcium, iron, zinc, bioactive compounds with antioxidant activity (e.g., phenols, phytates, and tannins), and antiproliferative compounds (Oliveira-Alves et al., 2020). Along with pequi, the baru fruit is well-known for its antioxidant activity among Cerrado fruits (Oliveira et al., 2020). Thus, Alves-Santos et al. (2021) have reviewed its roles in human health.

Table 1 summarizes, in chronological order, 30 articles published during 2016–2021 in scientific journals of high impact, compiled through the most relevant databases to the research areas of food Science and technology. These articles underscore the significance of baru almond.

Based on published works, trending topics and themes were noted. Accordingly, the publications were classified into five categories (A–E): group A: data referring to the composition and nutritional properties of baru almond; group B: studies exploring the development of products obtained from almonds or seedcake following oil extraction; group C: literature reviews on Cerrado fruits, including data on baru almonds; group D: development of hydro-soluble beverages extracted from baru almonds; group E: methodologies and techniques for extracting oil from baru almonds. In particular, articles focused on chemical composition (group A) and product development (group B) accounted for a large proportion of publications (10 articles each, 33.33%).

However, as publications regarding chemical composition are not the focus of the present review, works on the chemical composition of baru nuts and other Cerrado fruits are not discussed here. Group B included publications on the application of baru almonds as a substitute ingredient in traditional recipes, which originally used other oleaginous seeds, such as chestnuts, nuts, or peanuts. Specifically, we highlight the development of edible protein bars containing baru almonds (Lima et al., 2021), which are generally formulated with conventional nuts and cocoa cream (Campidelli et al., 2020); these bars are now very popular and widely accepted in the gastronomy compared with the original formulation containing hazelnuts.

In group D articles, the use of baru almonds in the preparation of hydro-soluble beverages is justified based on proven beneficial nutritional aspects observed after incorporating or replacing other ingredients in food products with these almonds. For instance, Lima et al. (2021) demonstrated that edible bars containing baru contained abundant proteins and minerals (potassium, magnesium, and zinc), in addition to total phenols (1171.95 mg GAE·100 g^{-1}), among other bioactive compounds with antioxidant activity (185.64 μg Trolox·g^{-1}). The lower water activity of products containing high concentrations of baru nuts was a key technological aspect, since these products tended to present longer shelf-life—a crucial issue in the food industry. Moreover, Campidelli et al. (2020) reported significant increases in the concentrations of minerals (calcium, magnesium, sulfur, and manganese) and MUFAs, particularly oleic acid (57.85 g·100 g^{-1}), among others, as well as the presence of vitamin C (24.37 mg·100 g^{-1}) in cocoa cream containing baru. In another study, da Cruz, Gama, Américo, and Pertuzatti (2019) studied the combination of baru almonds and cocoa; the authors developed a dairy dessert presenting antioxidant activity similar or superior to baru almonds *in natura* (3.513 mg GAE·kg^{-1} using FRAP assay vs. 639 mg GAE·kg^{-1} ABTS assay). The authors suggested that the combination of these two ingredients rich in phenolic compounds contributed to the high antioxidant activity of the products.

Table 1
Literature search of publications regarding baru almonds from 2016 to 2021 in the area of food science and technology.

Year	Technological application and product	Authors	Classification
2021	Edible cereal bars mixed with nuts	Lima et al.	B
	Symbiotic fermented beverages	Costa Fernandes et al.	D
	Fermented beverages (probiotics and green banana starch)	Coutinho et al.	D
	Baru seed oil extraction	Chañi-Paucar	E
	Spectroscopy to evaluate adulteration in high-commercial value vegetable oils	Nascimento et al.	A
2020	*In vitro* bioaccessibility of Cu, Fe, Mn, and Zn in baru pulp and almond	de Oliveira Gonçalves et al.	A
	Cocoa cream supplemented with baru almond	Campidelli et al. (a)	B
	Vegetable beverages mixed with nuts	Silva et al.	D
	Effect of drying on the nutritional properties of baru almond	Campidelli et al. (b)	A
	Optimization of phenolic compound extraction with focus on baru almond skin	Da Silva et al.	A
	Identification of functional compounds in baru nuts	Oliveira-Alves et al.	A
	Spectroscopic characterization and thermic behavior of vegetable oil from baru nuts	Alarcon et al.	A
2019	Dairy desserts with baru regulates gastrointestinal transit in rats	Cruz et al.	B
	Characteristics and potential of Cerrado fruits in the food industry	Reis & Schmiele	C
	Mayonnaise formulated with microencapsulated chia seeds, pumpkin seeds and baru oil	Rojas et al.	B
2018	Determination and drying kinetic analysis of whole and defatted baru flour	Reis et al.	A
	Comparison of baru almond, pulp, and peel	Santiago et al.	A
	Cupcakes with low levels of fat formulated from baru flour	Paglarini et al.	B
	Baru seed oil extraction using pressurized solvent technologies	Fetzer et al.	E
	Lamellar gel phase emulsion containing baru oil	Moraes et al.	B
2017	Cookies formulated with defatted baru seedcake	Caetano et al.	B
	Proteins isolated from baru nuts and defatted baru flour	Nunes et al.	B
	Physical characteristics of baru tree fruit targeting almond extraction	Martins et al.	A
	Flavored fermented beverages	Fiorante et al.	D
2016	Chemical quality of baru almond oil as a substitute for soy and olive oil	Siqueira et al.	A
	Edible seeds and nuts from fruits native to Cerrado with fatty acid profiles similar to conventional oils.	Alves et al.	C
	Literature review of Cerrado fruits: Indication of baru almond as a functional ingredient in the food industry	Silva and Fonseca, 2016	C
	Ultrasound-assisted oil extraction	Santos et al.	E
	Preparation and characterization of polyurethane with varying amounts of baru oil	Almeida et al., 2016	B
	Nutritional quality of chocolate bars added with baru almonds	Lubas et al., 2016	B

Classification based on the focus of publication: composition and nutritional properties (A)/new product development (B)/literature review of Cerrado fruits/baru almonds (C)/hydro-soluble beverages (D)/oil extraction methods (E).

Furthermore, Paglarini et al. (2018) and Rojas et al. (2019) developed mayonnaise and cupcakes with a functional appeal by incorporating baru oil and whole baru almond flour, respectively. Both the functionality and technological applications were attributed to the fatty acids profile of baru almonds. The higher proportion of MUFAs relative to that of saturated fatty acids (SFAs) and the absence of trans-fatty acids in baru almond flour contributed to the successful technological application, with complete or partial replacement of conventional fats in bakery products (Paglarini et al., 2018). Furthermore, high encapsulation efficiency of chia, pumpkin, and baru oils was observed for enriching mayonnaise. The affinity between lipidic compounds is justified by the hydrophobic nature of stearic acid, am SFA, with other fatty acids, such as MUFAs and PUFAs. Of note, baru almond oil presented a higher oleic acid concentration (42.42%), producing remarkable MUFA levels (45.10%) (Rojas et al., 2019).

Regarding technological aspects related to a particular profile or affinity of fatty acids in baru almond oil, Moraes, Anjos, Maruno, Alonso, and Rocha-Filho (2018) have proposed the development a lamellar phase emulsion, or a colloidal system, that can be used as a delivery system for medicines and skin cosmetics. Baru oil contains considerable levels of active photochemical compounds, tocopherols, and phytosterols (Rojas et al., 2019), which are higher than those in other vegetable oils widely used to facilitate the permeation of active molecules via cutaneous absorption. Furthermore, baru oil emulsions have been reported to exhibit excellent solubility in active lipophilic and hydrophilic ingredients, assuring the wide applicability of their products (Moraes et al., 2018). Similarly, Nunes, Favaro, Miranda, and Neves (2017) tested isolated proteins obtained from defatted baru almond seedcakes and highlighted the applicability of this product in fat product formulations due to its good capacity of absorbing and emulsifying oils, such as for producing stable foams with moderately acidic to neutral pH.

While some of the previous studies mentioned above used commercial baru oil purchased from the local markets, others (e.g., Caetano et al., 2017) extracted the oil during experiments. Specifically, in a previous study, cookies containing defatted baru almond flour were prepared. The nutritional focus of that study was the rich amino acid profile of cookies provided by the defatted baru seedcake used in the product preparation. Meanwhile, in other studies, defatted baru seedcake was used to exploit the proteic aspect of baru almonds. For instance, Nunes et al. (2017) isolated proteins and Fetzer, Cruz, Hamerski, and Corazza (2018) extracted oil from baru almond using supercritical fluid extraction (SFE) with pressurized solvents [propane and carbon dioxide (CO_2) + ethanol]. In both studies, the residues obtained from baru almond seedcakes were the byproducts of high nutritional value, presenting relatively low or even no trace of the remaining solvent. Thus, these seedcakes can serve as the potential sources of proteins and minerals.

Regarding efficient methods and techniques for extracting baru almond oil, three studies in group E applied SFE to recover high amounts of baru oil, enhancing the final product yield. Previously, various techniques have been implemented to optimize vegetable oil extraction in terms of yield, final recovery, or even improved physiochemical characteristics and fatty acid composition. Overall, SFE is an appealing “green technology” that uses CO_2, a nontoxic, nonflammable, and inert solvent.

Furthermore, Santos et al. (2016) combined the SFE and ultrasound techniques to evaluate temperature and pressure variations. The best operational conditions of SFE in terms of global yield were 35 MPa and 40°C, with values of 22.8% oil. Despite the increase in the extraction rate, ultrasound in SFE experiments did not affect baru oil fatty acid composition. Moreover, an increase in the solubility of fatty acids in supercritical CO_2 was observed due to pressure elevation, with consequent increase in solvation power. The authors also highlighted the advantages of using SFE to obtain baru fatty acids over conventional methods, such as Soxhlet or Bligh and Dyer extraction. Meanwhile, Fetzer et al. (2018) reported the highest extraction yield of 46.18% and 39.76% using the Soxhlet method with ethanol and hexane, respectively. Compared with values of lipid yield commonly reported in the literature, such as 24.2% by Gonçalves et al. (2020) and 41.69% by Lima et al. (2021), the values obtained by Fetzer et al. (2018) were higher. Nevertheless, Coutinho et al. (2021) detected 47.50% lipids in baru almonds but did not report the method was used. Regarding oil extraction using pressurized solvents and ethanol as a cosolvent, Fetzer et al. (2018) reported that the extracts generated from ethanol were peculiar in terms of their miscible polarity compared with products generated from pure CO_2, which is nonpolar. Ethanol was the preferred solvent in previous studies because of its low toxicity, and it was used to extract a vast number of compounds, including bioactive compounds. For instance, da Silva et al. (2020b) optimized total phenolics extraction and reported on the antioxidant capacity of non-peeled baru almonds using a solvent feed ratio of 79% ethanol per 2 mg mL^{-1} at 85°C.

Chañi-Paucar, Osorio-Tobón, Johner, and Meireles (2021) used SFE assisted by cold pressing (SFEAP) to extract baru oil and obtained a yield of up to 29% at 350 bar and 45°C. Of note, operational conditions, such as temperature and particle size, which significantly impact the extracted oil yield, differed among studies in group E. Overall, SFEAP may be promising alternative for use at the industrial scale because of the high extraction yields and low CO_2 consumption (flux = 7 g·min^{-1}).

Hydro-soluble beverages, associated with the concept of plant-based proteins, have become widespread (Bocker & Silva, 2022). Consistent with this market trend, four publications in group D have highlighted hydro-soluble beverages based on baru almonds. According to the Brazilian Health Regulatory Agency (Agência Nacional de Vigilância Sanitária, 2005), plant-based beverages are defined as hydro-soluble vegetable extracts, considered food products, obtained from the proteic parts of vegetable species. These products may be in the form of granules, powder, liquids, or others, except those non-conventional for feeding. Moreover, these products can be added with other ingredients, provided they do not change the product's color.

Fioravante, Hiane, and Braga Neto (2017) pioneered the development of a fermented beverage from baru almonds. They flavored the beverage with plums and stabilized it with carboxymethylcellulose (CMC) hydrocolloids and xanthan gum. Silva et al. (2020b) used the same stabilizer (CMC) to evaluate the rheological properties of a Brazil nut and baru almond-based beverage. In both studies, CMC, a food addictive from the functional thickeners class INS 468, was used. These thickeners promote dispersion, allow stabilization, and avoid the coalescence of substances in the suspension (Food and Agriculture Organization, 2019). Product stability is one of the most important issues in the food industry, as the destabilization of interfaces may alter the sensory attributes, consequently compromising the product's acceptability (Silva et al., 2020b). Since this is a proven challenge in preparing hydro-soluble baru almond-based-beverages, Coutinho et al. (2021) and Fernandes, Marcolino, Silva, Barão, and Pimentel (2021) proposed alternatives to CMC for stabilizing these beverages. Fernandes et al. (2021) developed a baru symbiotic fermented beverage containing the probiotic *Lacticaseibacillus casei* and the prebiotic inulin with potentialized viscosity and functional properties. Inulin addition positively affected the product's consistency, meeting the consumers' expectations. Meanwhile, Coutinho et al. (2021) adjusted the texture of a baru hydro-soluble fermented beverage by adding 4.5% green banana starch, assuring its acceptability among consumers in a sensory panel test.

Taken together, the above discussion demonstrates that the relevant nutritional quality of baru fruits is reflected in healthy products, confirming that the food matrix plays an essential role in chemical interactions that reflect directly on the nutritional value and potential of the final products developed. From these data, the relevance and consolidation of baru almonds are evident, highlighting the possibilities of their applications in food science and technology.

3.4. Epicarp, mesocarp, and endocarp: residue, byproduct, or coproduct?

After extracting the almond, almost 95% of the fruit, comprising the epicarp, mesocarp, and endocarp, is wasted (Martins et al., 2017), which calls attention to opportunities for making better use of the whole fruit. According to some authors, these remaining parts of the baru fruit are the residues or byproducts of **processing** (Ferreira, Florizo, & Argondoña, 2020; Morais et al., 2021). Research on the applications of these components and evaluation of their technological potential remains at the investigation stage, as evidenced by the remarkable increase in the number of relevant publications in 2021. Therefore, the classification of these fractions as residue may change after new research advances and innovations are showcased by the 13 articles published on this theme during 2016–2021 (Table 2).

Nevertheless, publications on the use of these baru fractions are scarce in the literature, opening new research avenues. Majority of the studies performed deal with nutritional evaluation, bioactive properties, and antioxidant capacity of baru mesocarp (Silva, Ferreira, Giunco, & Argandoña, 2021b), which are comparable to those of baru almonds (Santiago et al., 2018). In the light of recent updates on this theme, geographical differences and environmental conditions may significantly affect the composition and physicochemical properties of baru mesocarp (Gadioli et al., 2021). Silva et al. (2021b) found marked variations in the chemical composition and bioactive compound content of baru pulp. Moreover, the degree of such discrepancies even exceeded 100% between macronutrients and phenolic compounds (Table 3). Gadioli et al. (2021) reported 19.61–22.61 mg·GAE·100 g^{-1} of phenolics and 2.41–3.29 mg·CAE·100 g^{-1} of tannins in baru mesocarp, while the values reported by Silva et al. (2021b) were different for the same phenolics and tannins.

Post-harvest handling and processing of baru may affect its chemical composition (Silva et al., 2021b). As such, there were significant differences in the chemical composition of baru obtained during different harvest periods, and these differences were attributed to fruit handling, which differed among the harvest periods of 2013, 2014, and 2015. Even after harvest, fruits and vegetables exhibit metabolic activity to maintain their physiological systems, until fruit senescence starts subsequently. According to Morais et al. (2021), with the progress of maturation, the astringency of baru fruits caused by phenolics and, particularly, by tannins decreases. Furthermore, in their study evaluating the shelf-life of cookies prepared from baru pulp, Ferreira, Silva, Munhoz, and Argandoña (2020) recorded alterations in the sugar levels. The authors attributed the decrease in pH and increase in the acidity of baru cookies with the conversion of pulp sugars (fructose and sucrose) to acids.

In addition, Gadioli et al. (2021) evaluated baru mesocarp samples and recorded 50% total sugars, with glucose accounting for 29% of all sugars (Table 3). This composition allows for the crystallization and formation of sucrose granules from baru pulp. Silva et al. (2021b) did not characterize the classes of 67% carbohydrates present in baru mesocarp used for the preparation of a fermented alcoholic beverage. The authors discussed the short period between fruit harvest and its subsequent cold storage. The fruits were directly sent to the laboratory, packed, and stored in freezers for subsequent processing. Oliveira et al. (2020) have stated the same providences for collecting and storing the samples; however, their result of 6.9% total sugars contradicts the values reported by Gadioli et al. (2021) and Silva et al. (2021b). Overall, from these reports, we believe that for Cerrado fruits, access to the productive areas is restricted, which imposes difficulties in harvest. Therefore, to optimize the process, mature fruits are harvested after they fall. The period between fall and harvest time remains unmonitored and has not been described in the literature. Nonetheless, there is some evidence that these products may last for up to months post-harvest from July to mid-November.

The interest in new nutrient sources and need for preserving species native to Cerrado through their valorization have motivated an increasing number of investigations on baru pulp and endocarp, highlighting their technological potential and various applications in the food indus-

Table 2
Literature search of publications regarding baru epicarp, mesocarp, and endocarp from 2016 to 2021 with application in the area of food science and technology.

Year	Technological applications and research	Authors	Classification
2021	Nutritional potential and solvent effect of baru pulp and peel bioactive compounds	Da Silva et al.	A
	Nutritional properties, antioxidants, and sucrose crystallization of baru mesocarp	Gadioli et al.	B
	Baru fruit nut and pulp with advantageous nutritional and functional properties	Alves- Santos et al.	C
	Chemical monitoring of alcoholic fermented beverage of baru pulp	Silva et al.	B
	Effect of drying temperatures on the physiochemical characteristics of baru pulp	Morais et al.	A
	Comparative study of pyrolysis products of residues, suggesting application of baru biomass in diverse niches of the industry, including biofuels	Rambo et al.	D
2020	Physiochemical characterization, bioactive compounds, and correlations of fruits native to West Mato Grosso do Sul	De Oliveira et al.	A
	Energetic properties of baru endocarp	Teixeira et al.	D
	Cookies prepared with pre-treated baru pulp	Ferreira et al.	B
	Shelf-life of cookies prepared with baru pulp submitted to varying storage conditions	Barreto Ferreira et al.	B
2019	Chemical and bioactive properties of fruits native to Brazilian Cerrado	Almeida et al.	C
2018	High fiber and phenolic contents and antioxidant capacity of baru peel and pulp	Santiago et al.	A
2017	Physical characteristics of baruzeiro fruit with bias for almond extraction, proving its higher woody endocarp resistance than that of other nuts	Martins et al.	D

Classification based on the focus of publication: composition and nutritional properties (A)/new product development (B)/literature review of Cerrado fruits/baru components(C)/residue re-use (D).

Table 3
Chemical composition, bioactive compounds, and antioxidant capacity of baru mesocarp.

Component	Mesocarp (pulp)						
Macronutrient and energy (g·100 g^{-1})	Gadioli et al. (2021)	da Silva et al. (2021)	Morais et al. (2021)	Silva et al. (2021)	De Oliveira et al. (2020)	Almeida et al. (2019)	Santiago et al. (2018)
Moisture	16.10	15.26	-	19.30	-	17.1	14.9
Proteins	3.08	6.40	-	6.72	-	5.0	3.2
Lipids	1.83	2.30	-	3.00	-	0.9	3.7
Ash	2.88	4.30	-	3.54	-	1.8	3.1
Total fiber	28.71	3.93	-	-	-	-	18.0
Soluble fiber	23.36	-	-	-	-	-	-
Insoluble fiber	5.36	-	-	-	-	-	-
Carbohydrates	-	70.53	-	67.44	-	75.4	57.0
Total sugar	50.46	-	-	-	6.90	-	-
Glucose	2.48	-	-	-	3.30	-	-
Sucrose	29.52	-	-	-	-	-	-
Starch	0.02	30.00	-	-	-	-	-
Reducing sugars	-	40.90	-	24.17	-	-	-
Total reducing sugars	-	96.10	-	-	-	-	-
Pectin	-	1.30	-	-	-	-	-
Energy (Kcal·g^{-1})	-	328.40	-	323.67	-	328.9	276
Total soluble solids (°Brix)	17.91	-	3.90	29.87	4.00	-	-
Titratable acidity	1.30	-	0.95	-	2.30	-	-
pH	5.96	-	6.20	-	4.80	-	-
Activity of water (aw)	0.323	-	-	-	-	-	-
Bioactive compounds							
Tannins	39.30	2.73	14.82	531.00	-	-	-
Total phenolics (mg·GAE·100 g^{-1})	213.94	19.61	44.47	-	510.40	27.6	292.0
Flavonoids (μg·g^{-1})	-	2.77	1.59	-	-	2.4	-
Chlorophyll	-	-	-	-	-	3.8	-
Ascorbic acid	-	26.10	-	-	72.80	224.5	-
Antioxidant capacity (%)							
ABTS (μM Trolox g^{-1})	13.20	-	-	-	1.30	4.1	49.0
DPPH	10.50	-	88.13	-	283.40	68.6	21.2
FRAP	7.20	-	-	-	-	-	24.2

try. For instance, according to da Silva et al. (2021b), baru pulp extract containing abundant phenolics and tannins has serve many industrial purposes; as such, it can be used as a substitute for phenols in adhesive formulations or as an antioxidant in food, pharmaceutical, and cosmetic industrial applications. However, as previously discussed, in addition to these applications, the maturation stage of the fruit and adequate post-harvest handling must be evaluated to ensure desired chemical properties. In this context, Morais et al. (2021) indicated that the best temperature range to dehydrate the baru pulp is between 60 and 70°C, at which the bioactive potential and physicochemical properties of the mesocarp can be preserved.

Four publications in group B focused on the development of products: Gadioli et al. (2021) reported on granulate sugar; Silva et al. (2021b) addressed the development of fermented alcoholic beverages; and Ferreira et al. (2020) and Ferreira et al. (2020) developed cookies using pre-treated baru flour as a substitute for wheat flour, with shelf-life of 80 days when packed in low-density polyethylene (LDPE). The technological potential of baru mesocarp in the bakery industry has already been explored by Rocha and Santiago (2009); the authors prepared bread using baru mesocarp flour and highlighted the high fiber content (7.15%) and low fat concertation, in addition to increased acceptability of baru flour bread, as evaluated based on appearance, texture, and taste attributes, compared with that of wheat flour bread.

Three studies in group D must be highlighted for the reuse of residues. First, Teixeira, Santos, Araujo, Silva, and Alves (2020) tested the energetic properties (moisture, volatile, fixed carbon, and ash content) of the mesocarp and endocarp and concluded that these fractions present high reactivity as fuels (volatile content = 88%). Nonetheless, these fractions also demand attention due to their high ash content (9.24%), which may cause some problems while burning. For instance, ash may lead to the reduction of calorific power and accumulation on ashtrays in the case of direct burning in furnaces when applied as charcoal. Consistently, Rambo et al. (2021) compared the resulting products from the pyrolysis of raw and hydrolyzed baru residues and indicated baru biomass as a potential source for biofuel and biochar production (as an alternative to vegetable charcoal used to sequestrate carbon and reduce CO_2 emissions), proving the biorefinery potential of these residues.

In another study, the endocarp has been reported to be useful for producing vegetable charcoal (Vale & Olsen, 2013). Finally, Martins et al. (2017) characterized the physio-mechanical properties of the endocarp, such as compression and rupture, to determine the deformation tension limit of the fruit for optimizing the peeling process and obtaining undamaged almonds.

In 2021, 11 relevant studies regarding baru fruit were published, of which six were dedicated to the epicarp, mesocarp, and endocarp portions. This evident increase in research on baru fruits, particularly the targeted components, is consistent with the trends and demands of an expanding market.

Consumers expect functional products (Oliveira et al., 2020), and the expansion of and incentives to the commercialization of such products can help the families involved in the extractivist agricultural production chain of the Cerrado biome (Martins, Pimentel, Del Menezzi, & Schmidt, 2009); promote the processing and application of baru in the food industry, given its attractive sensory and technological aspects (Almeida et al., 2019); and corroborate the preservation and valorization of the Brazilian native biodiversity through sustainable exploitation of natural resources while meeting the demands of business niches related to expansion as well as to natural, functional, and sustainable food products (Martins et al., 2009).

Overall, highlights in investigations on the composition and nutritional properties as well as the search for new products of baru demonstrate the current research in consistent with the interests of a more demanding consumer market, since the development of innovative, appealing, healthy, and sustainable products is the most complex industrial challenge today.

4. Conclusions

In the present literature review, we verified that the baru fruit, in its entirety (i.e., including the epicarp, mesocarp, endocarp, and almond), presents evident technological potential for applications in the food industry and related areas. Regardless of the fraction of the fruit, we noted a predominance of relevant studies on chemical composition and new product development. Regarding the innovative applicability of baru almonds, the development of hydro-soluble beverages, formulations that use baru oil as a substitute for other vegetable oils, and preparation of desserts with baru nuts are remarkable. Among other fruit components, the use of the mesocarp is remarkable; this sweet pulp is useful to produce flour and granulated sugar and is also a source of phenolics.

The reuse of industrial waste to develop innovative products is consistent with the trend of a more conscious consumer market that seeks sustainable actions and industries that seek renewable raw materials with proven nutritional value.

Considering the social and environmental roles of baru fruits, it is essential to publicize and expand the potential for commercial exploitation of this fruit as well as its applicability in food science and technology.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

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