Future Foods 5 (2022) 100146

Contents lists available at ScienceDirect

Future Foods

journal homepage: www.elsevier.com/locate/fufo

A review on Brazilian baru plant (*Dipteryx alata* Vogel): morphology, chemical composition, health effects, and technological potential

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ARTICLE INFO

Keywords:
Cerrado
Oilseed
Obesity
Phenolic compounds
Emulsifier
Dyslipidemia

ABSTRACT

Among the native flora of the Brazilian Cerrado, there is baru (*Dipteryx alata* Vogel), a sensory pleasing fruit species of the Leguminosae family composed mainly of peel, pulp, and almond, which can be used in full and has high nutritional value and technological potential. Almonds are generally intended for fresh consumption or oil extraction, while the pulp can be minimally processed and become an ingredient for the preparation of food products. Nutritionally, baru has all the nutrients of a balanced diet, but special attention has been given to the minor bioactive compounds, which are responsible for providing antioxidant activity. Some studies have investigated the effects of baru consumption on health, revealing promising results regarding metabolic diseases, oxidative stress, cancer, atherogenesis, microbial infection, and snake venom poisoning. Technologically, baru has potential for application in several areas, such as food, microbiological, and energy. In this context, baru has been used as an emulsifying, foaming, viscosity, texturizing, and sanitizing agent, as well as to produce biofuel and charcoal. Thus, the objective was to deliver the most complete review on baru, presenting from its morphological and chemical composition aspects to health effects and technological use.

1. Introduction

Cerrado, also known as tropical savanna, is a global biodiversity hotspot, meaning it has areas that present high concentrations of endemic species and that has been experiencing an extremely and relevant loss of habitat. Considered the second biome in Brazil in terms of territorial extension (204.7 million hectares) and distributed in the states of Bahia, Maranhão, Piauí, Goiás, Mato Grosso, Mato Grosso do Sul, Minas Gerais, Tocantins, São Paulo, Distrito Federal, Paraná, and Rondônia (Fig. 1A), the Cerrado accommodates the main hydrographic basins responsible for water supply (43% of Brazil's surface water outside the Amazon), and participates actively on a large part of the country's agricultural production (Embrapa, 2001; Myers et al., 2000; Parente et al., 2021; Strassburg et al., 2017). In addition, Cerrado has a heterogeneous biodiversity, both in fauna and flora, second only to the Amazon in terms of species richness. It is estimated that there are around 4400 species of plants in the Cerrado, but only 30% of them are fully known concerning their benefits and potentials (Fank-de-Carvalho et al., 2015; Myers et al., 2000).

From the native flora of the Cerrado biome, baru (*Dipteryx alata* Vogel) is a fruit species of promising cultivation, with wide territorial coverage, pleasant sensory, and with high nutritional and economic potential (Corrêa et al., 2000; Magalhães, 2014). The fruit has a thin rind wall adhering to the pulp, which exhibits sweetness and peculiar astringency. Also, there is a firm and woody portion that surrounds and protects the seed (almond). The seed, covered by a thin film, has rigid consistency and flavor similar to peanuts (Fernandes et al., 2010; Oliveira et al., 2017).

Nutritionally, baru is a source of carbohydrates, proteins, lipids, and minerals. Additionally, it has very interesting contents of bioactive compounds, such as polyphenols and carotenoids. Due to its promising composition, some studies seek to investigate the existence of possible beneficial effects of baru on health. So far, researchers found that the species can be potentially used against metabolic diseases, oxidative stress,

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https://doi.org/10.1016/j.fufo.2022.100146
Received 24 November 2021; Received in revised form 21 March 2022; Accepted 24 April 2022

Abbreviations

ABTS	2,2′-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid) assay;
ALDH1	Aldehyde dehydrogenase 1
CKD	Chronic kidney disease
CRC	Colorectal cancer
CRP	C-reactive protein
DPPH	2,2-diphenyl-1-picrylhydrazyl assay
FRAP	Ferric reducing antioxidant power
HDL	High-density lipoprotein
HDL	High-density lipoprotein
LDL	Low-density lipoprotein
MUFA	Monounsaturated fatty acids
PUFA	Polyunsaturated fatty acids
TC	Total cholesterol
TG	Triglycerides
TPC	Total phenolic content
VLDL	Very-low-density lipoprotein.

cancer, microbial infections, and even snake venom poisoning (Souza et al., 2018, 2019; Ferraz et al., 2012; Ribeiro et al., 2014; Santos et al., 2017).

Regarding baru's technological potential, it was observed that the volume of research and discussion involving the use of this species is still very limited. Thus, a deeper analysis of existing studies allowed us to predict the technological properties of baru and suggest its possible applications in different areas, such as food, microbiological, and energy. In food systems, baru can act as an emulsifying, texturizing, and even foaming agent (Alves et al., 2010; Cruz et al., 2011; Guimarães et al., 2012; Koyoro and Powers, 1987; Pineli et al., 2015a 2015b; Sousa de Oliveira et al., 2020). Furthermore, as it has activity against pathogenic microorganisms, it can be used as a natural sanitizing agent (Ragozoni et al., 2021; Sadgrove et al., 2020). The technological role of baru in the energy production sector involves both the production of more efficient biofuels and the possibility of acting as an adsorbent for inorganic substances present in fuels (Batista et al., 2012; Beltrão et al., 2008; Mosquetta et al., 2011). Additionally, the rind of the fruit and the woody endocarp can be used for the production of high calorific value charcoal (Carrazza and Avila, 2010; Teixeira et al., 2020; Vale and Olsen, 2013).

Exploited by local extractivism with low environmental impact, baru is cultivated by rural communities, which benefit from the entire production chain, guaranteeing sustenance, and income. The ripe fruits are mainly taken from the almonds, which are destined for industries, cooperatives, and commercial organizations (Vera et al., 2009). Imperfect almonds are generally cold-pressed to remove the oil, being mainly intended for commercialization (Carrazza and Avila, 2010). The fleshy pulp is intended both for human consumption (minimally processed by roasting or in the form of elaborate food products) and for animal feed in periods of food shortage. However, the inconsistent infrastructure for the production and processing of fruits, seasonality, non-sustainability, and limited information about the consumer market are the main bottlenecks for the expansion of the baru crop (Magalhães, 2014; Parente et al., 2021).

Therefore, this work presents an updated set of information (taxonomy, plant characteristics, distribution, popular uses, bioactive composition, health benefits, and technological potential) regarding the baru plant in order to facilitate the understanding of the potential of this species in several areas. Additionally, aspects related to the preservation of the biome and the species will be addressed.

2. Taxonomy, morphology, distribution area, and popular uses

2.1. Taxonomy, morphology, and distribution area

Based on the Cronquist Classification System, baru belongs to the *Magnoliophyta* Division (*Angiospermae*), the *Magnoliopsida* Class (*Dicotyledoneae*), the *Fabales* Order, the Fabaceae Family (*Leguminosae*), the *Dipteryx* genus, and the species *Dipteryx alata* Vogel. Depending on the location, baru is known by different names, such as bajuró, cumaru, cumarurana, and feijão-coco (Carvalho, 1986).

The baru tree, also known as barueiro or baruzeiro, has an average height of 15 m and can reach up to 25 m in adulthood. It is characterized by irregular branches, has a low, wide, and rounded crown between 6 and 11 m in diameter. Its trunk is easily peelable, tortuous, light gray, and may have a smooth or irregular surface (Fig. 2A). The leaves are pinnate, have a bright green, alternate, petiolate, without stipules, and with winged rachis, giving rise to the species name (winged = *alata* in Portuguese language) (Fig. 2B). The flowers are purplish-white, hermaphrodite, and small, between 0.8 and 20.0 cm in size. The flowering of this species occurs at different times, depending on the location. In the states of Mato Grosso do Sul and Piauí, it occurs from October to November. On the other hand, in Mato Grosso and Minas Gerais, it occurs from November to May. Finally, in Goiás, São Paulo, and Distrito Federal it occurs from October to December, October to January, and November to December, respectively. The fruiting also depends on the location, so that in the states of Mato Grosso, Distrito Federal, Goiás, São Paulo, and Minas Gerais the fruits ripen from May to July, August to September, August to October, September to October, and October, respectively (Carvalho, 1986; Sano et al., 2009). The av-

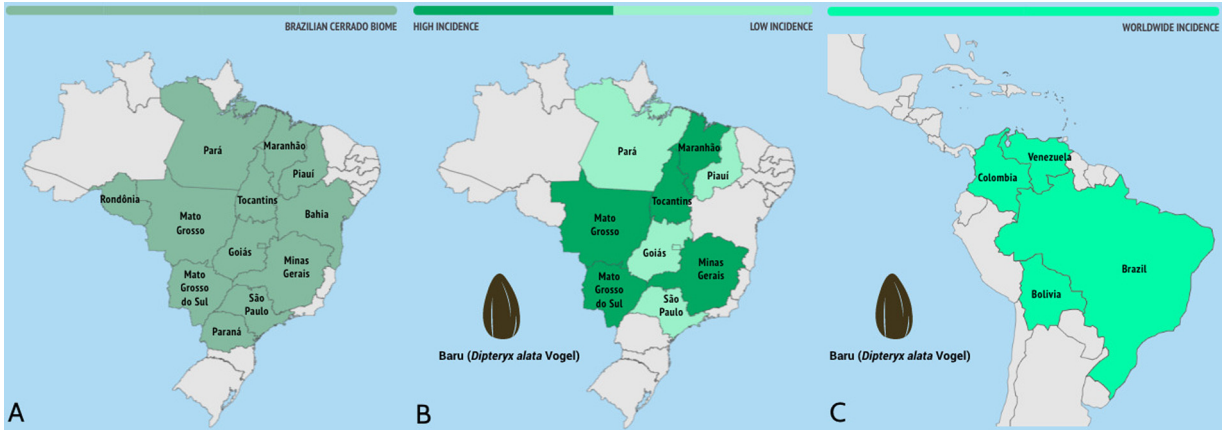

Fig. 1. A. Distribution of the Brazilian Cerrado biome. **B.** Distribution of the baru plant (*Dipteryx alata* Vogel) in Brazil. Areas with the highest incidence are represented as darker green. **C.** Worldwide incidence of the baru plant (*Dipteryx alata* Vogel).

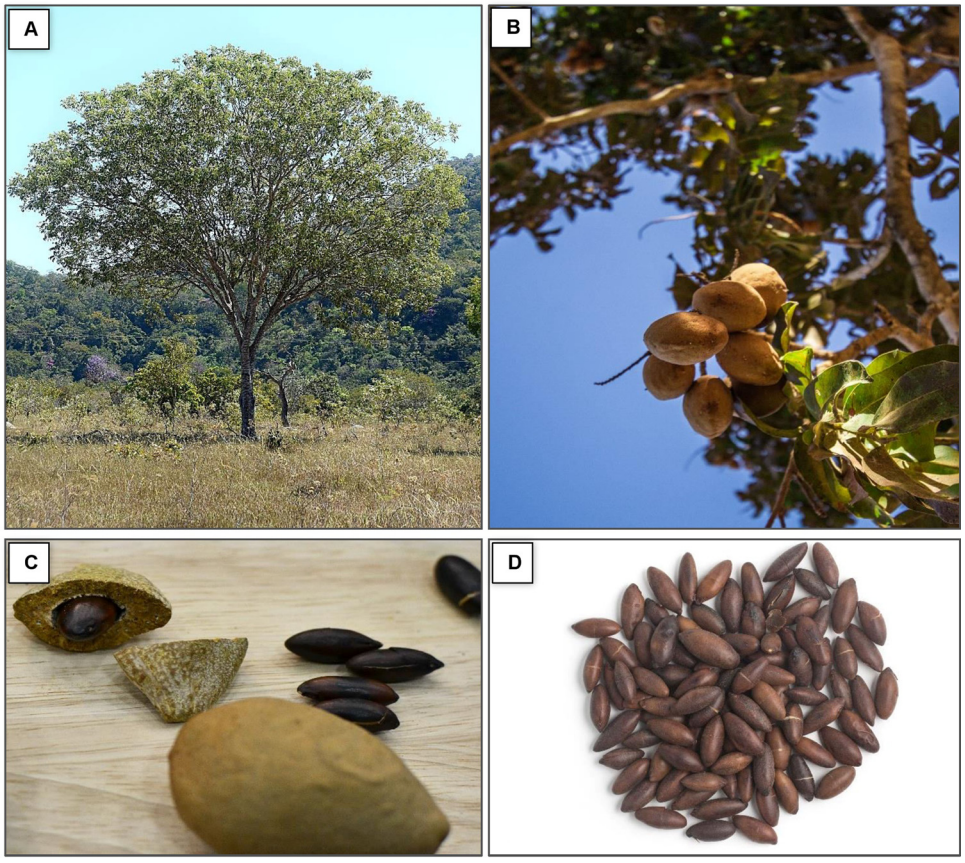

Fig. 2. **A.** Baru tree (*Dipteryx alata* Vogel). **B.** Branches, leaves and baru fruits. **C.** Whole baru fruit and wood endocarp surrounding the almond. **D.** Roasted baru almonds. Images: Shutterstock Inc., Standard License (Images code: A. 2008642472; B. 674070145; C. 12028339591; D. 623526749).

erage fruit production per tree can reach 6.000 fruits, depending on the area where it is located. Trees that develop in pasture areas, in general, have higher fruit production (Alves et al., 2010; Sano et al., 2004).

The fruits are classified as a drupe, have an ovoid shape, a slightly flat surface, and measure about 1.5 to 5.0 cm in length. The fruits are composed of a thin, rough, brownish-colored skin (epicarp); a fleshy, sweetened, and fibrous pulp, which is called mesocarp (about 30% of the fruit fresh weight); and a single almond (seed), which is surrounded by a woody and rigid structure, where both make up the endocarp, corresponding to 65% in fresh weight (Fig. 2C). The almond is characterized by ellipsoid shape, smooth texture, color ranging from reddish-brown to almost black, and by transverse cracks in the thin film that protects it, allowing visualizing the interior color, from white to cream (Carrazza and Avila, 2010; Martins et al., 2017; Sano et al., 2004).

Baru has a wide distribution in Brazil, occurring in the states of Goiás, Maranhão, Mato Grosso do Sul, Pará, Piauí, Tocantins, Minas Gerais, São Paulo, Mato Grosso, and in the Federal District (Carvalho, 1986). However, the highest incidences (probability > 20%) are in the States of Minas Gerais, Mato Grosso, Mato Grosso do Sul, Tocantins, and Maranhão (Serviço Florestal Brasileiro, 2019) (Fig. 1B). Abroad, baru is found in Paraguay, Bolivia, and Colombia (Fig. 1C). It grows very well in well-drained, sandy-clay soils, in medium fertility, and in tropical and altitude subtropical climates (Carvalho, 1986; Sueli Matiko Sano et al., 2004) (Fig. 1D).

2.2. Popular uses

Due to its economic potential and environmental aspects, baru is used in different ways (Rezende et al., 2019). However, the plant is at risk of extinction due to an the increase in indiscriminate exploitation practices for medicinal, logging, industrial, landscape, and forestry uses (Alves et al., 2010). Baru is well known in folk medicine for having anti-rheumatic and healing properties, in addition to contributing to the control of anemia, cholesterol, diabetes, and even increased fertility. The fruit bark is used in the treatment of snake bites, whereas the pulp is intended to produce sweets, liqueurs, cereal bars, and cookies, mostly consumed by the local population. The almond, the component of the fruit with the highest commercial value, is known to help reduce abdominal fat in overweight women, and it prevents oxidative stress-fighting free radicals. The oil, extracted from the almond, is used as an antipyretic, antirheumatic, and menstrual regulator (Leite et al., 2020; Lemos et al., 2012a; Puebla et al., 2010; Siqueira et al., 2012).

Due to its fleshy pulp, baru fruits are also used as food for birds and mammals, especially during the dry season, a period in which residents who subsist on almond extraction leave the fleshy pulp in the soil for the animals to feed. This makes baru a species of great importance for the maintenance of the natural fauna of the Cerrado (Boni et al., 2016). In the sustainability area, some farmers associations and family cooperatives that benefit and seek to preserve the baru and the Cerrado, began to cultivate it more intensely in springs, riverbanks, and streams, both to recover them and to promote the conservation and maintenance of several native species (Nepomuceno et al., 2006; Sano et al., 2004; Santos et al., 2012).

The nutritional and sensory characteristics of baru are so peculiar that it is considered a species of great interest for application in the formulation of new food products. In general, the fruit is used both as a substitute for some well-known culinary ingredients, such as flour and oils, and in the enrichment of bread, cakes, and cookies, for example, to increase the nutritional quality of these products (Ferreira et al., 2020; Freitas et al., 2014; Pineli et al., 2015b).

Some studies on the full use of baru in food formulations are presented next: preparation of low-fat cupcakes using baru almond flour (Ortolan et al., 2016; Paglarini et al., 2018); use of partially defatted baru almond flour, resulting from oil extraction, in the production of

Table 1
Nutritional composition of baru (Dipteryx Alata Vogel).

Nutrient	Almond (Raw)	Almond (Roasted)	Almond (Oil)	Pulp	Peel	Reference(s)
Moisture (g/100 g)	5.59 – 9.95	6.8 - 9.64	–	13.8 - 14.9	16.3	(Alves et al., 2010; Egea and Takeuchi, 2020; Santigo et al., 2018; D.V. Silva et al., 2019; Siqueira et al., 2015)
Calories (kcal/100 g)	345.2 – 546.2	345.23 - 501	476 - 560	269.8 - 276	240	(Alves et al., 2010; Bento et al., 2014; Fetzer et al., 2018; Santigo et al., 2018; Siqueira et al., 2015)
Carbohydrates (g/100 g)	12.25 – 37.13	11 – 13.6	7.28	54.9 - 57	51.5	(Alves et al., 2010; Bento et al., 2014; Campidelli et al., 2020; Fernandes et al., 2010; Fetzer et al., 2018; Santiago et al., 2018)
Dietary fibers (g/100 g)	12 – 16.12	16 – 16.12	19.04	18 – 19.1	24.1	(Alves et al., 2010; Bento et al., 2014; M. Campidelli et al., 2019; Santigo et al., 2018; Siqueira et al., 2015)
Protein (g/100 g)	19.72 – 30.0	22.9 – 25.8	29.59	3.2 – 4.2	2.5	(Alves et al., 2010; Fernandes et al., 2010; Fetzer et al., 2018; Santiago et al., 2018; Siqueira et al., 2015)
Lipids (g/100 g)	31.73 – 42.4	40.6 – 41.9	40.27	3.7	2.7	(Alves et al., 2010; Bento et al., 2014; Campidelli et al., 2019; Fernandes et al., 2010; Fetzer et al., 2018; Reis et al., 2018; Santiago et al., 2018; D.V. Silva et al., 2019; Siqueira et al., 2012; Zappi et al., 2015)
Fatty acids (mg/g)	–	–	SFA 192.5 - 270, MUFA 474 - 462.2, PUFA 281.9 - 267.8, ω6 265.5, ω3 2.3, ω6: ω3 115:1, OA 417.1 - 446.5, LA 264.6 - 280.5, other 0.4 - 83.0.	–	–	
Ashes (g/100 g)	1.55 – 3.81	3.1 – 4.44	–	3.1 – 4.3	2.9	(Alves et al., 2010; Campidelli et al., 2020; Santigo et al., 2018; D.V. Silva et al., 2019; A. Siqueira et al., 2015)
Minerals (μg/g)	Selenium 0.515, Zinc 4.7, Iron 6.5	Zinc 4, Iron 5	–	–	–	(Bento et al., 2014; Campidelli et al., 2020; Greco et al., 2018; Siqueira et al., 2015, 2012)
Vitamin C (mg/100 g)	18.8	18.5	–	–	–	(Campidelli et al., 2020b)
Vitamin E (mg/100 g)	–	21.4	–	–	–	(Bento et al., 2014)

Only published articles were considered for this table. Abbreviations: LA: linoleic acid, MUFA: monounsaturated fatty acids, OA: oleic acid, PUFA: polyunsaturated fatty acids, SFA: saturated fatty acids, ω: omega.

gluten-free cakes (Pineli et al., 2015a), and as a partial substitute for wheat flour in the preparation of cookies (Pineli et al., 2015b); preparation of "paçocas" (Brazilian peanut candy) with baru almonds, replacing peanuts (Santos et al., 2012); elaboration of fermented beverage flavored with a water-soluble extract from baru almond (Fioravante et al., 2017); production of biscuits from baru pulp flour (Freitas et al., 2014; Ferreira et al., 2020); preparation of mayonnaise containing baru oil (Rojas et al., 2019); cereal bar production using the pulp and almonds from baru, replacing oat bran, nuts, and dried fruits (Lima et al., 2010); granola production added with baru almond (Souza and Silva, 2015); yogurt production containing baru almond extract (Vieira, 2017).

Baru peel, in turn, can be used as raw material for the production of charcoal (Vale and Olsen, 2013). The extracted oil from almonds, beyond its consumption, is also used as fuel for the production of biodiesel (Batista et al., 2012). Finally, the pulpless fruits that should be disposable are used to make handicrafts (Carrazza and Avila, 2010).

3. Nutritional value, chemical characterization, and antioxidant capacity

Baru *in natura* presents the following structural average composition: 41.9% of pulp (epicarp and mesocarp), 53.8% of woody endocarp, and 4.3% of seed (De Andrade Martins et al., 2017). Studies that evaluated the composition of baru almonds highlight proteins and lipids as the main constituents (Carrazza and Avila, 2010). According to Campidelli et al., 2020b and Souza et al. (2018b), the nutrients in the baru almond are distributed as follow: 23 – 30% protein, 40% fat (18% saturated fatty acids, 51% monounsaturated fatty acids, 31% polyunsaturated fatty acids), 12% carbohydrates, 12.5% dietary fibers, and minor levels of minerals, such as calcium, iron, and zinc (Table 1).

The pulp has the highest energy value, while the concentration of proteins in the almond is outstanding (Fernandes et al., 2010). The seed has been the most used part of the fruit, which is rich in proteins, lipids, dietary fibers, and minerals mainly (Siqueira et al., 2016). In the roasted baru seeds, there is a high protein content (around 22.9 to 25.8 g/100 g), as long as lipids (40.6 to 41.9 g/100 g), and dietary fibers (around 16 g/100 g). The fiber content of the peel and pulp, however, when compared to the almond, is the highest, around 24% (Table 1). According to Santiago et al. (2018), a portion of 20 g of baru almonds can supply approximately 10% of the Dietary Reference Intake for dietary fibers.

Notably, the caring to process and cultivate the fruit is needed, once the morphological and structural parts of the plant are affected physiologically and biochemically (Silva et al., 2020a). Therefore, the physicochemical, mineral, microbiological properties, and sensorial aspects may vary considerable. In addition, the percentages of saturation and unsaturation of lipids can change, depending on the extraction process employed to obtain the baru oils (Alarcon et al., 2020). Regarding the storage conditions, the baru seeds undergo biochemical changes over time such as enzymatic activity, membrane peroxidation reactions, compound accumulation, and degradation. Even though baru fruit is found in regions with high sun exposure, some intrinsic characteristics of the plant's defense system promote protection through the biosynthesis of secondary compounds or bioactive agents (*e.g.*, polyphenols) (Campidelli et al., 2020c; Silva et al., 2020a).

3.1. Lipids

Baru has been regarded as a natural source for the extraction of a vegetable oil having a great nutritional quality (Siqueira et al., 2016). Regarding unsaturated fatty acids, both oleic acid and linoleic represent a major proportion in baru (Fernandes et al., 2010; Nunes et al., 2017;

Oliveira-Alves et al., 2020). In the seeds, the fatty acids have the following distribution: oleic (50–53%), linoleic (23 - 25%), palmitic (around 5%), stearic (around 5%), and arachidonic (around 4%) (Table 1) (Fetzer et al., 2018). The Dietary Guidelines for Americans recommends an average polyunsaturated fatty acids ingestion of 20 g daily, therefore, the consumption of 64 g of baru almonds can provide 100% of this amount (Campidelli et al., 2020b).

As a natural source of lipids (Siqueira et al., 2016), baru oil possess a low acidity index (about 0.28 mg KOH/g), which is another important parameter of quality. The value is closer to those observed in refined and processed commercial oils, such as virgin olive (0.22) and soybean (0.04) oils. Either, the iodine index measured in the baru oil was 72.9 (g I_2/100 g of oil), which is comparable to those from olive (71.4) and soybean (83.1) oils (A. P. S. Siqueira et al., 2016). These markers can indicate an interest stability and quality of the baru oil (Campidelli et al., 2020b).

Finally, baru oil has an adequate peroxide content for crude oils. The initial oxidation state of vegetable oils can indicate their deterioration powder which can prejudice some nutritional components, such as vitamin E. Alike soybean oil and olive oil, the peroxide index of crude baru oil is lower than 2.00 (1.61 meq O2/kg of oil). Also, according to (Siqueira et al., 2016), baru oil can be compared with peanut oil in terms of physicochemical parameters.

3.2. Protein

The protein content of baru almonds is higher than beans (*Phaseolus vulgaris* L.), lentils (*Lens culinaris* Med), peas (*Pisum sativum* L.), and chickpeas (*Cicer aretinum* L.) (Costa et al., 2006). Regarding its amino acids composition, the almond contents lysine deficiency in similarity to beans (*Phaseolus vulgaris*). However, the baru almonds tend to contain more sulfur amino acids than common beans, which are typical protein-based vegetable foods consumed in many countries, including Brazil (Fernandes et al., 2010).

The amino acids and bioactive compounds within baru seem to promote benefits to health since the consumption of vegetable-based diets is associated with the prevention of chronic diseases (Siqueira et al., 2016). However, the biodisponibility of amino acids depends on the digestibility of proteins of each organism (Guimarães et al., 2012). A study by Guimarães et al. (2012) compared the protein composition of baru defatted flour, protein concentrate, or their fractions, and performed an *in vitro* digestibility test. As results from this study, the majority of globulin is encounter in the flour, and the albumins, in the protein concentrate. The protein concentrate showed the best protein digestibility, around 7% higher. Furthermore, the residues of the extraction of seeds still presented high contents of proteins (32%) (Table 2), despite having gone through compressed propane, supercritical CO_2 with ethanol as a solvent, and the conventional Soxhlet extraction using ethanol and hexane (Guimarães et al., 2012).

Throughout thermal properties of thermogravimetry and differential scanning calorimetry, which are efficient ways to know the behavior in a linear temperature scale processing food, an experiment with the defatted, concentrated, and isolated baru nuts protein was performed. According to Vijayakumar & Kurup (1973), the high level of proteins present in baru suggests the need for energy to break the disulfide bonds. However, based on the same study, the results demonstrated that an increase in proteins concentration was not accompanied by an increase of enthalpy. Therefore, the authors suggest that the process applied to obtain the concentrate and isolate of baru leads to protein denaturation. Overall, this useful information should be better understood for functional and nutritional formulations.

In addition, It is known that plants with high contents of protein have the Bowman-Birk family of inhibitors. Their structures show two inhibitory sites to serine proteases-trypsin, chymotrypsin, and elastase. The inhibitory catalytic activities of proteolytic enzymes from some classes of plant proteins such baru may have a defensive function against pathogens, wounding, and stress. However, studies of isoinhibitors present in plants are still to be understood (Kalume et al., 1995).

3.3. Minerals

The macronutrients composition of the baru almond are well known, however, micronutrient contents are not completely clarified by studies yet (Fernandes et al., 2010). According to Vera et al. (2009), calcium, iron, and zinc can be found in high concentrations in the baru almond. The authors showed that the almond, however, is limited in sulfur amino acids. A recent report made by (Greco et al., 2018) showed that the baru nut has interesting amounts of selenium, between 0.515 – 0.657 $\mu g/g$.

Regarding bioaccessibility tests after digestion *in vitro*, baru almond showed the following mineral recovery percentages: copper (16.8), iron (21.4), manganese (80.3), and zinc (81.3) (de Oliveira Gonçalves et al., 2020). Among that, contents of potassium, calcium, phosphorus, magnesium, iron, zinc, copper, and manganese from the epicarp and mesocarp were also reported. The authors suggest that the fruit flours might be a potential functional food when thinking of mineral enrichment (Silva et al., 2019). This species has already been gain commercially valued due to it is high protein value, zinc, and iron contents (Zuffo et al., 2017).

3.4. Carotenoids, phenolic compounds, and antioxidant capacity

Baru is also a source of bioactive compounds, such as carotenoids, phenolic compounds, and tannins. For example, a research by Siqueira et al. (2016) found a total carotenoids content around 11.40 μg/100 g in the whole baru almond. More recently, the contents of α-carotene, β-carotene, and lycopene in the almond were described as 19.5, 20.7, and 15.1 $\mu g/g$, respectively (de Oliveira Gonçalves et al., 2020).

In addition to its carotenoids content, according to Oliveira-Alves et al. (2020), in the crude baru nut extract is possible find at least 12 phenolic acids and 6 tannins types. For that, two extracts were characterized; crude and hydrolyzed. The main phenolics identified in both forms were p-coumaric, isoferulic acid, ellagic acid, gallic acid, and gallic acids derivatives such as gallic acid esters and gallic tannins (Table 2). In the baru fruit, gallic acid, catechin, ferulic acid, and tannins seem to be the main phenolic compounds responsible for its antioxidant capacity (Santigo et al., 2018). Overall, the importance of baru in an antioxidant role mainly concerns to its phenolic acids, phytic acid, and tannin arrangement compositions (Campidelli et al., 2020c).

Regarding the antioxidant capacity, which was measured by 2,2′-azinobis-(3-ethylbenzothiazoline-6-sulfonate (ABTS), 2,2′-diphenyl-1-picrylhydrazyl radical (DPPH), or ferric reducing antioxidant power (FRAP) assays, the raw baru almond had the highest antiradical capacity, as the values found in the roasted almond were 7% to 24% lower. As expected, the raw almond has around 50% more phenolics than its roasted version (Santigo et al., 2018) (Table 2). Lastly, the antioxidant capacity of the pulp plus peel was comparable to that of baru almond (Santigo et al., 2018) (Table 2).

When the peel and pulp fractions of baru are included in the extraction process, the values of phenolic compound are even higher (Araújo et al., 2017). A study by (Silva et al., 2020b) using an extraction optimization method for the phenolic compounds of baru almond associated with the pulp and peel was performed. The product showed an interesting phenolic content and antioxidant capacity when compared to other oilseeds (Egea and Takeuchi, 2020; Fioravante et al., 2017). The pulp with peel of baru presented a great total phenolic content (TPC) than that of the roasted almond, which was higher in comparison to other ten fruits widely consumed in Brazil, including açai (*Euterpe oleracea*) and red grape (*Vitis vinifera* L.) (Santigo et al., 2018).

According to (Campidelli et al., 2020b), the main minor bioactive compounds (and content) found in the ethanolic extract from

Table 2
Minor bioactive compounds and antioxidant capacity of baru (Dipteryx Alata Vogel).

Product	Carotenoids	Phenolic compounds	Antioxidant capacity	Reference(s)
Almond flour *in natura*	Carotenoids (μg^{-1} of lutein) 10.7	TPC (mg of GAE/100 g) *** 186.2 Total flavonoids (mg of pyrocathechin/100 g) 6.70	ABTS test (μmol TE/g) * 13.82 *DPPH test (μmol TE/g) * 9.53	(D.V. Silva et al., 2019)
	1.43	TPC (mg/100 g) 588.11 Tanins (mg/100 g) 992.51	DPPH (μmol TE/g) * (Spectrophotome-try) 130.93 Tocopherol (mg/100 g) (HPLC-DAD) 1.46	(Siqueira et al., 2015)
	–	TPC (mg GAE/100 g) *** 728	(μmol TE/g) * ABTS 77.0 DPPH 76 FRAP 126.8	(Santigo et al., 2018)
Bark (tree)	–	Vanillic acid, Vanillin, and Protocatechuic acid 6 mg	–	(Puebla et al., 2010)
Roasted baru	–	–	(mg GAE/g) ABTS*** 1.17 FRAP*** 8.34	(da Cruz et al., 2019)
Raw Almond (oil)	–	TPC (mg GAE/100 g extract) *** (Soxhlet method) 1260 (Hexane) 1118 (Ethanol)	Tocopherol total (mg/100 g) Soxhlet method 9.45 (Hexane) 8.85 (Ethanol) (μmol TE/g)* ABTS (μmol TE/g)* by Soxhlet method 9.98 (Hexane) 23.20 (Ethanol)	(Fetzer et al., 2018)
Peel	–	TPC (mg GAE/100 g) *** 477	(μmol TE/g) * ABTS 60 DPPH 45 FRAP 50	(Santigo et al., 2018)
Peeled and Roasted nuts	β-Carotene/linoleate inhibition (%/g) (Spectrophotometry) Aqueous 6.0 Ethylacetate 0.6	TPC (mgTAE 100/g) Aqueous 154.6 Ethylacetate 3.1 Tannins (mg/100 g) 472.2	DPPH (μmol TE/g) * Tannic acid equivalents (mgTAE 100/g) Aqueous 0.8 Ethylacetate 0.6 FRAP (FeSO4μmol/g) ** Aqueous 8.3 Ethylacetate 1.2	(Siqueira et al., 2012)
Pulp	–	Total phenolics (mg GAE/100 g)*** 292	(μmol TE/g)* ABTS 49 DPPH 21.2 FRAP 24.2	(Santigo et al., 2018)
Almond; roasted or its flour	–	TAC (mg/g) 0.005 TCC (mg/g) 0.005	Antioxidant activity (%) 99.42	(Ragassi Fiorini et al., 2017)
Raw Almond	–	TPC (mg GAE/100 g) 1.107	(μmol TE/g) * ABTS 100 DPPH 81.0 FRAP 157	(Santigo et al., 2018)
	β-carotene/linoleic acid system (% protection) as ascorbic acid (Spectrophotometry) TPC; * ***GAE 91.72	TPC GAE (mg/100 g) *** 1254.12 TPC (Fast Blue BB) GAE (mg/100 g) *** 179.14 Monomeric Anthocyanins (mg/100 g) as malvidin-3,5-diglucoside (Spectrophotometry) 0.38 TFC QE (mg/100 g) as equivalents of catechin (Spectrophotometry) 9.17 Tannins CE (g/100 g) as equivalents of catechin (Spectrophotometry) 1.51	ORAC (μmol/g) 4.06 DPPH (% SRL) 69.02	(Campidelli et al., 2020b)
	–	TPC (mg GAE/100 g) *** 561.98	(μmol TE/g) * ABTS 170.72 DPPH 259.10 FRAP 144.49	(Silva et al., 2020b)
	Carotenoid (μg/100 g) (HPLC) 11.40 ± 0.40	TPC (mg GAE/100 g) *** 388.04 Tanins (mg/100 g) 562.87	DPPH (μmol TE/g)* (Spectrophotome-try) 67.00 Tocopherol (mg/100 g) (HPLC-DAD) 11.61	(Siqueira et al., 2016)
Almond; hydro-methanolic extracts (crude or hydrolyzed)	–	Crude extract* **** TPC (mg/100 g) 492 Hydrolyzed extract* ***** TPC (mg/100 g) 574	Crude extract* **** ORAC (mg/g) 88.71 HOSC (mg/g) 116.22 Hydrolyzed extract* ***** ORAC* (mg/g) 88.71 HOSC*(mg/g) (Liquid chromatography) 116.22	(S.C. Oliveira-Alves et al., 2020)

Only published articles were considered for this table. Abbreviations: DPPH – 2,2-diphenyl-1-picrylhydrazyl assay; FRAP – Ferric reducing antioxidant power assay; GAE – Gallic acid equivalent; TE – Calibration curve of Trolox; TPC – Total phenolic content; HPLC – High-performance liquid chromatography; TCC – Total carotenoids content; TFC – Total flavonoids content; ORAC: oxygen radical absorbance capacity; ABTS: 2,2-azinobis 3-ethylbenzthiazoline-6-sulfonic acid radical scavenging assay; HPLC: high-performance liquid chromatography. *Antioxidant results are presented in μmol of Trolox equivalent/g; **Antioxidant results are presented in μmol FeSO4/g; ***Antioxidant results are presented in mg of gallic acid equivalent/g; **** For crude methanolic extract: 10 g of ground baru nuts were extracted with 100 mL of methanol: water (80:20, v/v) solution at room temperature (BCE); ***** For hydrolyzed methanolic extract: 10 g of ground baru nuts were extracted with 100 mL of methanol: water: HCl (80:16:4, v/v/v) (S.C. Oliveira-Alves et al., 2020).

the baru almond are: tannins (1.51 g/100 g), total flavonoids (9.17 mg/100 g), vitamin C (39.14 mg.100 g^{-1}), and monomeric anthocyanins (0.38 mg/100 g). Also, from this study, the antioxidant capacity by oxygen radical absorbance capacity, DPPH, and TPC assays were measured. The results were 4.06 mg/100 g, 69.02%, and 1254.12 mg of gallic acid equivalent/100 g, respectively (Table 2). Regarding the detection of TPC, specifically, two different procedures were used. The TPC indicated 1254.12 (mg/100 g), and the Fast Blue BB showed 179.14 (mg/100 g) of gallic acid equivalent/g (Table 2). In more details, the composition of α-tocopherol content, phenolic values, and antioxidant capacity by ABTS, DPPH, and FRAP assays are detailed in Table 2.

Baru has an interesting content in polyphenols (catechin, rutin, gallic acid, caffeic acid, chlorogenic acid, o-coumaric, and trans-cinnamic acid), sterols, vitamins C and E, minerals (boron, zinc, copper, manganese, magnesium), and monounsaturated (linoleic) and polyunsaturated (oleic) fatty acids. Therefore, it has been suggested that the fruit could be a substitute of other nutrients-rich and polyphenol-rich nuts consumed worldwide. such as almonds, walnuts, cashews, hazelnuts, macadamia nuts, pistachios and walnuts (Campidelli et al., 2020c).

4. Health effects

As a plant with none or low cytotoxicity or genotoxicity (Esteves-Pedro et al., 2011, 2012; Ribeiro et al., 2014), baru, its extracts, and/or bioactive compounds might be used to improve the general well-being and prevent or treat communicable and noncommunicable diseases. According to our research, a total of 19 literature publications, dating from 2010 to 2021, have demonstrated the direct effects of the baru plant on

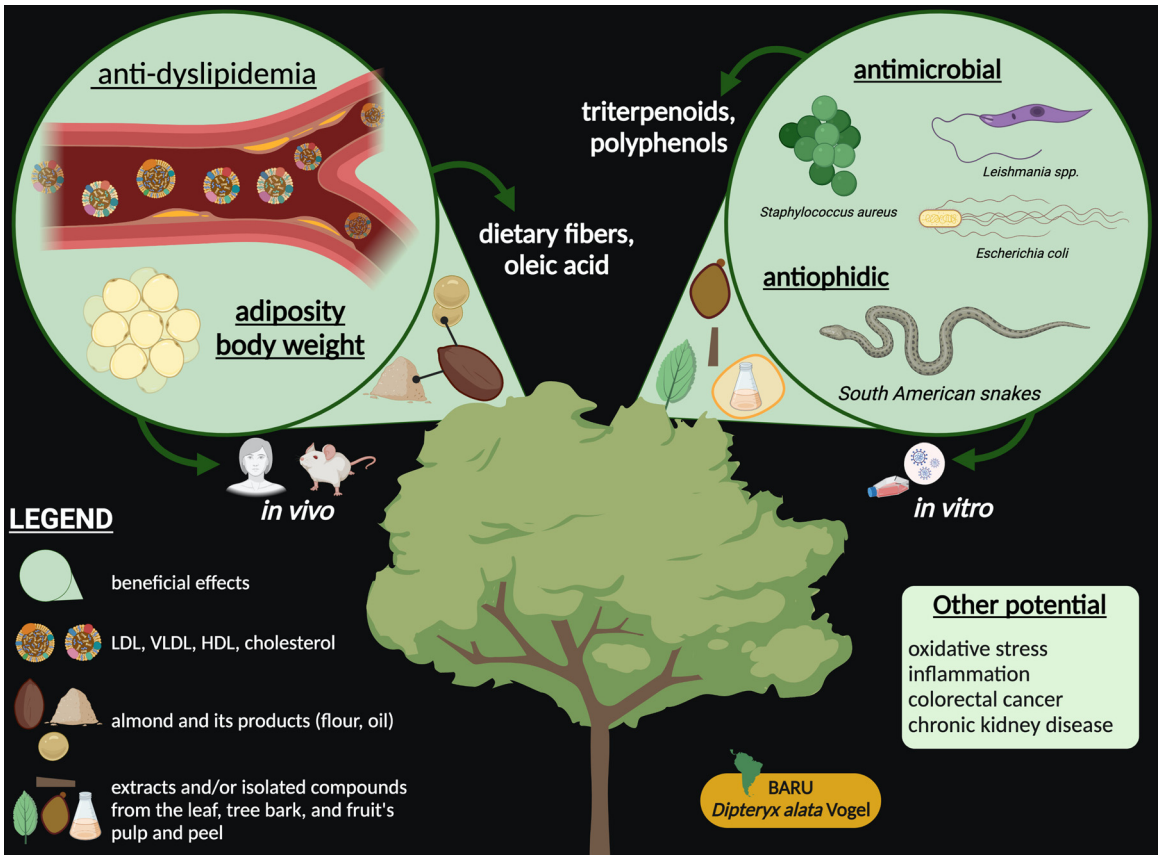

Fig. 3. The health effects and potential of the baru plant (*Dipteryx alata* Vogel) and its bioactive compounds. Image created on BioRender.

health. Investigations are spread similarly among *in vitro* (7), animal (7), and human (5) protocols. Articles testing the fruit's roasted almond or its products (flour and extracts) account for the majority of the studies (14). Other less-frequent tested fractions include the fruit's peel and pulp, the plant leaves, and the tree bark.

So far, the baru plant has shown potential benefits against metabolic conditions or diseases (Araújo et al., 2017; Bento et al., 2014; Fernandes et al., 2015; Ravagnani et al., 2012; Reis et al., 2018; Souza et al., 2018, 2019), microbial infection (Ribeiro et al., 2014; Santos et al., 2017), snake venom poisoning (Ferraz et al., 2012, 2014; Nazato et al., 2010; Puebla et al., 2010), chronic kidney disease (CKD) (Schincaglia et al., 2020, 2021), colorectal cancer (CRC) (Oliveira-Alves et al., 2020), and oxidative stress (Siqueira et al., 2012). In addition, the plant has been linked to anti-atherogenesis (Ragassi Fiorini et al., 2017) and gastroprotective (da Cruz et al., 2019) effects in preclinical studies.

The effects of the baru plant on health will be detailed on Table 3 and discussed as follows. Fig. 3 represents visually the health effects and potential of the baru plant.

4.1. Metabolic conditions or diseases

Body weight gain and obesity represent eminent risks for altered lipid plasma profile or dyslipidemia, a condition associated with approximately 4.2 million deaths in 2019 if considered only mortality-linked high serum low-density lipoprotein (LDL). Cardiovascular diseases are the final and most common mortality-related implications of obesity and dyslipidemia (Pirillo et al., 2021). Prevention though natural medicine (*e.g.*, green tea herbals, curcumin products) have been considered a new path to combat metabolic conditions or diseases, as demonstrated by recent meta-analyses (Adel Mehraban et al., 2021; Payab et al., 2020). Although not a very well-known plant, investigations with baru are surprisingly advanced in this field, as three studies with humans have already been conducted. Obesity has been the main illness investigated employing baru, and specifically its nut or derived products (flour, oil) (Table 3).

Initially, preliminary evidence indicate that the baru plant may have a beneficial metabolic role in healthy subjects, therefore helping prevent dyslipidemia and cardiovascular diseases (Table 3). Da Cruz et al. (2019) and Ragassi Fiorini et al. (2017) showed that diets enriched with the nut flour (14 - 40%) for 14 - 40 days are capable of improving the serum lipid profile of healthy rats by increasing high-density lipoprotein (HDL) and decreasing very-low lipoprotein (VLDL), LDL, total cholesterol (TC), and triglycerides (TG) serum levels (Da Cruz et al., 2019; Ragassi Fiorini et al., 2017). Additionally, Ragassi Fiorini et al. (2017) showed that the baru nut may have an cardioprotective role, as the product reduces atherogenic and cardiac risk indexes, however, no further studies have been carried out applying the baru plant directly on cardiovascular diseases.

Other investigations show that dietary interventions with baru nut can be beneficial on already installed metabolic conditions or diseases (Table 3). The preclinical studies performed so far indicate that the baru nut flour, supplemented at variable proportions in the diet (8%, 35%) for eight to nine weeks, can help prevent or treat high-fat diet-induced obesity by increasing HDL and reducing body weight, glycemia, and VLDL, LDL, TC, and TG serum levels (Araújo et al., 2017; Fernandes et al., 2015). On the other side, Reis et al. (2018) demonstrated that the baru nut oil can prevent hepatic damage and aorta oxidation in rats with lipid emulsion-induced dyslipidemia. Ravagnani et al. (2012), however, could not find the same results of Reis et al. (2018) when testing a similar oil on obese rats; no significative effects were found by this study.

More meaningfully, Bento et al. (2014) and Souza et al. (2018, 2019) utilized randomized controlled-placebo trials to understand the role of baru nut on individuals with mild hypercholesterolemia and

Table 3
Health effects of baru (Dipteryx Alata Vogel) based on experimental studies.

Baru product	Composition (mg/g), Antioxidant capacity	Experimental model	Dosage, Period	Main results	Reference(s)
Almond; roasted nut or its flour.	TPC: 1.54 (aqueous), 0.03 (ethyl acetate); DPPH*: 0.8 (aqueous), 0.6 (ethyl acetate); FRAP**: 8.3 (aqueous), 1.2 (ethyl acetate); β-carotene/linoleate inhibition: 6.0%/g (aqueous), 0.6%/g (ethyl acetate).	Oxidative stress; male Wistar rats, 10.5 mg/day of FeSO4 via gavage.	10% in the diet (flour without the peel), prevention, 17 days.	↓: carbonyl concentration (liver, heart, and spleen).	(Siqueira et al., 2012)
	CHO: 122.5, PTN: 299, LIP: 424, SFA: 55, palmitic acid: 25, stearic acid: 23, arachidic acid: 5.5, MUFA: 193, oleic acid: 175.5, nervonic acid: 16.5, PUFA: 105, linoleic acid: 103.5, TDF: 92, SF: 20.5, IF: 72, calcium: 1.10, iron: 0.03, magnesium: 1.64, zinc: 0.04, phosphorus: 8.32, selenium: 3×10^{-6}, vitamin E: 0.21.	Dyslipidemia; 20 adults mildly hypercholesterolemic individuals, randomized crossover placebo controlled.	20 g/day, diet supplement, treatment, 6 weeks.	↓: TC, LDL, non-HDL.	(Bento et al., 2014)
	CHO: 107.9, PTN: 289.4, LIP: 424, Ash: 30.1, SFA: 55, MUFA: 193, oleic acid: 175.5, PUFA: 105, linoleic acid: 103.5, other fatty acids: <25, TDF: 117, SF: 24, IF: 93, zinc: 0.06, selenium: 0.0026, vitamin E: 0.21.	Obesity; male Wistar rats, high-fat diet.	35.38% in the diet (flour), prevention, 9 weeks.	↑: HDL, vitamin E (liver); ↓: final body weight, body weight gain, diet intake, TC, TG, MDA (liver).	(Fernandes et al., 2015)
	The authors did not perform the composition analyses of baru .	Obesity; male Swiss mice, high-glucose diet.	8.2% in the diet (flour), treatment, 8 weeks.	↓: glycemia, TG, body weight.	(Araújo et al., 2017)
	Vitamin C: 0.18, TAC: 0.005, TCC: 0.005, antioxidant activity: 99.42%.	Atherogenic protective; healthy male Wistar rats.	20, 30, and 40% in the diet (flour), 40 days.	↑: HDL; ↓: ALT (20, 30%), TG, VLDL, LDL, CRP, atherogenic index, atherogenic coefficient, cardiac risk ratios, non-HDL.	(Ragassi Fiorini et al., 2017)
	CHO: 122.5, PTN: 299, LIP: 424, SFA: 55, MUFA: 193, PUFA: 105.	Obesity; 46 overweight or obese adult woman, randomized placebo-controlled trial.	20 g or 15 units/day, diet supplement, treatment, 8 weeks.	↑: MUFA intake, HDL, plasma MUFA, plasma Gpx, plasma copper, plasma cobalt. ↓: waist circumference, plasma CETP.	(Souza et al., 2018, 2019)
	Baru - Ashes: 29.4, LIP: 436, TDF: 139.8, ABTS***: 1.17, FRAP***: 8.34. *Dairy desserts enriched with baru (2–12%)* - Ashes: 7.5–13.1, LIP: 89.7–139.2, TDF: 6.9–26.9, ABTS***: 0.30–1.30, FRAP***: 2.27–4.34.	Gastroprotective; healthy male Wistar rats.	14% in the diet (flour or dairy desserts enriched with flour), 2 weeks.	*Baru* – ↑: HDL, total protein; ↓: TG, VLDL. *Dairy desserts enriched with baru* - ↑: HDL, TC, MGET (regarding dairy dessert without baru), MCAT (regarding dairy dessert without baru), MSBTT (regarding dairy dessert without baru); ↓: TG, VLDL.	(da Cruz et al., 2019)
Almond; ethereal extract or oil	*The authors did not perform the composition analyses of baru.*	Obesity: Wistar rats (gender not mentioned), high-fat diet.	Quantity not clear (ethereal extract) in the diet, treatment, 8 weeks	No significative effects.	(Ravagnani et al., 2012)
	SFA: 192.5, MUFA: 474, PUFA: 281.9, not identified: 7.6, oleic: 446.5, linoleic: 280.5, palmitic: 58.7, lignoceric: 46.4, stearic: 43.4, behenic: 31.8, cis-11-eicosenoic: 27.4, arachidic: 11.5, α-linolenic: 1.4, tricosanoic: 0.8.	Dyslipidemia; male Wistar rats, lipid emulsion (10 mL/kg).	1 g/kg/day via gavage (extracted oil), prevention, 15 weeks.	↑: sinusoid capillaries VD (liver), hepatocytes cellularity, total hepatocytes, total hepatocytes/interstitial cells, interstitial cells VD (liver), normal hepatocytes VD; ↓: aorta MDA, hepatocytes VD, steatosis VD, ballooning degeneration VD.	(Reis et al., 2018)
	SFA: 270, MUFA: 462.2, PUFA: 267.8, ω6: 265.5, ω3: 2.3, ω6/ω3: 115:1, oleic acid: 417.1, linoleic acid: 264.6, other fatty acids: 0.4–83.0.	Chronic kidney disease: 29 or 35 adult/elderly hemodialysis patients, randomized double or single-blind, placebo-controlled or not.	5 g or 10 capsules/day (oil), diet supplement, treatment, 12 weeks.	↑: time spend sitting; ↓: plasma CRP, PUFA intake, Rome IV score (gastrointestinal), straining on the evacuation score, self-perception of constipation.	(Schincaglia et al., 2020, 2021)
Almond; hydroethanolic extracts.	*The authors did not perform the composition analyses of baru.*	Bacterial and fungal infections; *in vitro, Staphylococcus aureus, E. coli, Pseudomonas aeruginosa, and Candida albicans*	50 μL, 24 (bacteria) or 42 h (fungus).	General low inhibitory activity.	(Santos et al., 2017)
Almond: hydrometha-nolic extracts (crude or hydrolyzed).	Identified compounds: quinic acid derivative, GG, gallic acid, monoGG, methyl gallate-glucoside, gallic acid-GG, p-coumaric acid, diGG, isoferulic acid, digallic acid, methyl gallate, triGG and tetraGG, methylgalloyl-GG, ethyl gallate, pentaGG, ellagic acid, gallic acid-methyl gallate, gallic acid-ethyl gallate. *Crude* – TPC: 4.92, ORAC*: 88.71, HOSC*: 116.22. *Hydrolyzed.*- TPC: 5.74, ORAC*: 110.44, HOSC*: 136.31.	Colorectal cancer; *in vitro*, HT29 monolayers (2D) and spheroids (3D) cell lines.	6.25 to 200 mg/mL, 72h	*Crude* – EC50 (mg/mL): 7.95 (2D), 31.71 (3D, dose-dependent); ↓: ALDH1 activity (cancer stem cells marker). *Hydrolyzed* – EC50 (mg/mL): 8.82 (2D), 139.50 (3D).	(S.C. Oliveira-Alves et al., 2020)

(*continued on next page*)

Table 3 (*continued*)

Baru product	Composition (mg/g), Antioxidant capacity	Experimental model	Dosage, Period	Main results	Reference(s)
Bark (tree); 1. hexane, dichloromethane, ethyl acetate, and methanol derived from a hydroethanolic extract; 2. the same four solvents and a derived hydroethanolic extract.	1. *Dichloromethane* - identified compounds: lupeol, lupenone, 28-hydroxylup-20(29)-en-3- one, botulin, 8-O-methylretusin, 7-hydroxy-5,6,4′-trimethoxyisoflavone, afrormosin, 7-hydroxy-8,3′,4′-trimethoxyisoflavone, 7,3′- dihydroxy-8,4′-dimethoxyisoflavone, odoratin, 7,8,3′-trihydroxy-4′-methoxyisoflavone, 7,8,3′-trihydroxy-6,4′-dimethoxy-isoflavone, dipteryxin, isoliquiritigenin, sulfuretin, vanillic acid, vanillin, and protocatechuic acid. 2. *Hydroethanolic* - identified compounds: apigenin, rutin, quercetin, tannic acid, caffeic acid, chlorogenic acid; tannins: 0.79****	Snake venom poisoning; *in vitro, Bothrops jararacussu* (1 and 2) or *Crotalus durissus terrificus* (2).	50 μg/mL, 30 min.	1. ↓ neuromuscular blockade: 98% (dichloromethane), 95% (methanol), and 80% (ethyl acetate). 2. *Bothrops jararacussu* – 100% (methanol), ~15% (dichloromethane); ↓: time-dependent neuromuscular blockade (hydroethanolic), fibers damage (methanol).	(Nazato et al., 2010; P Puebla et al., 2010)
Bark (tree); isolated triterpenoids lupeol, lupenone, 28-OH-lupenone, and betulin	*Not applicable.*	Snake venom poisoning; *in vitro, Bothrops jararacussu* and *Crotalus durissus terrificus.*	200 μg/mL, 30 min.	*Bothrops jararacussu* - ↓: neuromuscular blockade (lupeol 70%, betulin 68%, 28-OH-lupenone 54%, lupenone 45%), myotoxicity index (betulin plus lupeol). *Crotalus durissus terrificus* - ↓: neuromuscular blockade (lupenone 49%, betulin 39.5%), myotoxicity index (betulin plus lupenone).	(Ferraz et al., 2012)
Bark (tree); isolated 7,8,3′-trihydroxy-4′-methoxyisoflavone.	*Not applicable.*	Snake venom poisoning; *in vitro, Bothrops jararacussu.*	200 μg/mL, 30 min.	↓: non-toxin (84%) and toxin neuromuscular blockade, fibers damage.	(Ferraz et al., 2014)
Leaf; ethanolic and hexanic extracts.	*Ethanolic extract* – not characterized. *Hexanic extract* – Identified compounds: tannins, flavonoids, triterpenes, steroids, lupeol, betulinic acid; TPC: 40, TFC: 8.	Parasitic infection; *in vitro, Leishmania amazonensis.*	0.08, 0.16, 3, and 5 µg/mL, 48h	*Ethanolic* – IC50 (µg/mL): 51.46. *Hexanic* - IC50 (µg/mL): 0.08; ↓: parasite burden (dose-dependent).	(Ribeiro et al., 2014)
Peel; hydroethanolic extracts.	*The authors did not perform the composition analyses of baru.*	Bacterial and fungal infection; *in vitro, Staphylococcus aureus, E. coli, Pseudomonas aeruginosa, and Candida albicans*	50 μL, 24 (bacteria) or 42 h (fungus).	High inhibitory activity against *Staphylococcus aureus* and mild against *E. coli.*	(Santos et al., 2017)
Pulp; hydroethanolicextracts.	*The authors did not perform the composition analyses of baru.*	Bacterial and fungal infection; *in vitro, Staphylococcus aureus, E. coli, Pseudomonas aeruginosa, and Candida albicans*	50 μL, 24 (bacteria) or 42 h (fungus).	High inhibitory activity against *Staphylococcus aureus.*	(Santos et al., 2017)

Only published articles were considered for this table. *Antioxidant results are presented in μmol of Trolox equivalent/g; **Antioxidant results are presented in μmol FeSO4/g. ***Antioxidant results are presented in mg of gallic acid equivalent/g. ****Results are presented in mg/mL. Meanings: ↑: increased and ↓: decreased in comparison with a control (if healthy subjects) or disease group. Abbreviations: ω: omega, ABTS: 2,2′-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) assay, ALDH1: aldehyde dehydrogenase 1, ALT: alanine aminotransferase, CETP: cholesteryl ester transfer protein, CHO: carbohydrates, CRP: C-reactive protein, DPPH: 2,2-diphenyl-1-picrylhydrazyl assay, FRAP: ferric reducing antioxidant power, GG: galloyl glucose, Gpx: glutathione peroxidase, HDL: high-density lipoprotein, HOSC: hydroxyl radical scavenging capacity, IC50: 50% inhibitory concentration, IF: insoluble fiber, LIP: lipids, MCAT: mean cecum arrival time, MDA: malonaldehyde, MGET: mean gastric emptying time, MSBTT: mean transit time through small bowel, MUFA: monounsaturated fatty acids, ORAC: oxygen radical absorbance capacity, PTN: proteins, PUFA: polyunsaturated fatty acids, SF: soluble fiber, SFA: saturated fatty acids, TAC: total anthocyanins content, TC: total cholesterol, TCC: total carotenoids content, TDF: total dietary fiber, TFC: total flavonoids content, TG: triglycerides, TPC: total phenolic content, VD: volume density, VLDL: very low-density lipoprotein.

obesity, respectively (Table 3). After 6 or 8 weeks of intervention with 20 g/day, the authors found a few positive effects, such as reduced waist adiposity, and improved serum levels of HDL, LDL, and TC (Bento et al., 2014; Souza et al., 2018). However, the studies failed to find other metabolic benefits (*e.g.*, body weight, apoliproteins, glucose metabolism, inflammatory cytokines) from the consumption of baru nut (Bento et al., 2014; Souza et al., 2018, 2019).

The results of studies performed so far indicate the potential of baru against an elevation of lipids in the blood of obese and hypercholesterolemic subjects. The benefits behind the effects are majorly linked, as suggested by the aforementioned studies, with their content in monounsaturated fatty acids, mostly oleic acid. However, although oleic acid is theorized to improve blood health, this can be extremely questionable, as foods tested in experimental studies, such as extra-virgin olive oil and peanuts, can also be sources of polyphenols or other minor bioactive compounds with anti-inflammatory and antioxidant potential (Del Monaco et al., 2015; Orsavova et al., 2015; Tutunchi et al., 2020). The clinical trials of Bento et al. (2014) and Souza et al. (2018, 2019) did not quantify the minor molecules in the baru nut, making it difficult for further conclusions, however, a couple of studies indicate that this product can be an interesting source of phenolic acids, flavonoids, tannins, and tocopherols (Fetzer et al., 2018; Lemos et al., 2012; Marques et al., 2015).

Dietary fibers and phytosterols also occur in interesting amounts in the baru nut products and are common associated with a limited intestinal absorption of lipids due to gel formation or ligand substitution, respectively (Bento et al., 2014). Since the peel of the baru flour is a richer source of total dietary fibers than the pulp and the roasted nut (24.1 vs. 18 and 16%), it may serve as a promising option for future studies with metabolic conditions or diseases (Santigo et al., 2018). The

specific composition of dietary fibers found in the baru fractions needs further investigation, as different lipid-lowering responses and mechanisms can be triggered depending on the types of molecules found in their composition (Nie and Luo, 2021).

4.2. Microbial infection

In addition to provoking adverse effects in individuals, common pharmacological therapies for microbial infections may lose their efficiency due to microbial drug resistance. For example, leishmaniosis (*Leishmania* spp.*)* medical treatment may fail up to 60% of patients, depending on the population and choice of treatment (Capela et al., 2019; Poirel et al., 2018; Ponte-Sucre et al., 2017; Wiederhold, 2017). As a solution to this emerging obstacle, new biologically active molecules, including natural plant products, have been suggested as alternative therapeutic options that could avoid drug resistance, at least initially. Baru is an example of a new plant with antimicrobial potential *in vitro* (Ribeiro et al., 2014; Santos et al., 2017).

Ribeiro et al. (2014) demonstrated that the hexanic extract from the leaves of baru has a high inhibition capacity (IC50 = 0.08 μg/mL) against stationary-phase *Leishmania amazonensis* promastigotes (Table 3). Such inhibition activity was comparable with the antifungal drug amphotericin B (IC50 = 0.08 μg/mL) and superior than other 42 extracts from 15 Brazilian plants (IC50 = 4.69 - 199.4 μg/mL), including jacarandá (*Jacaranda cuspidifolia*), jamelão (*Syzygium cumini*), jatobá grande (*Hymenaea stignocarpa*), and pitanga (*Eugenia uniflora*). In addition to providing the highest inhibitory capacity against L. *amazonensis* promastigotes, the hexanic extract of baru also promoted a dose-depending reduction (up to 95%) of internalized parasites in macrophages (Ribeiro et al., 2014). As suggested by Ribeiro et al. (2014), the benefits of baru against L. *amazonensis* infection appear to be associated with its content in flavonoids, tannins, and/or triterpenoids. Possibly, an extract with more nonpolar-orientated compounds (*e.g.*, hexanic) appear to represent a better antimicrobial option, since baru leaves' ethanolic extract showed a much less inhibitory activity (Ribeiro et al., 2014). Further studies are necessary to confirm this allegation.

The hydroethanolic extracts of baru's almond, peel, and pulp have also demonstrated their capacity to decrease microbial infection (Table 3). The study of (Santos et al., 2017) investigated the antimicrobial potential of baru against bacteria species *Staphylococcus aureus, Escherichia coli,* and *Pseudomonas aeruginosa*, and fungus *Candida albicans.* Except for *P. aeruginosa,* baru extracts showed capacity to inhibit the infected zones *in vitro*. Surprisingly, baru's peel and pulp extracts appeared to be more promising antimicrobial agents than the almond (Santos et al., 2017), but no characterization analyses on the extracts were done in order to understand this outcome. According to the study of Santiago et al. (2018), baru almond has a higher antioxidant capacity and levels of total phenolic compounds in comparison with the peel and pulp, therefore, it should represent a better remedial option. However, since comparison studies and the characterization of non-conventional baru fractions (*e.g.*, peel, pulp) are extremely scarce, remains poorly known their medicinal potential in comparison with the almond. Other health-related studies with baru's peel and pulp are nonexistence, apparently.

4.3. Snake venom poisoning

Snakebite occurs frequently in tropical and subtropical areas, causing each year at least 20,000 deaths worldwide (Kasturiratne et al., 2008). Due to the high cost, low availability, and sometimes poor efficacy of the traditional antivenom serum therapies, natural plant products have been postulated as new interesting and promising options. Brazil is one of the leading countries on the use and research of antiophidic plants. Castor bean (*Ricinus communis*), cassava (*Manihot esculenta*), and physic nut (*Jatropha curcas*) are examples of native medicinal crops traditionally applied, but new and usually underappreciated native plants have also shown antivenom potential (Félix-Silva et al., 2017).

The studies of the Brazilian research group led by Yoko Oshima-Franco indicate the antiophidic potential of the baru plant (Table 3). The researchers tested *in vitro* different extracts and isolated bioactive compounds from the bark of the baru tree against the venoms of South American jararacussu (*Bothrops jararacussu)* and rattlesnake (*Crotalus durissus terrificus)* serpents, mostly finding positive results (Ferraz et al., 2012, 2014; Nazato et al., 2010; P Puebla et al., 2010). Initially, Nazato et al. (2010) and Puebla et al. (2010) tested, using a dose of 50 μg/mL, the polar and apolar extracts (dichloromethane, ethyl acetate, hexane, hydroethanolic, methanol) from the baru bark on snake venom (Table 3). The dichloromethane, hydroethanolic, and methanolic fractions stood out as the most promising, as they were capable of significantly decreasing the neuromuscular blockage induced by jararacussu venom on the phrenic nerve-diaphragm. Especially, the methanolic extract had a higher protective neuromuscular capacity (95 - 100%) in both studies, in addition to reducing myonecrosis as showed in the histological analysis. Some extracts (dichloromethane, hydroethanolic) were analyzed by the authors and revealed to contain polyphenols (isoflavones, phenolic acids), triterpenoids, and tannins, which probably contributed to the effects found (Nazato et al., 2010; Puebla et al., 2010).

Considering the positive implications of the baru extracts, the following studies tested their most prominent bioactive compounds, applying an elevated dosage of 200 μg/mL (Table 3) (Ferraz et al., 2012, 2014). In order of least to most efficient, the isolated triterpenoids lupenone, 28-OH-lupenone, betulin, lupeol, and the isoflavone 7,8,3′-trihydroxy-4′-methoxyisoflavone shown between 48 and 84% protection against the neuromuscular blockage caused by jararacussu venom. Additionally, for the first time, the products of the baru plant also shown inhibitory capacity against rattlesnake venom; lupenone and betulin protected partially against muscular damage (Ferraz et al., 2012, 2014). The triterpenoids betulin and lupeol can also be found in other plants, including the ones of the *Betula* and *Zanthoxylum* species, respectively. Besides the aforementioned studies with baru, other investigations tested the commercial available betulin or plant-extracted lupeol, highly suggesting their capacity against snake venom. Betulin, for example, has shown efficacy against neuromuscular damage *in vitro* and myotoxicity *in vivo* caused by jararacussu (Ferraz et al., 2015). Lupeol, on the other side, can partially inhibit the effects of bothropic and krait (*Bungarus sindanus*) venoms by binding to toxic and damaging proteins (Ahmad et al., 2014; Dos Santos et al., 2021). An oxidized product of betulin, betulinic acid, has also been suggested as a potent inhibitor of snake venom proteins. In a report by Tseng & Liu (2004), betulinic acid exhibited a strong interaction with secretory molecules of the *Naja nigricollis* venom, such as phospholipases A2 enzymes, which are among the most abundant, active, and toxic snake proteins. Also, in the study of Preciado et al. (2018), betulinic acid revealed to be a great binding ligand to snake metalloproteinases, especially BRCA1-associated protein-1, therefore a candidate against hemorrhagic activity and local tissue damage following envenomation.

The studies performed so far indicate the high potential of baru's methanolic extract and triterpenoids against snake venom poisoning. Experimental studies *in vivo* with products from the baru tree bark are necessary in order to advance the research regarding the subject, which appear to have not continued since 2014. In addition, more complete triterpenoids characterization studies with other fractions of the baru plant may extend the interest for application on antivenom research.

4.4. Other conditions or diseases

More recently, the effects of the baru nut have been investigated against CKD (Table 3). The randomized controlled trials by Schincaglia et al. (2020, 2021) tested the effects of 5 g/day of the

nut oil, rich in oleic and linoleic acids, on hemodialysis patients. Despite having performed a 12-week intervention, most of the results found by the authors were non significative. Baru oil did not improve CKD-related parameters (urea, potassium, phosphorus), oxidative stress (catalase, superoxidase dismutase, malondialdehyde), or serum protein levels (HDL, LDL, TC, VLDL). The effects of the oil were limited to a reduction on serum C-reactive protein (CRP), an inflammatory marker, and to improved bowel function, although the last one was self-reported (Schincaglia et al., 2020, 2021). Ragassi Fiorini et al. (2017) also found reduced levels of serum CRP, but in healthy rats receiving large amounts of baru nut flour (20–40%) for 40 days. Interestingly, in a recent meta-analysis based on clinical trials, oleic acid-rich foods showed to effectively reduce serum CRP (Wang et al., 2020). It is also important to notice that If done incorrectly or applied to a disease with no potential, the addition of baru oil on the diet can favor a unhealthy profile, since the oil has a high omega-6:omega-3 ratio (115:1) (Schincaglia et al., 2020). A recommended omega-6:omega-3 ratio for chronic disease prevention is up to 5:1 (Gómez Candela et al., 2011; Simopoulos, 2008).

The abovementioned study by Schincaglia et al. (2021) was not the solo study to have found positive results on bowel function. By providing dairy desserts enriched with 14% of baru flour to healthy rats, da Cruz et al. (2019) encounter interesting results regarding gastric emptying and intestinal transit (Table 3). Two weeks of intervention with baru were capable of regulating alterations caused by the consumption of high amounts of milk (43% in the diet) by increasing the mean gastric emptying time, cecum arrival time, and transit time through small bowel (da Cruz et al., 2019). As an interesting source of total dietary fibers (~14%), baru flour has the ability to improve gastrointestinal function and possibly chronic constipation, even when associated with a dysregulated diet. Additionally, by delaying the digestion and absorption of nutrients (*e.g.*, glucose, cholesterol), baru can increase mechanisms of anti-obesity, anti-dyslipidemia, and anti-diabetes (da Cruz et al., 2019).

Another evidence of the effects of baru on gastrointestinal health was demonstrated by Oliveira-Alves et al. (2020) (Table 3). The polyphenol-rich hydromethanolic crude and hydrolyzed extracts from the roasted baru nut significantly reduced the cell growth of CRC cell line HT29 *in vitro*. As the crude extract was more efficient, this portion was tested against a marker of tumor-initiating cells or cancer steam cells, namely aldehyde dehydrogenase 1 (ALDH1). The extract greatly decreased the colonic levels of ALDH1 in comparison with control cells or cells treated with a mix of gallic acid derivatives (Oliveira-Alves et al., 2020), revealing to be a potential product against tumor development and metastasis. As it reduces ALDH1 activity, the hydromethanolic extract of baru may also be used to avoid chemotherapy and radiotherapy resistance caused by cancer stem cells (Vinogradov and Wei, 2012). Further studies with other cell lines and/or mouse models are necessary to advance the research on the effects of baru on CRC.

Finally, as product with high antioxidant capacity measured *in vitro*, baru has also been suggested against the direct effects of oxidative stress (Table 3). Siqueira et al. (2012) evaluated the implications of 10% baru nut flour on the diet of Wistar rats with iron-induced oxidative stress. After 17 days of treatment, animals receiving baru achieved reduced levels of carbonyl in the liver, heart, and spleen in comparison with the group without intervention. Carbonyl levels are increased after the oxidation of tissue proteins and are considered a general biomarker of protein oxidation. Several oxidative stress-linked diseases, including diabetes and inflammatory bowel diseases, can augment the accumulation of protein carbonyls (Dalle-Donne et al., 2003), therefore suggesting the health potential of the baru nut as investigations continue hereafter. The positive effects found by Siqueira et al. (2012), however, were limited to the carbonyl analysis, as the authors could not find significative data on other parameters, such as lipid oxidation and antioxidant enzymes. Other isolated findings of the positive effects of baru nut on oxidative stress include reduced malonaldehyde (liver and aorta) and increased glutathione peroxidase (serum) levels, as seen in more recent studies with rats or humans having a metabolic disease (Fernandes et al., 2015; Reis et al., 2018; Souza et al., 2019). These studies indicate that, at least minimally, baru nut's bioactive compounds may have a helpful impact on oxidative stress *in vivo*.

5. Technological potential

The available literature does not clearly show the technological potential of baru, making this area of study little explored scientifically. In this review, we search in the chemical composition of baru explanations that lead us to understand its physicochemical properties, and the technological potential of the species. Technological applications are extremely valuable for industry so that unveiling the uses of baru allows us to find new solutions to the challenges in the processing sector. Table 4 summarizes the scientific findings regarding the technological potential of baru.

Using baru protein fractionation techniques is possible to observe the majority presence of globulins, followed by albumins, glutenins, and prolamins. In the globulin fraction, there are proteins known as legumins, which are attributed to the technological emulsifying property (Cruz et al., 2011; Koyoro and Powers, 1987). Thus, it becomes possible to use baru almond proteins in the production of emulsified food systems, expanding the range of existing functional vegetable proteins (Gharsallaoui et al., 2011).

Vegetable proteins have gained ground in microencapsulation, acting as carriers and protectors of active substances. A recent Brazil nut oil encapsulation study, using gum arabic, rice, pea, and soybean proteins, which have protein fractions similar to those found in baru almond, observed that the combination can improve the stability of the oil against oxidation (Oliveira et al., 2020). Another study involving the encapsulation of sunflower oil, which also used the aforementioned wall materials, in addition to hemp and sunflower proteins, noted a reduction in the oxidation induction time compared to pure sunflower oil, as a result of greater encapsulation efficiency (Le Priol et al., 2019). These results may be associated with the amphiphilic character of the proteins, allowing them to be adsorbed on the surface of the oil droplets, reducing surface tension, and facilitating emulsification process. The stability of the emulsion is one of the factors that directly affect the encapsulation efficiency (Dickinson, 2003; Labuschagne, 2018).

In this context, the solubility of proteins is noteworthy, as it influences emulsification processes. The quality of the formed emulsions is as good as the greater the solubility of proteins in the medium. In the case of baru proteins, the maximum solubility is reached in alkaline media – pH 10 (83% solubility), while in more acidic media (pH around 4 to 5), the solubility tends to decrease. Therefore, protein concentrates or isolates of baru almond proteins, when used in alkaline emulsified systems, can present good results. Additionally, properties, such as water and oil absorption capacity and foam formation, are also evidence for these proteins. Baru almond protein concentrate has water and oil absorption capacity similar to soybeans and can be used as a substitute for it. For foaming ability, baru protein concentrate shows maximum levels at neutral pH (Guimarães et al., 2012; Sousa de Oliveira et al., 2020).

Furthermore, proteins can be used as ingredients in the preparation of consistent food products. They can interact with each other forming a gel network that gives more firmness to the products (Cubides et al., 2019). In this context, Lima et al. (2021) observed that nutritional bars formulated with baru almond have a greater firmness concerning those made with Brazil nut, correlating this characteristic to the higher protein content present in the almond. In another study, replacing wheat flour (9.8%) with partially defatted baru almond flour (29.46% of protein), considered an oil extraction co-product, resulted in strengthening of the gluten network for the production of cookies. The authors argue that protein coagulation, which occurs during cooking, gives structure to the dough (Pineli et al., 2015b). Then, it is possible that the addition of partially defatted baru almond flour can improve fermentation processes in the bakery sector.

Table 4
Technological potential of the baru (Dipteryx Alata Vogel) fruit.

Fraction or chemical constituent	Technological process / Purpose	Potential applications/Technological properties	Major findings	References
Baru protein	Fractionation and isolation technique of almond proteins.	Emulsifying property	Some proteins are known legumins (globulinas) which are attributed the technological potential	(Cruz et al., 2011; Koyoro and Powers, 1987)
	Obtaining the concentrate by alkaline extraction followed by drying in spray drying	Water and oil absorption capacity and foaming property	Maximum foaming capacity at neutral pH and maximum solubility at pH 10	(Guimarães et al., 2012; Oliveira et al., 2020)
	Substitution of traditional ingredients or addition	Food products with greater firmness and consistency	Strengthening the gluten network by protein coagulation during cooking	(L. de L. de O. Pineli et al., 2015)
Baru oil	Microencapsulation	Viscosity modifier	Relation of activation energy with changes in viscosity because of temperature variations.	(Rojas et al., 2019; Steffe, 1996)
	Transesterification	Production of biodiesel	High energy efficiency associated with a high proportion of monounsaturated fatty acids.	(Batista et al., 2012; Silva et al., 2015)
Almond	Washing and stirring with deionized water and nitric acid (HNO3) followed by neutralization to pH 7.0 and vacuum drying	Bioadsorbent of inorganic contaminants	Adsorption capacity related to the presence of proteins and fatty acids (dependent on pH)	(Mosquetta et al., 2011)
Peel, pulp, and almond	Hydroalcoholic extraction	Natural alternative source of preservative and sanitizing agent (antimicrobial potential)	Effects against *S. aureus, E. coli*, and *C. albicans* may be associated with isoflavones, triterpenes, and phenolic compounds	(Ragozoni et al., 2021; Sadgrove et al., 2020; Santos et al., 2017; Silvério et al., 2013)
Pulp	Substitution of wheat flour by baru pulp flour	Texture agent (volume and filling to the products)	Biscuits had a suitable dough for baking, probably associated with the high starch content	(Alves et al., 2010; Hamaker, 2021)
		Changes in color	The caramelization of sugars due to the cooking process resulted in brown coloration	(Ferreira et al., 2020)
Peel	Carbonization of biomass from wood	Production of charcoal	Greater hardness than traditional wood, resulting higher density charcoal (longer burning time and high calorific power)	(Rodrigues and Junior, 2019; Teixeira et al., 2020; Vale and Olsen, 2013)

Only published articles were considered for this table.

About the lipid content of baru almond, research using microparticles containing chia, pumpkin, and baru oils to enrich commercial mayonnaise observed changes in the rheological properties of the product. From the supplementary material provided by the authors, it was possible to infer that the addition of 2.5, 5.0, and 7.5% of microparticles increased the viscosity of mayonnaise at 25 °C for all oils. On the other hand, at 37 °C there was no difference in viscosities between the control mayonnaise and those added with the same concentrations of baru almond oil microparticles, indicating that they all had the same flow resistance. Among the microparticles produced, the one composed of baru oil had the lowest activation energy (98.6 kJ/mol) (Rojas et al., 2019). According to Steffe (1996), oils with lower activation energy are less sensitive to changes in viscosity when temperature variations occur. Also, according to Rojas et al. (2019), the texture parameters (firmness, cohesiveness, adhesion, and consistency) and sensory perception were not modified with the addition of microparticles to the mayonnaise. Thus, the microparticles of baru oil can be incorporated into oil-in-water type emulsions, with no relevant technological changes from an industrial and consumer point of view, which may be desirable for such traditional products.

In the field of biofuel production, researchers evaluated the use of baru oil as an alternative raw material for the production of biodiesel (Batista et al., 2012; Silva et al., 2015). Batista et al. (2012), when producing biodiesel through transesterification of baru oil using methanol and ethanol, reported a conversion efficiency of 91% and 86%, respectively. After evaluating the physical and chemical characteristics of the oil and biodiesels produced (acidity index, iodine index, kinematic viscosity, water content, saponification, and refraction index), the authors observed equivalence to the official quality requirements, enabling the application of the oil of baru in the generation of biofuels (Batista et al., 2012).

To produce quality biodiesel, the fatty acid profile of the raw material and the carbon chain size must be analyzed to obtain the cetane number, which is related to the quality of combustion. In addition, other parameters must be observed, such as cloud point, the possibility of clogging, and chemical instability. Based on these attributes, studies confirm that biodiesels which contain a higher proportion of monounsaturated fatty acids exhibit better technological quality, which may explain the efficiency of using baru oil for biodiesel production since it presents mostly oleic acid (Beltrão et al., 2008).

Another differentiated use for the baru almond is the possibility of adsorbing inorganic contaminants, such as metallic ions, present in ethanol. The authors mention that the adsorption capacity of natural substances is related to the functional groups of proteins and fatty acids. The active sites present in these constituents, dependent on pH, will bind to the contaminant ions, adsorbing them. By this mechanism, baru almonds are able to remove the nickel ion present in alcohol, presenting themselves as potential bio adsorbent agents (Mosquetta et al., 2011).

As previously mentioned, due to the presence of bioactive compounds with antimicrobial potential, the hydroalcoholic extracts from

baru peel, pulp, and almond were evaluated against different pathogenic microorganisms, namely *Staphylococcus aureus*, *E. coli, Pseudomonas aeruginosa*, and *Candida albicans*. The pulp extract (30% m/v) showed greater inhibition against the *S. aureus*, while the peel and almond extracts (30% m/v) showed inhibition against *E. coli* e *C. albicans*, respectively. It is believed that isoflavones, triterpenes, and phenolic compounds found in baru may be responsible for the antimicrobial activity of the species (Ragozoni et al., 2021; Sadgrove et al., 2020; Santos et al., 2017; Silvério et al., 2013). Thus, the potential application of baru as a natural alternative source of preservative and sanitizing agents is noted. However, further reliable antimicrobial studies are lacking.

Baru pulp, rich in starches (about 38%) and sugars, presents itself as a potential ingredient for the manufacture of different food products (Carrazza and Avila, 2010; Ferreira et al., 2020; D.V. Silva et al., 2019). The starch from baru pulp is considered an unconventional starch, as it is not yet commercialized, and may have technological properties similar or superior to common starches, obtained basically from cereals and tubers, such as corn and cassava (Tagliapietra et al., 2021). A study that evaluated the replacement of 25% wheat flour by baru pulp flour in the preparation of biscuits found that the dough exhibited adequate texture, probably explained by the pulp's high starch content. (Alves et al., 2010). Thus, it is possible to use baru pulp as a texture agent in the bakery sector and, in general, starch is widely used in the food industry for providing volume and filling to the products (Hamaker, 2021; Srinivasan and Parkin, 2019). In another study, Ferreira et al. (2020) prepared cookies from the replacement of wheat flour by baru pulp flour with or without pretreatment by acidification with acetic acid followed by ultrasound treatment. The authors found that the addition of pulp flour caused a change in the color of the cookies, a phenomenon that occurs during baking and is known as sugar caramelization. As a result, the biscuits acquired a brown color and were rated as more attractive by the tasters (Ferreira et al., 2020).

Finally, the fruit peel, often considered a waste material, presents energy potential to be used in the production of charcoal, an important source of renewable energy obtained through the carbonization of biomass from wood (Carrazza and Avila, 2010; Rodrigues and Junior, 2019; Teixeira et al., 2020; Vale and Olsen, 2013). After breaking the woody endocarp to remove the seed, the portion is directed to the production of charcoal, since it has high levels of ash (11.01%) and volatile materials (82.02%). Because it has a greater hardness than traditional wood, the combustion of the peel generates higher density charcoal, allowing for a longer burning time. In addition, the calorific power of coal from baru peel is higher than conventional coal (Carrazza and Avila, 2010; Teixeira et al., 2020; Vale and Olsen, 2013).

6. Conclusions

Based on the studies available in the literature, our review gathered relevant information involving the current scenario of the Brazilian Cerrado and the state of the art about the baru. The Cerrado is home to one of the greatest biodiversity in the world, however intense unsustainable activities that involve deforestation and illegal fires, added to the lack of significant interventions, are excluding the local flora and fauna. Still little known and scientifically explored, baru stands out for positive impacts on health, technological applicability, and as functional ingredient in the preparation of food products. The cultivation of baru is promising, generates low environmental impact, and provides income for small local farmers. Baru almond is the most commercially interesting part of the plant. It is a source of proteins, unsaturated fatty acids, dietary fibers, and minor bioactive compounds, and its consumption is associated with an improvement in the blood lipid profile. The almond, the peel, and the pulp of fruit as well as the leaves showed antimicrobial potential *in vitro* and the barueiro tree bark has shown to be promising against snake venom. Baru almond concentrates or isolated proteins can be used as emulsifying and foaming agents in food systems. In the energy area, the oil extracted from the almond can produce better quality biofuels, and the fruit peel and woody endocarp are raw materials that can be used by the coal industry. Especially, characterization and health-related studies are necessary to understand the potential of baru's fruit pulp and peel. Further experimental studies may establish baru as an indispensable plant for various uses in society.

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.

Acknowledgments

MRA was supported by Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) - process 131555/2019-7; and RPN was supported by Fundação de Amparo à Pesquisa do Estado de São Paulo – process 2019/03228-9.

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