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Original Article

Baru (*Dipteryx alata*): a comprehensive review of its nutritional value, functional foods, chemical composition, ethnopharmacology, pharmacological activities and benefits for human health

Baru (*Dipteryx alata*): uma revisão abrangente do seu valor nutricional, alimentos funcionais, composição química, etnofarmacologia, atividades farmacológicas e benefícios para a saúde humana

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Abstract

Baru (*Dipteryx alata* Vogel) is recognized as a widespread Brazilian tree species, and its almonds and pulp have gained commercial prominence due to their nutritional value. All parts of the baru are important for the environment and are used by traditional communities to treat various diseases. This review provides a comprehensive and current overview of the nutritional composition, human food applications, ethnopharmacological uses, and chemical and biological properties of *Dipteryx alata*, "baru" (Fabaceae). This study followed the recommendations of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) methodology. Studies were searched in the Medline (PubMed), Scopus, SciELO, and ScienceDirect databases using the descriptors "*Dipteryx* alata" OR "baru nut" OR "baru almond" OR "cumaru" OR "*Coumarouna*". The exclusion criteria included duplicate articles, review articles, case reports, short communications, conference documents, incomplete access to the text, and articles not related to the objective of this review. The initial search yielded 822 results, 127 of which met the inclusion criteria. The almond was the most extensively studied part (59.8%), whereas leaves received the least attention (1.6%). Baru almond is a rich source of proteins (19 to 30 $g.100\ g^{-1}$), unsaturated fatty acids (75 to 81%), and essential amino acids, while the pulp is rich in carbohydrates (22.5 to 75.4%), dietary fiber (4.4 to 41.6 $g.100\ g^{-1}$) and vitamin C (113.48 and 224.5 $mg.100\ g^{-1}$). Phenolic compounds were the main metabolites, with a greater content in the almond (3.1 to 1.306,34 $mg\ GAE\ g^{-1}$) than in the pulp (186 to 477 $mg\ GAE\ g^{-1}$). Terpenes were also detected in the almond, pulp, and bark. The most evaluated biological activity was the antioxidant activity (n = 32.1%), followed by effects on oxidative stress (n = 12.5%). Therefore, emphasis on baru cultivation and bioprospecting could benefit human nutrition and health, strengthen family farming in various regions of the country and favour the achievement of Zero Hunger and Sustainable Agriculture and Health and Well-Being in the UN 2030 Agenda for Sustainable Development Goals.

Keywords: cumaru, nut, phenolic compounds, traditional medicine, bioprospecting.

Resumo

O baru (*Dipteryx alata* Vogel), Fabaceae, é reconhecido como uma espécie brasileira de ampla distribuição, e suas amêndoas e polpa ganharam destaque comercial devido ao seu valor nutricional. Todas as partes do baru são importantes para o meio ambiente e são utilizadas por comunidades tradicionais no tratamento de várias doenças. Esta revisão fornece uma visão abrangente e atualizada da composição nutricional, aplicações alimentares humanas, usos etnofarmacológicos e propriedades químicas e biológicas de *Dipteryx alata*, "baru". Este estudo seguiu as recomendações da metodologia Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). Estudos foram buscados nas bases de dados Medline (PubMed), Scopus, SciELO e ScienceDirect usando os descritores "*Dipteryx alata*" OU "baru nut" OU "baru almond" OU "cumaru" OU "Coumarouna". Os critérios de exclusão incluíram artigos duplicados, artigos de revisão, relatos de casos, comunicações breves, documentos de conferências, acesso incompleto ao texto e artigos não relacionados ao objetivo desta revisão. A busca inicial resultou em 822 artigos, dos quais 127 atenderam aos critérios de inclusão. A amêndoa foi a parte mais extensivamente estudada (59,8%), enquanto as folhas receberam menos atenção (1,6%). A amêndoa de baru é uma fonte rica em

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proteínas (19 a 30 g.100 g^{-1}), ácidos graxos insaturados (75 a 81%) e aminoácidos essenciais, enquanto a polpa é rica em carboidratos (22,5 a 75,4%), fibra alimentar (4,4 a 41,6 g.100 g^{-1}) e vitamina C (113,48 e 224,5 mg.100 g^{-1}). Compostos fenólicos foram os principais metabólitos, com um maior conteúdo na amêndoa (3,1 a 1.306,34 mg GAE g^{-1}) do que na polpa (186 a 477 mg GAE g^{-1}). Terpenos também foram detectados na amêndoa, polpa e casca. A atividade biológica mais avaliada foi a atividade antioxidante (n = 32,1%), seguida pelos efeitos sobre o estresse oxidativo (n = 12,5%). Portanto, o destaque para o cultivo de baru e a bioprospecção poderiam beneficiar a nutrição e a saúde humana, fortalecer a agricultura familiar em várias regiões do país e favorecer o alcance da Fome Zero e Agricultura Sustentável e Saúde e Bem-Estar na Agenda 2030 da ONU para os Objetivos de Desenvolvimento Sustentável.

Palavras-chave: cumaru, noz, compostos fenólicos, medicina tradicional, bioprospecção.

1. Introduction

The Cerrado is the second largest biome in South America (which encompasses 15 states), occupying an area of approximately 25% of the Brazilian territory, and has the second greatest biodiversity richness (Brasil, 2024a). It is considered a global hotspot (areas particularly rich in species) and has vast social importance (Brasil, 2024b). Many populations, such as indigenous people, quilombolas, riverine dwellers, and floodplains, use their natural resources for food, medicinal purposes, local survival, and income generation. Together, these communities are part of the Brazilian historical and cultural heritage and hold traditional knowledge of local biodiversity (Brasil, 2024b). The exchange of knowledge that has taken place for decades between indigenous, riverside, and descendant peoples from the northeast, north, and south regions of Brazil has made the microregion north of Araguaia, Mato Grosso, Brazil, a source of ethnocultural diversity and propagation of traditional knowledge (Ribeiro et al., 2017).

In this context, *Dipteryx alata* Vogel., Fabaceae, is a leguminous native plant to the Brazilian Cerrado that is popularly known as “baru” or “cumaru” (Carvalho et al., 2022; ITIS Catalogue of Life, 2019). It is a fruit tree that can reach more than 25 meters in height, and fruit production per tree can reach up to 5 thousand units (Sano et al., 2016; Rinaldi et al., 2021). Leaves promote an increase in organic matter in the soil due to the high level of nitrogen, and baru wood is utilized in civil construction (Bispo and Braga, 2021). Souza et al. (2023) underscore the positive impact of the symbiotic relationship between arbuscular mycorrhizal fungi and baru, enhancing both biomass production and seedling quality, thus highlighting baru’s potential for forest recovery (Bispo and Braga, 2021).

Baru (bark, stem, leaves, fruits, and seed) is used by microregion Norte do Araguaia and traditional communities of other regions in Brazil for various applications in human food (Ferreira et al., 2020a; Rojas et al., 2019), extractive income sources, forest recovery (Bispo and Braga, 2021), and traditional medicine (Ribeiro et al., 2017; Bueno et al., 2020; Guimarães et al., 2022; Paim et al., 2023).

The present review discusses the nutritional value and traditional uses of the bark, stem, leaves, fruits, and almond of *D. alata.* Encouraging the use of this plant could benefit human nutrition and health and strengthen family farming in various regions of the country. A bibliographical survey of the phytochemical composition and biological activities of this plant is also presented to better understand its potential for use and perspectives for future applications.

2. Materials and Methods

2.1. Search strategy

This review followed the recommendations of the methodology Preferred Reporting Items for Systematic reviews and Meta-Analyses - PRISMA. The flow diagram for data collection was described in Scheme 1. The review was performed by two independent evaluators (J.M.D.S. and J.A.T.B.) in the Medline (PubMed), Scopus, Scielo, and ScienceDirect databases using the descriptors “*Dipteryx alata*” OR “baru nut” OR “baru almond” OR “cumaru” OR “*Coumarouna*”, during May and July 2023. No restrictions on language or date were made. All selected studies were imported into the Mendeley reference manager.

2.2. Eligibility, exclusion, and inclusion criteria

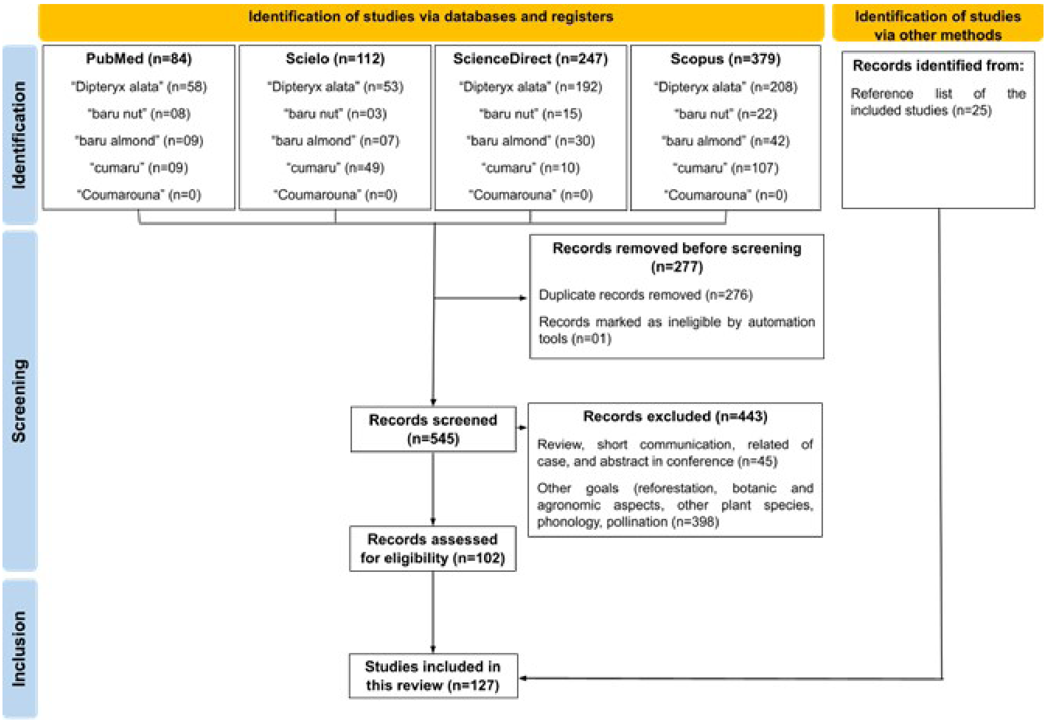
Exclusion criteria were: i) review articles; ii) case reports, short communication, and conference documents; iii) incomplete text access, and iv) not related to the goal articles (e.g.: agriculture). Inclusion criteria were: i) original studies covering one or more of the goals: nutritional value and application on human food, ethnopharmacological use, chemical composition, and biological properties of *D. alata* Vogel; ii) studies published in journals with a rigorous peer review, and iii) books published online.

2.3. Study selection and data collection process

Two independent reviewers (J.M.D.S., J.A.T.B, and S.M.D.S.) performed an initial screening. Duplicates were excluded. Then, the title and abstract were read to apply the exclusion criteria. In case of discrepancies, a third evaluator (A.S.N.F.) judged the inclusion or exclusion of the study. Furthermore, articles found by a manual search performed in the reference list of the selected studies were included in this review. After reading each article in full (J.M.D.S; R.M.M.F.S.; V.D.K; A.S.N.F.), the studies were included in this review if they met one or more of the inclusion criteria. At the end of the selection, all articles were organized in Microsoft Excel software, by date of publication, descending (J.M.D.S and V.D.K).

2.4. Studies included

Scheme 1 summarizes the study selection strategy. The initial electronic database se-arch yielded 822 results. After removing duplicates (n = 276) and inaccessible text (n = 01), a total of 545 records were screened by title and abstract. After applying the exclusion criteria (n = 443), 102 records were eligible. Additionally, the manual



Scheme 1. Identification of eligible studies for this review (PRISMA, 2020 flow diagram).

bibliography yielded 25 records, totalling 127 studies. All the included articles with titles, authors, publication years, and collection sites are detailed in Table S1 in the supplementary material.

3. Results and Discussion

3.1. Distribution of studies by collection site

We observed that all the articles were performed with plants collected in Brazil. The main baru collection site was in the state of Goiás (41.73%), followed by Mato Grosso (13.39%), Mato Grosso do Sul (11.81%), Minas Gerais (7.87%), Tocantins (7.09%), and Distrito Federal (5.51%). The least sought-after locations were São Paulo (3.15%) and Paraná (0.79%). In addition, one study compared more than one state (0.79%), and 7.87% of the studies did not report the collection site or reported the species in general. Furthermore, the most studied part of the plant was the almond, while the leaves were the least studied (Figure 1).

3.2. Taxonomy, botanical aspects, and distribution

Dipteryx alata Vogel, basionym *Dipteryx pterota* Benth, *Dipteryx pteropus* Mart., *Coumarouna alata* (Vogel) Taub., and *Cumaruna alata* (Vogel) Kuntze, is commonly known as "baru", "baruzeiro", "barujó", "coco-feijão", "cumaru", "cumaruna", "cumarurana", "cambaru", and "almendro" (Carvalho et al., 2022; Tropicos, 2022; Bueno et al., 2020; ITIS Catalogue of Life, 2019). The scientific classification (I) class: Equisetopsida C. Agardh; (II) subclass: Magnoliidae Novák ex Takht.; (III) superorder: Rosanae Takht.; (IV) order: Fabales Bromhead; (V) family: Fabaceae Lindl.; (VI) subfamily: Papilionoideae; (VII) tribe: Dipterygeae; (VIII) genus: *Dipteryx* Schreb., and (IX) species: *Dipteryx alata* Vogel (The Plant List, 2013; Tropicos, 2022).

Baru is a fruit tree (Figure 2) that can reach more than 25 meters in height. The stem can be smooth or irregularly shaped, with scaling plaques that are light grey or cream in colour. The leaves alternate, except for the primordial leaves, compound pinnate, petiolate, without stipules, and winged rachis, which give rise to the species name. The number of leaflets can vary from 7 to 12, and they can be alternate or subopposite, subsessile, or with a petiole up to 2 mm long. The panicle-like inflorescence is formed at the terminal part of the branches and in the axils of the upper leaves, with approximately 200 to 1000 flowers; valve bracts with translucent pits are deciduous before anthesis. The flowers are hermaphroditic. The fruit is of the drupe type, ovoid, slightly flattened, and brown in colour, with no change in colour when ripe. It is approximately 3 to 6 cm long. The endocarp is woody and hard and darker in colour than the fibrous mesocarp. There is a single almond per fruit, rarely more than one. The almonds are ellipsoidal, yellowish-brown, or reddish to almost black, occasionally with darker spots or transverse slits highlighted by lighter cotyledons. They are approximately 2.5 cm in length and 1.0 cm in width, with masses between 1 and 1.2 g and a harder consistency than roasted peanuts. These characteristics may be variable between trees but are uniform across a tree (Sano et al., 2016; Rinaldi et al., 2021).

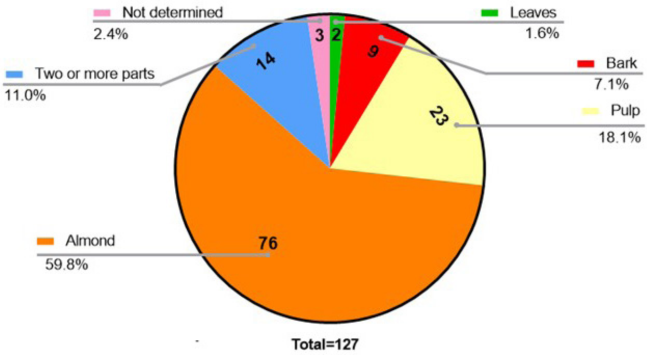


Figure 1. Number of articles included by plant part.

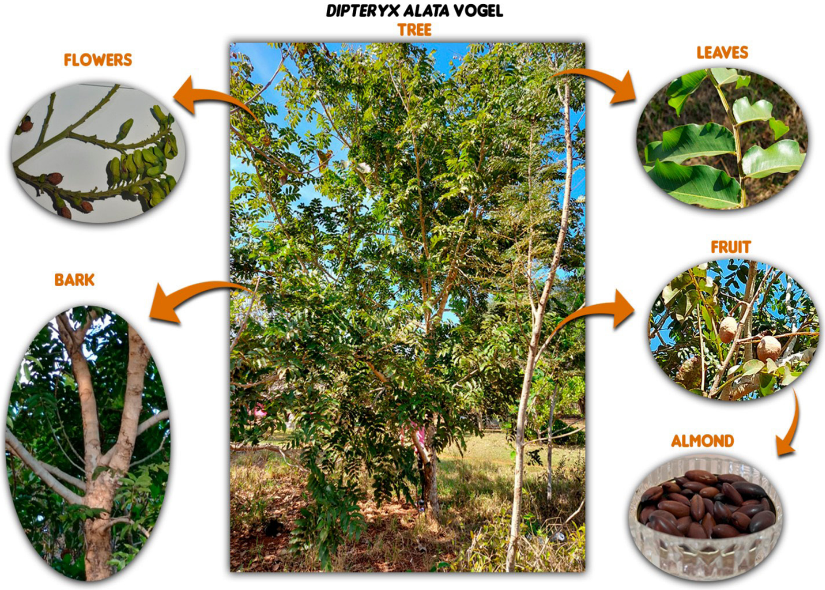


Figure 2. Baru (*Dipteryx alata* Vogel). Tree, bark, leaves, flowers, pulp, and almonds. Original images from Santos, J.M.

Baru is a native plant from Bolivia, Paraguay, Peru and Brazil (ITIS Catalogue of Life, 2019). In Brazil, it is found in the states of Rondônia, Tocantins, Bahia, Maranhão, Minas Gerais, São Paulo, Goias, Mato Grosso, and Mato Grosso do Sul and is considered a fast-growing plant that requires few nutrients from the soil, developing well in ciliary forests or Gallery, seasonal semideciduous forests, and the Amazon Savanna (Carvalho et al., 2022).

Baru trees have favourable characteristics for planting, such as high germination and seedling survival rates (Sano et al., 2016). This species is sensitive to postflooding stress, and although it can adjust and recover its metabolic characteristics (after 100 days) after water stress, the quality of the seedlings does not recover (Linné et al., 2021). Furthermore, baru has the ability to form symbiotic relationships with mycorrhizal fungi, contributing positively to biomass production and seedling quality (Souza et al., 2023).

This species has a long flowering period, occurring from November to February, during the rainy season. Its fruits ripen when the tree is almost leafless, from July to October, varying from year to year and by location. The physiological maturation of the seed occurs at the beginning of fruit and leaf fall (Sano et al., 2016).

Although Sano et al. (2016) claim that fruit production per tree can reach up to 5 thousand units, production may vary by region and year, as reported by Rinaldi et al. (2021), who reported a production of fewer than 2 thousand fruits. In this context, the characteristics of sustainable exploitation and dependence on seasonal production cause economic devaluation (Egea and Takeuchi, 2020).

3.3. Nutritional value of baru almond and pulp

Baru almond is consumed in human food and has high nutritional value because it is rich in proteins, total lipids, and several minerals. Macronutrients such as carbohydrates, proteins, and fats are essential for the body's structure and operation. They provide energy through oxidation, generating adenosine triphosphate (ATP) along with carbon dioxide and water as byproducts. ATP serves as the cell's primary energy currency. Carbohydrates are broken down into glucose, the main energy source. Proteins, which are composed of amino acids, contribute to muscle building. Lipids are crucial for cell membrane structure and function, aid in fat-soluble vitamin absorption, and serve as the body's primary long-term energy storage (Matthewman and Costa-Pinto, 2022).

In this sense, previous studies characterized the proximal composition of baru almonds (Table 1). The carbohydrate content of the raw almond (15 to 37%) was greater than that of the roasted almond (9 to 29%). Studies have reported that the carbohydrate content of raw almond is up to two times greater of one study (Campidelli et al., 2019) to another (Siqueira et al., 2015) and two to three times greater than that of roasted almond. According to Campidelli et al. (2019) and Oliveira-Alves et al. (2020), the sum of the values of the proximal component was greater than 100, and the value of dietary fiber was not subtracted from the carbohydrate content. Gonçalves et al., and Filbido (2020) reported a low lipid content (24.2 g.100^{-1}), and the carbohydrate content differed. In these cases, the adjusted carbohydrate content would be similar to that in other studies (Table 1).

A high protein content in baru almonds (19 to 30 g.100 g^{-1}) has been reported (Table 1). In comparison with other seeds, the protein content in baru almonds is higher than that in Brazil nuts (16 g.100 g^{-1}) (Cardoso et al., 2016) and similar to that in cashew nuts (23 g.100 g^{-1}) and peanuts (32 g.100 g^{-1}) (Freitas et al., 2012). In addition, baru almond showed a high *in vitro* digestibility relative to that of casein, with higher levels of globulins (61.7%), albumin (14%), and globulin (3.3%) (Cruz et al., 2011).

In contrast to the findings of most studies, Gonçalves et al., and Filbido (2020) reported that the lower lipid content of roasted almond (24 g.100^{-1}) (Table 1) may be related to the use of the Goldfish method, since other studies that showed superior lipid content used Soxhlet or Bligh & Dyer for the determination of lipids (Fernandes et al., 2015; Santiago et al., 2018; Oliveira-Alves et al., 2020). Furthermore, the lipid content (24 to 45 g.100 g^{-1}) and total energy (458 to 603 Kcal.100 g^{-1}) in baru almonds were lower than those in Brazil nuts (67 g.100 g^{-1}; 714 Kcal.100 g^{-1}) (Cardoso et al., 2016) and pequi almonds (50 g.100 g^{-1}; 570 Kcal.100 g^{-1}) (Cruz et al., 2011). Consequently, almonds are less caloric than these oilseeds.

The dietary fiber content in almond is high (6 to 16 g.100 g^{-1}), especially insoluble fiber (7 to 13 g.100 g^{-1}) (Table 1). The reported values were similar between studies, except for Oliveira-Alves et al. (2020), who reported a lower dietary fiber content (6.1 g.100 g^{-1}), although the analysis method was the same as that used in other studies. Moreover, almond had a greater dietary fiber content than other oilseeds, such as cashew nuts (3 to 6 g.100 g^{-1}) and peanuts (5 to 10 g.100 g^{-1}) (Sousa et al., 2011; Freitas et al., 2012). Dietary fibers are complex carbohydrates that resist breakdown by the body's internal enzymes in the small intestine, thus not contributing to energy intake. Fibers offer various health advantages, such as lowering the chances of cardiovascular disease and promoting stool bulkiness and softness (Matthewman and Costa-Pinto, 2022).

The proximal composition of baru pulp has also been studied (Table 2). Baru pulp is rich in carbohydrates (22.5 to 75.4%) and dietary fiber (4.4 to 41.6 g.100 g^{-1}) (Table 2). When the carbohydrate content was higher (75.4%), this difference was indirectly detected (Almeida et al., 2019). This is the case, as the adjusted values of carbohydrate content would be similar between studies.

Pulp is a source of several sugars, such as glucose, sucrose, and starch. However, the content differed between studies (Table 2). This variation between studies may be associated with the different regions of fruit origin (Vallilo et al., 1990; Silva et al., 2021b) and the fact that Vallilo et al. (1990) evaluated the starch content by difference. Considering the low number of articles, further studies are needed to determine which sugars are present in pulp and their respective amounts.

The lower lipid content in the pulp (0.90 ± 0.10 g.100 g^{-1}) (Almeida et al., 2019) may be associated with the different methods used to analyse the lipids, such as the AOAC (method 920.39) versus the methods of Bligh & Dyer chosen by the other two studies (Santiago et al., 2018; Silva et al., 2021b) (Table 2).

The relatively high dietary fiber content in the pulp and peel makes the baru an interesting source, especially insoluble fiber. However, the dietary fiber contents have diverged among studies (Table 2). This variation may be related to the local collection and maturation of the pulp. In addition, the dietary fiber in pulp (4 to 40%) is greater than that in other Cerrado fruits, such as cagaita (1.56%), buriti (2.65%), araçá (9.30%), and yellow mombin (15.23%) (Schiassi et al., 2018). The intake of approximately 21 to 38% of daily dietary fiber is recommended for the maintenance of health at different stages of life (IOM, 2011). In Brazil, the daily reference value for dietary fiber consumption is 25 g.100 g^{-1} of food (Brasil, 2020). Thus, baru pulp is an ideal option for supporting the adequate consumption of dietary fiber.

Pulp is a good source of energy (Table 2). Compared with those of the other Cerrado fruits, the total energy of baru was greater (145 to 366 Kcal.100 g^{-1}) than that of araçá (38 Kcal.100 g^{-1}), cagaita (39 Kcal.100^{-1}), yellow mombin (53 Kcal.100 g^{-1}), mangaba (67 Kcal.100 g^{-1}) buriti (93 Kcal.100 g^{-1}), marolo (113 Kcal.100 g^{-1}) (Schiassi et al., 2018), and macauba (258 Kcal.100 g^{-1}) (Almeida et al., 2019).

Although baru almond and pulp exhibit distinct nutritional compositions, both serve as sources of essential nutrients and energy; the almond is rich in lipids, proteins, and essential amino acids, while the pulp is rich in dietary fibers, sugars, and vitamin C. In this regard, baru is considered a sociobiodiverse species with nutritional value, and its acquisition in the National School Feeding Program is encouraged by public policies (Brasil, 2021a, 2023) (Figure 3).

3.4. Vitamins in almond and pulp

Studies have detected ascorbic acid and tocopherol in almond (Fiorini et al., 2017; Gonçalves et al., and

Table 1. Proximal composition of baru almonds.

Content (%)	Raw almonds						Roasted almonds							
Moisture	6.63 ± 2.31	9.9 ± 0.1	7.38 ± 0.19	3.99	6.10 ± 0.20	5.80	2.07 ± 0.03	2.17 ± 0.10	3.20 ± 0.04	6.8 ± 0.10	3.17 ± 0.11	3.58 ± 0.24	1.98 ± 0.23	3.49 ± 0.08
Protein	22.96 ± 0.32	21.3 ± 0.1	19.72 ± 0.11	26.25	23.9 ± 0.60	23.45	24.95 ± 0.68	24.30 ± 0.30	27.06 ± 0.08	22.9 ± 0.20	28.94 ± 0.30	30.92 ± 1.10	27.96 ± 0.53	29.92 ± 0.37
Lipid	31.73 ± 2.09	36.3 ± 1.4	38.37 ± 0.07	33.28	38.20 ± 0.40	41.65	41.69 ± 1.21	24.20 ± 0.30	45.80 ± 0.05	40.6 ± 1.10	42.40 ± 0.65	41.25 ± 1.72	42.69 ± 1.69	41.95 ± 0.44
Carbohydrate %	37.13 ± 0.54	18 ± 1.0	19.47 ± 0.22	-	15.80 ± 0.60	23.02	-	29.40 ± 0.50	20.71 ± 0.02	11.0 ± 1.0	10.79	9.20 ± 1.61	10.03	12.25
Dietary fiber	14.44 ± 0.98	12 ± 0.4	12.60 ± 0.30	-	13.40 ± 0.30	-	-	16.60 ± 0.40	6.10 ± 0.09	16.0 ± 1.0	11.70 ± 0.20	12.08 ± 1.44	14.26 ± 0.13	9.21 ± 0.21
Soluble fiber	-	-	-	-	2.50 ± 0.20	-	-	-	-	-	2.40 ± 0.10	1.31	0.90	2.03
Insoluble fiber	-	-	-	-	10.90 ± 0.30	-	-	-	-	-	9.30 ± 0.10	10.77	13.35 ± 0.17	7.18
Ash	1.55 ± 0.30	2.7 ± 0.1	2.46 ± 0.43	-	2.70 ± 0.06	2.85	3.10 ± 0.17	3.06 ± 0.10	3.24 ± 0.03	3.1 ± 0.0	3.01 ± 0.04	2.98 ± 0.90	3.08 ± 0.25	3.18 ± 0.01
Energy (Kcal.100 g^{-1})	-	483 ± 1.0	502 ± 0.22	-	502 ± 3.00	561	-	-	603 ± 0.07	501 ± 9.0	574 ± 6.15	531 ± 12.50	536	546
Minerals (mg.100 g^{-1})														
Calcium	240 ± 0.49	-	88 ± 3.00	300	140 ± 4.00	82	638	-	-	-	-	129 ± 9.42	-	110 ± 1.36
Copper	2.8 ± 0.64	-	1.00 ± 0.04	1.67	1.45 ± 0.06	1.08	0.96	1.80 ± 0.10	-	-	-	-	-	-
Iron	6.5 ± 0.10	-	3.00 ± 0.30	19.81	4.24 ± 0.08	5.35	9.53	8.65 ± 0.60	-	-	-	3.18 ± 0.15	-	3.57 ± 0.09
Magnesium	330 ± 0.67	-	107 ± 3.00	130	178 ± 3.00	143	200	8.85 ± 0.20	-	-	-	-	-	164.81 ± 1.29
Selenium	-	-	-	-	-	-	-	-	-	-	0.26 ± 0.03	-	-	-
Sodium	-	-	2.00 ± 0.02	-	-	3.30	-	-	-	-	-	9.83 ± 2.74	-	7.46 ± 1.51
Zinc	-	-	2.00 ± 0.10	2.36	4.1 ± 0.10	1.04	2.26	4.83 ± 0.30	-	-	6.74 ± 0.04	3.46 ± 0.48	-	4.29 ± 0.16
Potassium	1810 ± 0.69	-	-	920	827 ± 46.00	811	943	-	-	-	-	-	-	980.35 ± 5.31
Phosphor	-	-	-	730	358 ± 6.00	317	331	-	-	-	-	-	-	832.80 ± 2.66
Reference	Campidelli et al. (2019)	Santiago et al. (2018)	Cruz et al. (2011)	Vera et al. (2009)	Takemoto et al. (2001)	Vallilo et al. (1990)	Lima et al. (2021a)	Gonçalves et al., and Filbido (2020)	Oliveira-Alves et al. (2020)	Santiago et al. (2018)	Fernandes et al. (2015)	Czeder et al. (2012)	Freitas et al. (2012)	Cardoso et al. (2016)

(-) not determined.

Table 2. Proximal composition of baru pulp.

Content	Peel	Pulp									Peel and pulp	
Moisture %	16.30 ± 0.40	14.11 ± 0.02	10.28 ± 0.39	20.84 ± 0.16	19.30 ± 0.28	17.1 ± 0.40	14.90 ± 0.10	20.00 ± 0.09	13.76 ± 0.57	24.45 ± 0.18	20.23	9.64 ± 0.17	21.05 ± 0.05
Protein %	2.50 ± 0.10	10.05 ± 0.37	8.84 ± 0.22	15.60 ± 0.24	6.72 ± 0.13	5.00 ± 0.70	3.20 ± 0.10	5.60 ± 0.30	4.17 ± 0.70	5.88 ± 0.10	5.00	3.19 ± 0.47	4.45 ± 0.06
Lipid %	2.70 ± 0.20	1.79 ± 0.01	3.54 ± 0.08	4.40 ± 0.09	3.00 ± 0.10	0.90 ± 0.10	3.70 ± 0.10	3.10 ± 0.03	3.73 ± 0.14	3.57 ± 0.10	4.13	4.82 ± 0.67	3.30 ± 0.26
Carbohydrates %	51.50 ± 0.70	70.05 ± 0.09	39.87 ± 0.42	55.29 ± 0.45	67.44 ± 0.22	75.40 ± 0.80	57.00 ± 2.0	63.19 ± 0.05	54.90	22.50	-	77.43 ± 0.40	65.01 ± 0.19
Glucose	-	-	6.32 ± 0.70	-	-	-	-	5.90 ± 0.65	-	-	23.09	-	-
Sucrose	-	-	-	-	-	-	-	30.91 ± 0.50	-	-	7.71	-	-
Fructose	-	-	7.76 ± 0.82	-	-	-	-	22.50 ± 0.22	-	-	-	-	-
Starch	-	-	-	25.10 ± 0.34	-	-	-	-	-	-	32.38	-	-
Dietary fiber	24.10 ± 0.50	-	32.90 ± 0.42	6.32 ± 0.31	-	-	18.00 ± 2.0	4.61 ± 0.40	19.10 ± 0.20	41.60 ± 0.10	5.71	-	4.39 ± 0.16
Soluble fiber	-	-	<0.10	-	-	-	-	-	-	2.10 ± 0.17	-	-	-
Insoluble fiber	-	-	32.90 ± 0.42	-	-	-	-	-	-	39.50 ± 0.20	-	-	-
Ash	2.90 ± 0.10	-	4.56 ± 0.03	-	3.54 ± 0.04	1.80 ± 0.10	3.10 ± 0.10	3.50 ± 0.03	4.34 ± 0.30	2.00 ± 0.06	1.70	4.44 ± 0.16	1.79 ± 0.01
Energy (Kcal.100 g^{-1})	240 ± 3.00	336.49 ± 0.94	226.73 ± 1.73	322.30	323 ± 0.47	328 ± 2.00	276 ± 6.00	-	269	145.65	310	366	-
Minerals (mg.100 g^{-1})		-											
Calcium	-	-	-	-	-	-	-	-	-	-	75.20	115.88 ± 6.97	-
Copper	-		-	-	-	-	-	-	-	-	3.54	3.38 ± 0.39	-
Iron	-	-	-	-	-	-	-	-	-	-	5.94	3.59 ± 1.39	-
Magnesium	-	-	-	-	-	-	-	-	-	-	3.90	80.00 ± 7.50	
Sodium	-	-	-	-	-	-	-	-	-	-	1.74	-	-
Zinc	-	-	-	-	-	-	-	-	-	-	1.08	8.75 ± 1.70	-
Potassium	-	-	-	-	-	-	-	-	-	-	572	1187 ± 272.0	-
Phosphor	-		-	-	-	-	-	-	-	-	82.20	113.63 ± 6.19	-
Reference	Santiago et al. (2018)	Viana et al. (2023)	Alves-Santos et al. (2023)	Silva et al. (2021a)	Silva et al. (2021b)	Almeida et al. (2019)	Santiago et al. (2018)	Araujo et al. (2013)	Alves et al. (2010)	Lima et al. (2010)	Vallilo et al. (1990)	Silva et al. (2019)	Rocha and Cardoso Santiago (2009)

(-) not determined.

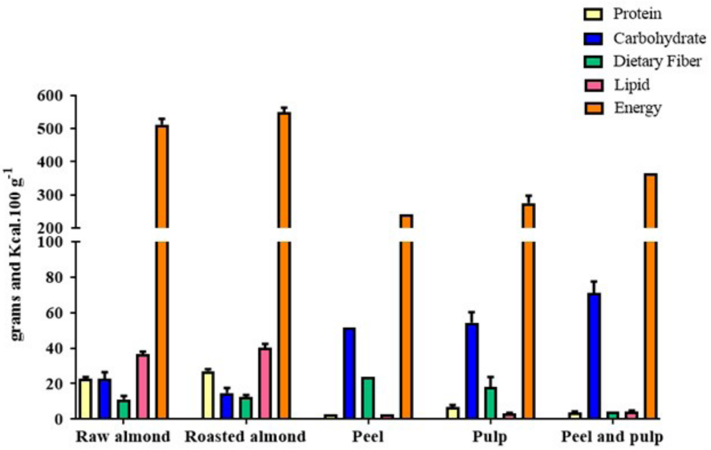


Figure 3. Amount of essential nutrients (grams.100 g^{-1}) and energy (kilocalories.100 g^{-1}) in baru almond and pulp.

Filbido, 2020; Campidelli et al., 2020a) and ascorbic acid in pulp (Leite et al., 2020; Silva et al., 2021a). The ascorbic acid content in the pulp (113.48 and 224.5 mg.100 g^{-1}) (Almeida et al., 2019; Leite et al., 2020) was greater than that in the raw (18.80 and 39 mg.100^{-1}) and roasted (18.5 to 37.8 mg.100 g^{-1}) almond. This outcome was expected, given that ascorbic acid is hydrophilic (Tiozon et al., 2021).

Peixoto et al. (2022) used different methods and solvents for the extraction of almond oil and obtained better results for tocopherol (3 to 212 mg.100 g^{-1}) than reported in the literature (0.19 to 11 mg.100 g^{-1}) (Lemos et al., 2016; Fetzer et al., 2018; Campidelli et al., 2020a). Vitamins are vital to human health (Tiozon et al., 2021). It acts as an enzyme cofactor and performs catalytic functions in organism (Askin et al., 2021), ensuring physiological and metabolic homeostasis (Tiozon et al., 2021). Tocopherol is fat soluble and acts synergistically with endogenous antioxidant components to scavenge reactive species (Mattioli et al., 2021), while ascorbic acid is a water-soluble vitamin. Both are natural antioxidants that act on the body as detoxifiers and ensure the protection of vital organs such as the liver and kidneys (Shotop and Al-Suwiti, 2021).

3.5. Minerals in almond and pulp

Nutritional studies with baru almond and pulp also related the presence of several minerals, such as potassium, copper, zinc, and phosphor, and the presence of calcium, iron, magnesium, selenium, and sodium. However, there was variation between studies (Tables 1 and 2). This variation may be related to the region and time of harvest of the plant, sample preparation, and method chosen for the analysis. In this way, it is possible to optimize the extraction of a certain nutrient based on the analysis of the reports of previous studies.

The potassium content of baru almond (811 to 1810 mg.100 g^{-1}) was greater than that of pequi almond (835 mg.100 g^{-1}), cashew nut (556 mg.100 g^{-1}), and peanut (668 mg.100 g^{-1}) (Sousa et al., 2011). The iron content (3 to 19 mg.100 g^{-1}) was greater in baru almonds than in Brazil nuts (2.2 mg.100^{-1}), cashew nuts (5.4 mg.100 g^{-1}), hazelnuts (2.5 mg.100 g^{-1}), and walnuts (2.1 mg.100 g^{-1}). The zinc content (1 to 6 mg.100 g^{-1}) was greater in baru almonds than in Brazil nuts (2.4 mg.100 g^{-1}), cashew nuts (3.0 mg.100 g^{-1}), hazelnuts (25.1 mg.100 g^{-1}), and walnuts (1.8 mg.100 g^{-1}). The calcium content (82 to 638 mg.100 g^{-1}) was greater than that of cashew nuts (25.1 mg.100 g^{-1}) and walnuts (73.1 mg.100 g^{-1}). The selenium content (260 µg.100 g^{-1}) was greater than that of Brazil nuts (57.7 µg.100 g^{-1}) (Cardoso et al., 2016), Pequi almonds (1.40 µg.100 g^{-1}), cashew nuts (1.02 µg.100 g^{-1}) and peanuts (2.51 µg.100 g^{-1}), and the phosphorus content was less than that of Pequi nuts (2214 mg.100 g^{-1}) and cashew nuts (1101 mg.100 g^{-1}) (Sousa et al., 2011). However, the magnesium content (8 to 200 mg.100 g^{-1}) was less than that of Brazil nuts (221.2 mg.100 g^{-1}) and cashew nuts (195.7 mg.100 g^{-1}) (Suliburska and Krejpcio, 2014).

In our organism, these minerals are necessary for important biochemical functions, such as forming structural components of bones (calcium, magnesium, phosphorus), red blood cell formation, blood coagulation (copper, iron, calcium), electrolytes, neuromuscular functions (potassium, sodium, calcium, magnesium, phosphorus), protein synthesis (zinc and potassium), glucose and glycogen synthesis (potassium and phosphorus), fatty acid synthesis (magnesium), enzymatic cofactors and antioxidants (selenium and copper), cardiovascular excitability (magnesium), endocrine secretory function and cell membrane integrity (calcium), immunity and growth of genital organs (zinc) and pH maintenance (phosphorus) (Doley, 2017; NIH, 2022).

In addition, evaluating the gastrointestinal bioaccessibility of minerals is important for understanding the nutritional value of Brazilian Cerrado fruits and almond. Mineral bioaccessibility represents how much of a certain mineral will be released from food and may be absorbed by the gastrointestinal tract during the digestion process (Gonçalves et al., and Filbido, 2020).

Gonçalves et al., and Filbido (2020) evaluated the *in vitro* bioaccessibility of some minerals present in baru almond using a gastrointestinal simulation. The bioaccessibility was

16.8%, 21.4%, 80.3%, and 81.3% for copper, iron, manganese, and zinc, respectively. Pearson's correlation coefficient verified that phytic acid and ascorbic acid can influence bioaccessibility (Gonçalves et al., and Filbido, 2020). A form of better bioaccessibility is to inhibit phytate activity by roasting almond (Feizollahi et al., 2021). In contrast, ascorbic acid facilitates the absorption of Fe (Cilla et al., 2018). Thus, baru almond and pulp are natural sources of minerals that are bioaccessible to the human body.

3.6. Amino acids in almond

All the essential amino acids in the baru almond were compatible with or superior to the recommended dietary allowances (RDAs) established by the Dietary Reference Intakes (IOM, 2005) (Table 3).

In addition, almond exhibited excellent protein digestibility-corrected amino acid score (PDCAAS) values (73 and 91%) (Sousa et al., 2011; Fernandes et al., 2010), outperforming other oilseeds, such as Brazil nut and peanut (63 and 69%, respectively) (Freitas et al., 2012). The PDCAAS has been recommended by the FAO/WHO as a tool for evaluating the nutritional value of protein for human consumption (WHO, 2007). According to the PDCAAS criteria, baru almond has a high nutritional protein content. Thus, it can be an alternative protein source, especially for people who follow a vegetarian or vegan lifestyle, to increase protein intake.

3.7. Fatty acids in almond

Baru almond oil contains approximately 50% monounsaturated fatty acids, 30% polyunsaturated fatty acids (PUFAs), and 20% saturated fatty acids, with high concentrations of oleic acid (C18:1) and linoleic acid (C18:2), respectively (Table 4). Fetzer et al. (2018), using supercritical CO_2 with ethanol, and Soxhlet, using ethanol and hexane for the extraction of almond oil, reported similar results for oleic acid (50 to 53%) and less linoleic acid (23 to 25%) when compared with other studies (Lemos et al., 2016; Siqueira et al., 2016; Oliveira-Alves et al., 2020). Martins et al. (2013) reported that the extraction method affects the linolenic acid content; when the oil was extracted by Bligh & Dyer, it contained 94.70% more linolenic acid than that obtained by the Shoxlet method. The efficiency of extraction depends on the solvent characteristics. Soxhlet uses hexane, which is known for its effectiveness with apolar acids, although continuous heating may risk lipid oxidation. Bligh & Dyer employed a mixture of methanol and chloroform to efficiently extract a variety of fatty acids, including neutral, polar, and apolar fatty acids (Saini et al., 2021).

Table 3. Amino acids composition of baru almonds.

Amino acids (mg.g protein^{-1})	**Raw almonds***	**Roasted almonds**				**DRI/ RDA (mg.kg^{-1})**
Essentials						
Histidine	29.07	26.42 ± 0.26	25.70	23.40	23.40	14
Isoleucine	41.92	25.61 ± 0.25	29.80	32.50	37.50	19
Leucine	85.37	79.22 ± 0.47	83.00	74.40	77.80	42
Lysine	59.36	54.42 ± 0.32	36.20	66.40	48.40	38
Methionine+Cysteine	27.36	27.00 ± 0.11	21.20	29.80	22.00	15
Phenylalanine+Tyrosine	89.35	76.09 ± 0.12	79.90	88.50	77.20	33
Threonine	36.72	44.47 ± 0.11	43.40	55.30	44.90	20
Tryptophan	20.20	18.10 ± 0.41	13.90	11.20	20.20	05
Valine	47.74	32.99 ± 0.03	38.30	55.60	51.80	24
Total	416.89	384.32	371.30	437.10	403.20	-
Non-essentials						
Asparagine	116.59	103.68 ± 0.92	-	91.40	101.60	-
Glutamine	250.61	214.26 ± 0.16	-	176.9	216.80	-
Alanine	41	46.81 ± 0.21	-	42.60	46.10	-
Arginine	100.98	95.82 ± 0.21	-	151.40	85.60	-
Glycine	43.15	49.11 ± 0.41	-	41.70	47.20	-
Proline	40.70	57.03 ± 0.19	-	3.80	55.30	-
Serine	48.65	48.99 ± 0.22	-	58.40	44.10	-
Total	641.68	-	-	566.20	-	-
Reference	Siqueira et al. (2015)	Czeder et al. (2012)	Freitas et al. (2012)	Sousa et al. (2011)	Fernandes et al. (2010)	IOM (2005)

*In natura BAF = partially defatted baru almond flour (BAF); (-) not determined.

Table 4. Fatty acids composition of baru almonds.

Fatty acid (g.100 g lipid⁻¹)	Raw almonds					Roasted almonds					Oil almonds			
Lauric (C12:0)	0.24 ± 0.06	-	-	-	-	-	0.08 ± 0.06	-	-	0.12 ± 0.01	-		-	-
Myristic (C14:0)	0.16 ± 0.03	-	0.03	-	-	-	0.05 ± 0.02	-	-	0.18 ± 0.03	-		0.03 ± 0.00	-
Palmitic (C16:0)	6.59 ± 0.04	6.57 ± 0.00	6.10	7.40	9.44	6.80 ± 0.01	6.16 ± 0.01	6.61 ± 0.2	7.16 ± 1.69	5.94 ± 0.48	6.45 ± 0.05	5.52	6.32 ± 0.12	6.4 ± 0.14
Heptadecanoic (C17:0)	0.09 ± 0.03	-	-	-	-	-	0.08 ± 0.01	-	0.06 ± 0.02	0.04 ± 0.00	-	-	0.08 ± 0.00	-
Stearic (C18:0)	4.39 ± 0.21	4.89 ± 0.20	5.27	3.12	7.46	4.70 ± 0.01	5.22 ± 0.12	4.84 ± 0.2	4.97 ± 0.00	5.42 ± 0.26	1.62 ± 0.18	5.12	4.88 ± 0.04	3.9 ± 0.14
Arachidic (C20:0)	1.06 ± 0.07	1.52 ± 0.20	1.39	0.82	0.40	1.20 ± 0.01	1.21 ± 0.16	1.48 ± 0.2	0.86 ± 0.01	1.27 ± 0.03	1.20 ± 0.01	4.23	1.26 ± 0.00	-
Heneicosanoic (C21:0)	-	-	0.09	-	-	-	-		-	-	-	-	0.06 ± 0.01	-
Behenic(C22:0)	3.47 ± 0.25	2.26 ± 0.10	4.39	2.12	6.34	3.40 ± 0.01	3.73 ± 0.43	2.34 ± 0.1	0.51 ± 0.00	-	3.70 ± 0.02	-	4.16 ± 0.08	-
Lignoseric (C24:0)	-	3.38 ± 0.30	5.42	-	9.24	4.80 ± 0.01	-	3.31 ± 0.1	1.90 ± 0.00	-	4.30 ± 0.08	-	4.94 ± 0.11	-
Palmitoleic (C16:1)	0.08 ± 0.01	-	-	-	-		0.07 ± 0.02	-	0.11 ± 0.00	-	-	-	0.08 ± 0.01	-
Heptadecenoic (C17:1)	0.15 ± 0.02	-	-	-	-	-	0.13 ± 0.76	-	-	0.05 ± 0.01	-	-	-	-
Oleic (C18:1)	48.99 ± 0.07	47.34 ± 0.10	47.15	50.17	11.81	47.20 ± 0.01	51.01 ± 0.62	47.40 ± 0.1	51.45 ± 0.03	41.41 ± 2.08	50.76 ± 0.05	50.52	45.81 ± 0.05	49.2 ± 0.00
Linoleic (C18:2)	24.28 ± 0.23	31.34 ± 0.00	25.51	30.70	30.73	28.20 ± 0.01	26.89 ± 0.04	31.42 ± 0.1	28.57 ± 0.01	24.40 ± 1.31	28.87 ± 0.17	23.66	28.95 ± 0.02	27.3 ± 1.20
Linolenic (C18:3)	0.14 ± 0.01	-	0.13	-	-	0.05 ± 0.01	0.12 ± 0.05	-	3.14 ± 0.01	-	014. ± 0.01	3.48	-	4.2 ± 0.07
Eicosenoic (C20:1)	2.40 ± 0.87	2.68 ± 0.10	2.71	-	1.05	2.70 ± 0.01	2.56 ± 0.19	2.60 ± 0.0	-	0.13 ± 0.00	2.66 ± 0.03	-	2.83 ± 0.01	-
Erucic (C22:1)	0.26 ± 0.06	-	0.05	-	0.57	0.30 ± 0.01	-	-	-	-	0.30 ± 0.03	-	-	-
Docasadienoic (C22:2)	3.93 ± 0.35	-	-	-	-	-	4.13 ± 0.32	-	-	0.10 ± 0.02	-	-	-	
DHA (22:6)	-	-	-	-	-	-	-	-	-	0.29 ± 0.02	-	-	-	-
Σ saturated fatty acid	16.32 ± 0.71	18.62	22.92	-	33.67	21.10 ± 0.01	16.79 ± 0.65	18.58	15.47 ± 0.04	12.98 ± 0.76	17.27 ± 0.7	-	21.72 ± 0.01	-
Σ MUFA	51.91 ± 1.98	-	-	-	36.72	50.65 ± 0.01	54.08 ± 1.54	-	51.57 ± 0.03	45.49 ± 2.01	53.72 ± 0.01	-	49.07 ± 0.04	-
Σ PUFA	31.50 ± 1.04	-	-	-	31.01	28.25 ± 0.01	31.25 ± 0.69	-	31.71 ± 0.01	24.79 ± 1.31	29.01 ± 0.18	-	29.16 ± 0.02	-
Σ unsaturated fatty acid	-	81.36	75.58	-	-	-	-	81.42	-	-	-	-	-	-
Reference	Campidelli et al. (2020b)	Lemos et al. (2016)	Vera et al. (2009)	Vallilo et al. (1990)	Bidô et al. (2023)	Oliveira-Alves et al. (2020)	Campidelli et al. (2020b)	Lemos et al. (2016)	Alves et al. (2016)	Fernandes et al. (2015)	Peixoto et al. (2022)	Fetzer et al. (2018)	Borges et al. (2015)	Siqueira et al. (2016)

DHA, Docosahexaenoic acid; MUFA, Monounsaturated fatty acids; PUFA, polyunsaturated fatty acids; Σ, Sum, (-) not determined.

The oleic acid content was greater in baru almond (~ 50%) than in Brazil nut (27%), peanut (41%), and pequi almond (44%). The linoleic acid content was greater than that in cashew nuts (0.03%) (Alves et al., 2016).

The relatively high concentration of unsaturated fatty acids present in almond makes it an interesting source of these fatty acids. Linoleic acid is not synthesized in the human body (Chañi-Paucar et al., 2021). Oleic and linoleic acids promote anti-inflammatory effects (Mohammadi et al., 2020; Pegoraro et al., 2021), and linoleic acid promotes cardiovascular protection (Marangoni et al., 2020) and antidiabetic effects (Yoon et al., 2021). Moreover, the Atherogenic Index of the raw (0.09 ± 0.09) and roasted almond (0.08 ± 0.34) samples were very low. Although no parameter has been established for Atherogenic Index, the smaller the result is, the greater the chances that food will promote cardiovascular protection (Campidelli et al., 2020a).

3.8. Anti-nutrients

Baru pulp has low amounts of antinutrients such as tannins (472 mg quercitannic acid, 100 g pulp^{-1} and 440 to 609 mg catechin, 100 g pulp^{-1}) (Marin et al., 2009; Silva et al., 2021a) and phytic acid (0.43% to 1%) (Marin et al., 2009; Gonçalves et al., and Filbido, 2020). For baru almond, trypsin inhibitors were used for sequencing (Kalume et al., 1995). It is known that the interaction of tannins with carbohydrates, proteins, and microelements may reduce the bioavailability of these nutrients (Das et al., 2022). Phytic acid may reduce the bioavailability of copper, iron, and manganese (Gonçalves et al., and Filbido, 2020), and the presence of trypsin inhibitors can reduce the digestive activity of this enzyme (Nath et al., 2022). Unbalanced concentrations cause adverse effects, such as reduced bioavailability of minerals and digestibility of protein, and may also lead to toxicity (Nath et al., 2022). Most secondary metabolites, which act as antinutrients, elicit very harmful biological responses, while some of them are widely applied in nutrition and as pharmacologically active agents; for example, tannins have been reported to have strong antioxidant and bactericidal effects (Pizzi, 2021).

In an attempt to minimize the concentration of tannins or be used as a pretreatment to remove part of the tannins (Silva et al., 2021a) and improve the acceptability of the pulp flour and products developed, researchers have reported the combination of methodologies (Ferreira et al., 2020b). Phytic acid can be inactivated by heat treatment (3 h at 100 °C or 1.5 h at 121 °C) (Feizollahi et al., 2021). Therefore, partial, or total elimination depends on the purpose of the application of the food.

3.9. Applications in human food and ethnopharmacological uses

Whether for health reasons or because of concerns about the environment, eating less or no meat is becoming more popular around the globe (WHO, 2021a). Thus, new sources of protein need to be explored. In this sense, baru almonds are rich in protein and amino acids (Siqueira et al., 2015; Sousa et al., 2011; Czeder et al., 2012). This vantage has been explored in the elaboration of functional foods. Flour and defatted flour (Siqueira et al., 2015; Reis et al., 2018a; Alves et al., 2021a; Arruda-Silva et al., 2022; Aracava et al., 2022), concentrates, and protein isolates constitute potential sources of proteins (Guimarães et al., 2012a; Nunes et al., 2017).

The process of producing autoclaved partially defatted baru almond flour (autoclaved BAF), which involves removing a portion of the lipids, results in a protein content greater than 50%, a dietary fiber content of 40%, and a phenolic compound content of 70% compared to that of whole almond flour. The autoclaved partially defatted baru almond flour (autoclaved-BAF) results in a protein content greater than 50%, 40% greater dietary fiber, and 70% greater phenolic compound content than whole almond, which in part involves removing a portion of the lipids. In addition, autoclaved BAF is 30% less caloric and has a lower phytate content (Siqueira et al., 2015). BAF has been used in the preparation of various nutritious and functional foods, such as cookies (Freitas et al., 2014; Pineli et al., 2015a; Caetano et al., 2017) and cakes (Pineli et al., 2015b; Paglarini et al., 2018). Moreover, when used as a substitute for wheat flour, baru flour can benefit individuals with gluten intolerance (Freitas et al., 2014; Silva et al., 2015; Pineli et al., 2015b).

Protein isolates from BAF presented higher protein content than soybean, casein, and albumin commercial protein isolates and showed high *in vitro* digestibility. The technological properties, which include water absorption capacity, oil absorption capacity, emulsifying properties, and foamability, indicate the possibility of their use for the development of functional foods (Guimarães et al., 2012b; Nunes et al., 2017). The BAF was also used to develop a fermented flavoured drink with probiotics that presented nutritional characteristics and good acceptability in sensory tests (Fioravante et al., 2017; Coutinho et al., 2021; Fernandes et al., 2021).

Another common approach is the addition of crushed almond to improve the nutritional and functional quality of preparations such as cereal bars (Lima et al., 2010; Mendes et al., 2013; Campidelli et al., 2020a; Lima et al., 2021a), granola (Souza and Silva, 2015), sweets (Santos et al., 2012; Pinho et al., 2015; Silva et al., 2018; Cruz et al., 2019; Jesus et al., 2023), and frozen yogurt (Arelhano et al., 2019). The addition of almond to a dairy dessert preserved the antioxidant capacity of the product (Cruz et al., 2019).

Considering the high content of unsaturated fatty acids in almonds, baru oil has been extracted by different methods, most of which employ organic solvents (Martins et al., 2013; Fetzer et al., 2018), authorized as adjuvant technologies (Brasil, 2021b). Several studies have shown the advantages of the supercritical extraction process (SFE), which is a highly selective method using pressurized fluids as solvents (Santos et al., 2016; Fetzer et al., 2018; Chañi-Paucar et al., 2021; Peixoto et al., 2022). In SFE, temperature, pressure, type of solvent, and flow, among other factors, can be controlled to maximize the total yield of the oil or a specific compound. In addition, the SFE can be combined with other techniques (Santos et al., 2016; Chañi-Paucar et al., 2022). In this sense, ultrasound assisted SFE increased the initial extraction rate for all groups of fatty acids without modifying the fatty acid composition (Santos et al., 2016). Compared with the normal SFE, SFE assisted by cold pressing results in a baru oil rich in unsaturated fatty acids and bioactive compounds with a higher yield and lower manufacturing cost (Chañi-Paucar et al., 2021). Subsequently, SFE-integrated mechanical cold pressing was as efficient as the Soxhlet method for oil extraction but had the advantage of significantly reducing the extraction pressure used (Chañi-Paucar et al., 2022).

With increasing market interest in new sources of vegetable oils, ensuring oil quality is essential. In this sense, analysis by ^{1}H and ^{13}C NMR (Nascimento et al., 2021; Prestes et al., 2007) and ATR-FTIR (Nascimento et al., 2021) spectroscopy can provide information about the chemical composition and adulteration. Considering the feasibility and cost of this methodology, it is interesting that new techniques have been explored to ensure a quality product at an affordable cost for the final consumer.

Fernandes et al. (2020) reported that roasted baru almonds maintain the composition of unsaturated fatty acids when packaged in different packages and stored for up to 150 days. Futhermore, after 180 days of storage, the sensory characteristics and chemical composition of baru oil were preserved, and it presented acceptable peroxide and acidity values (Pineli et al., 2015c). For flour, storage at a temperature between 25 and 35 °C is recommended, according to water and lipid content (Alves et al., 2021b), making it an excellent alternative for the development of foods rich in polyunsaturated fatty acids. Mayonnaise formulated with microencapsulated oil showed good protection against oxidative degradation and high added nutritional value (Rojas et al., 2019).

In addition to functional foods, research has tested the technological potential of almonds and oil for other products, such as lamellar gel phase emulsions for cutaneous application (Moraes et al., 2018), in the production of bio-oil, biochar (Rambo et al., 2020), or epoxidized oil that can be used as a lubricant (Alarcon et al., 2020). Recently, Prando et al. (2023) developed a nanoemulsified system from baru oil, enhancing the antioxidant activity of the plant extract of *Oenocarpus bacaba* Mart.

Baru pulp is consumed less than the whole almonds (Silva et al., 2021c). Normally, the peel and pulp are considered byproducts and are discarded during almond extraction (Alves-Santos et al., 2023). The pulp can be consumed in natura. It presents a variation in texture, from farinaceous to pasty, and the taste can be sweet to bitter (Sano et al., 2006). A high content of tannins can give it an astringent and bitter taste and thus reduce the palatability and acceptability of the pulp for consumption (Ferreira et al., 2020b).

With the increased interest in foods that are beneficial to human health, the use of baru pulp for the production of flour (Resende and Franca, 2019; Oliveira et al., 2018) and the development of functional foods such as cookies (Viana et al., 2023; Ferreira et al., 2020b), bread (Rocha and Cardoso Santiago, 2009), bars (Lima et al., 2010), cupcakes (Ortolan et al., 2016), and fermented beverages (Silva et al., 2021b) has increased. When used for the production of cake, it becomes dark, resembling chocolate (Sano et al., 2016).

Studies have sought to establish the thermodynamic properties of pulp. Araujo et al. (2013) observed that sugar extraction was optimized at 35 °C for 90 minutes; Resende et al. (2017, 2018) established the best drying conditions (266.3 hours for a temperature of 40 °C and 22.8 hours for a temperature of 100 °C); and Ferreira et al. (2020a) revealed that drying extends the storage time (80 days without microorganism growth) of products developed from it, increases their technological application, and reduces waste.

Furthermore, different parts of baru are used as medicine by Brazilian communities (Ribeiro et al., 2017; Paim et al., 2023). Ethnopharmacological studies have reported the use of different baru parts, such as almond, pulp, leaves, and bark, to treat several illnesses. However, we observed that some ethnopharmacological studies do not specify the part of the plant used and/or the preparation method for that specific disease. Table 5 shows the medicinal uses of this species in Brazil.

3.10. Secondary metabolites of almond, pulp, and bark

Phytochemical screenings of the almond and pulp revealed the presence of total phenolic compounds (TPC) (Lemos et al., 2012; Siqueira et al., 2012, 2013; Santos et al., 2016; Santiago et al., 2018; Almeida et al., 2019; Silva et al., 2019; Oliveira-Alves et al., 2020; Campidelli et al., 2020a; Leite et al., 2020; Barizão et al., 2021; Barros et al., 2021; Silva et al., 2021a; Alves-Santos et al., 2023; Bidô et al., 2023) and carotenoids (Fiorini et al., 2017; Almeida et al., 2019; Silva et al., 2019; Gonçalves et al., and Filbido, 2020).

The reported TPC values range from 3.1 to 1,306.34 mg GAE g^{-1} for almond (Siqueira et al., 2012; Campidelli et al., 2020a) and from 186 to 477 mg GAE g^{-1} for pulp (Santiago et al., 2018; Silva et al., 2019). Factors such as the solvent used and heat treatment can influence the TPC of almond and pulp. Silva et al. (2021a) reported the effect of different solvents on the extraction of phenolic compounds from baru pulp flour (BFF), with acetone being the least efficient (6.60 ± 0.15 mg GAE g^{-1}) and sodium hydroxide 3%/sodium sulfite 3% being the most efficient (360.50 ± 0.69 mg GAE g^{-1}).

Heat treatment at 105 °C for 30 min did not seem to affect the TPC (Campidelli et al., 2020a), but heat treatment at 140 °C for 30 min reduced the TPC by 34% compared to that of raw almond (Santiago et al., 2018). On the other hand, BFF had a 2.3 times greater TPC when heated to 100 °C (Silva et al., 2019). In this sense, the baru almond and the pulp are a great source of phenolic compounds, and knowing the influencing factors, their extraction can be optimized according to the application of interest.

High-performance liquid chromatography (HPLC) revealed more than thirty phenolic compounds, especially phenolic acids, and flavonoids in extracts from almond (Lemos et al., 2012; Oliveira-Alves et al., 2020), pulp or pulp+peel (Leite et al., 2020; Barizão et al., 2021), and bark (Ferraz et al., 2014; Nazato, et al., 2010; Puebla et al., 2010). The compounds identified from the different parts of the baru are described in Table 6 and Figures 4 to 9.

Table 5. Ethnopharmacological uses of baru.

Medicinal use	Part plant used	Form of preparation	Brazilian state/ population	Reference
Back, muscle and body pains, diuretic, kidney pains, kidneys, infections, intestine infection, vaginal discharge, uterus and ovary infection, vaginal infection, uterine inflammation, prolonged menstruation, menstrual regulation, prostate, sexual impotence, depurative, hemorrhage, thrombosis, gallstones, sinusitis, gastritis, ulcer, high cholesterol, diabetes, osteoporosis, rheumatism, wound healing, bone healing, snake bites, and memory.	Bark, stem, leaves, fruits, seed	Decoction, infusion, maceration, fresh, cataplasm	Mato Grosso/ riverine	Ribeiro et al. (2017)
Back pain. Food and treatment of intoxication for cattle	Wood chip	ND	Goias /residents and livestock farmers	Paim et al. (2023)
Kidney stones and kidney problems	Bast fruit, seeds	Infusion	Goias/rural	Guimarães et al. (2022)
Uric acid, gout, and rheumatism	ND	ND	Mato Grosso/ healers	Bueno et al. (2020)
Column	Stem	Decoction	Goias/healers	Souza et al. (2016)
Cardiac problems	ND	ND	Tocantins/rural	Bessa et al. (2013)
Bronchitis, healing, diarrhea, dysentery, pain, throat, flu, snakebite, and cough	ND	Infusion	Mato Grosso/ urban	Bieski et al. (2012)
High fevers and snakebite	Almond	Oil	Tocantins/urban	Puebla et al. (2010)
Anti-rheumatic, tonic, regulator menstrual	ND	ND	Goias/urban	Souza and Felfili (2006)

ND, Not determined.

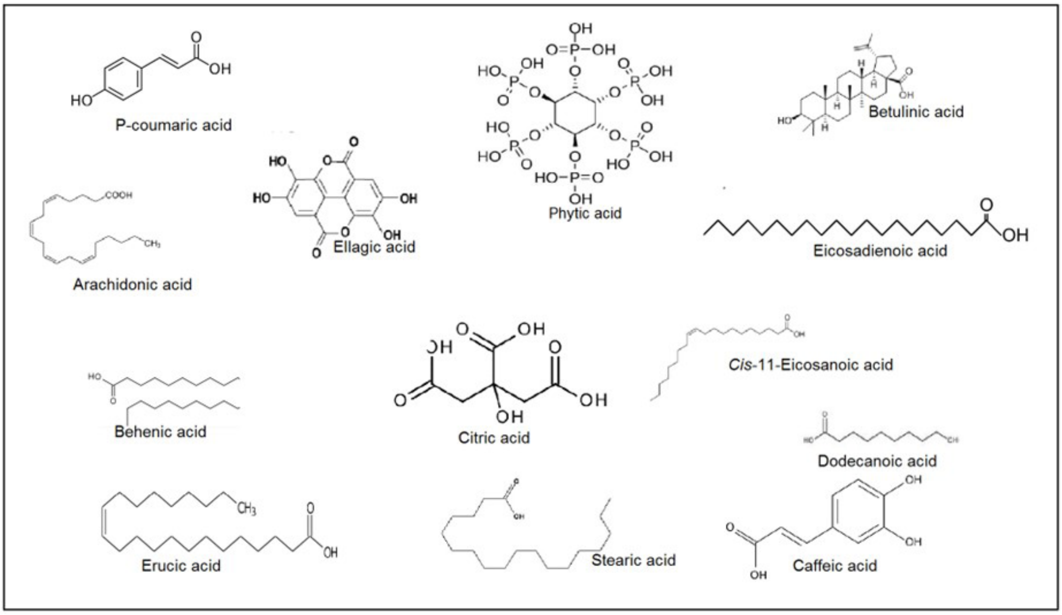


Figure 4. Chemical structures of compounds found in different parts of the baru - part 1.

Phenolic compounds have the ability to eliminate and stabilize reactive species, chelate, or complex with metals (El-Megharbel and Hamza, 2022; Boudou et al., 2019) and inhibit peroxidation reactions (Shokry et al., 2022). Furthermore, some phenolics have been described in the literature for their antioxidant (El-Megharbel and

Table 6. Phytochemical composition of baru.

Part	Extract type	Compounds	Reference
Almond	No determined	gallic acid, catechin, chlorogenic acid, caffeic acid, vanillin, p-coumaric acid, ferulic acid, m-coumaric acid, o-coumaric acid, trans-cinnamic acid, quercetin and rutin	Campidelli et al. (2020b)
	Methanolic	gallic acid, ferrulic acid, ellagic acid, hydroxybenzoic acid, caffeic acid, epicatechin, quercetin, myricetin, coumarin, kaempferol	Lemos et al. (2012)
	Oil	caryophyllene, elemene, caryophyllene, and limonene, sitosterol, stigmasterol, campesterol, and cycloartenol	Marques et al. (2015)
	Hydromethanolic;Hydrolyzed extract	quinic acid derivative, galloylglucose, gallic acid, mono- to pentagalloylglucose, methyl gallate-glucoside, gallic acid–galloylglucose, p-coumaric acid, isoferulic acid, digallic acid, methyl gallate, methylgalloyl–galloylglucose, ethyl gallate, ellagic acid, gallic acid–methyl gallate, gallic acid–ethyl gallate, 3-methyl-1-butanol, hexanal, methyl-pyrazine, 2-furanmethanol, 1-hexanol, 2-heptanone, heptanal, 2,5-dimethyl pyrazine, 2-heptenal, 1-heptanol, 1-octen-3-ol, 2-pentyl-furan, 2-ethyl-5-methylpyrazine, trimethyl-pyrazine, octanal, methyl hexanoate, d-limonene, 2-acetylpyridine, pantolactone, 4-hydroxy-2,5-dimethyl-3-(2h)-furanone, 2-octenal, benzeneaceltaldehyde, 1-octanol, 3-ethyl-2,5-dimethylpyrazine, 2-ethyl-3,5-dimethyl-pyrazine, tetramethyl-pyrazine, 2,5-diethyl-pyrazine, nonanal, 2,3-diethyl-5-methylpyrazine, 3,5-diethyl-2-methylpyrazine, 1-nonanol, decanal	Oliveira-Alves et al. (2020)
pulp	Lyophilized pulp	di-O-hexoside acid, O-hexosyl, protocatechuic acid, vicenin 2, coumaric acid, luteolin, di-O-methoxydihydroxiisoflavone, hexadecanoic acid, octadecenoic acid, diterpene	Leite et al. (2020)
	Freeze-dried pulp	caffeic acid, chlorogenic acid, *p*-coumaric acid, syringic acid, catechin, epicatechin gallate, epigallocatechin gallate, procyanidin B1, procyanidin B2, hesperidin, myricetin, quercetin-3-glucoside, rutin, *cis*-resveratrol	Alves-Santos et al. (2023)
pulp and peel	Aqueous; methanol; ethanol; hydromethanolic; hydroethanolic	gallic acid, protocatechuic acid, hydroxybenzoic acid, chlorogenic acid, vanillic acid, (−)-epicatechin, caffeic acid, syringic acid, (−)-epicatechin gallate, *p*-coumaric acid, sinapic acid, ferulic acid, rutin, *trans*-resveratrol, ellagic acid, myricetin, quercetin, luteolin, naringenin, *trans*-cinnamic acid, apigenin	Barizão et al. (2021)
Bark	Hydroethanolic extract hexane fraction; CH2Cl2 fraction. Hexane; dichloromethane; ethyl acetate; methanolic	lupane, betulin, lupeol, lupenone, 28-hydroxylup-20(29)-en-3-one, betulin, 8-O-methylretusin, 7-hydroxy-5,6,4’-trimethoxyisoflavone, afrormosin, 7-hydroxy-8,3’,4’-trimethoxyisoflavone, sulfuretin, caffeic acid, odorotin, 7,3’-dihydroxy-8,4’-dimethoxyisoflavone, vanillic acid, dipteryxin, 7,8,3’-trihydroxy-4’-methoxyisoflavone, vanillin, rutin, tannic acid, isoliquiritigenin, 7,8,3’-trihydroxy-6,4’-dimethoxyisoflavone, protocatechuic acid, apigenin, quercetin, chlorogenic acid	Puebla et al. (2010), Nazato et al. (2010)
Leaves		No determined	

Hamza, 2022), antimicrobial (Sorrentino et al., 2018), and anti-inflammatory effects (Lee et al., 2020) and for their ability to control body weight gain (Santamarina et al., 2019a). Terpenes are volatile compounds known for their antimicrobial (Li et al., 2021), anti-inflammatory (Yang and Liao, 2021), and antioxidant potential (Dzoyem et al., 2017). Phytosterols and their derivatives can reduce the concentration of low-density lipoprotein-cholesterol (LDL-C) in human plasma (Bai et al., 2021). In this sense, the compounds present in baru may be, at least in part, responsible for its biological properties.

3.11. Biological activities

It is common knowledge that plant products are used to maintain good health. Plants contain chemical compounds that possess medicinal and healing properties (Parveen et al., 2021). In this context, baru is used for the treatment and prevention of many diseases. Almond and stem bark are the most commonly evaluated parts, although leaves and fruits are also used in traditional medicine. Due to the widespread use of these terms, in this review, the biological effects were grouped into 12 categories (Figure 10) and subsequently described.

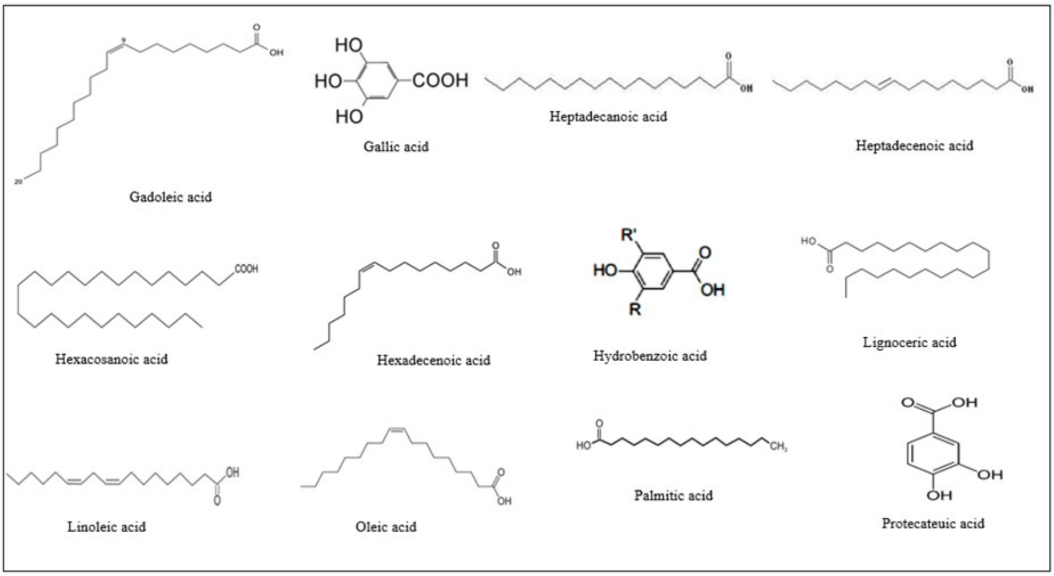


Figure 5. Chemical structures of compounds found in different parts of the baru - part 2.

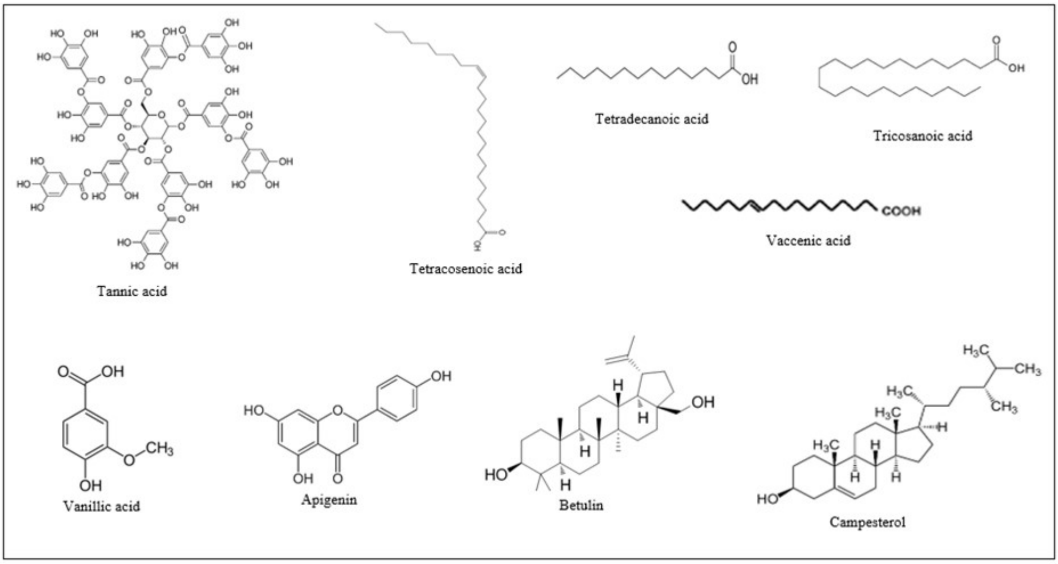


Figure 6. Chemical structures of compounds found in different parts of the baru - part 3.

3.11.1. Toxicological evidence (TXE) and antiproliferative activity (APA)

The hydroethanolic extract from the pulp + peel showed weak cytotoxicity against nontumor (HaCaT and L929) cell lines (0.7 mg.mL^{-1}) (Barizão et al., 2021). The lyophilized pulp was not toxic to the nematodes (Leite et al., 2020). The hexane and ethanol extracts from the leaves were not toxic to the macrophages (Ribeiro et al., 2014). The ethanolic extract of the bark had no toxic effect on the Chinese hamster ovary (CHO) cell Line K1131 and did not cause abnormalities in the offspring of pregnant rats (500 mg.mL^{-1}) (Esteves-Pedro et al., 2012). When exposed to the ethanolic extract of the bark, different strains of *Salmonella sp*. showed no mutagenicity (Esteves-Pedro et al., 2012). However, in the presence of the metabolic activation system and hydroalcoholic extract of bark (0.016 and 0.05 mg.mL^{-1}), CHO cells showed an increase in micronucleus frequency, which can indicate genotoxicity (Esteves-Pedro et al., 2011). However, a hyperlipidic diet supplemented with almond (30%) for 35 days did not show genotoxicity (Campidelli et al., 2022).

The antiproliferative potential of these compounds was also investigated. Extracts from almond and their phenolic compounds reduced the proliferation of monolayer and

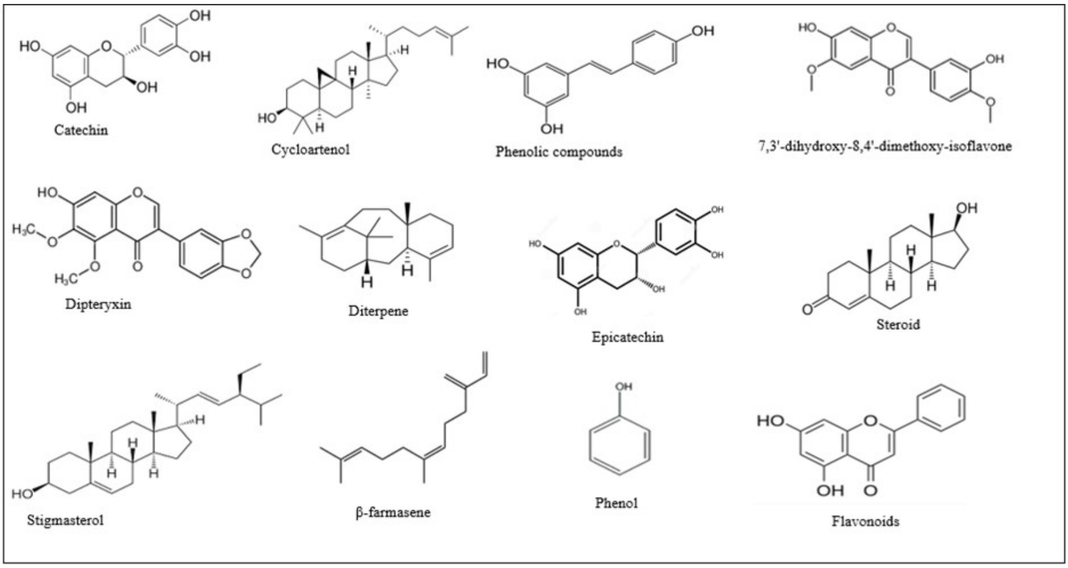


Figure 7. Chemical structures of compounds found in different parts of the baru - part 4.

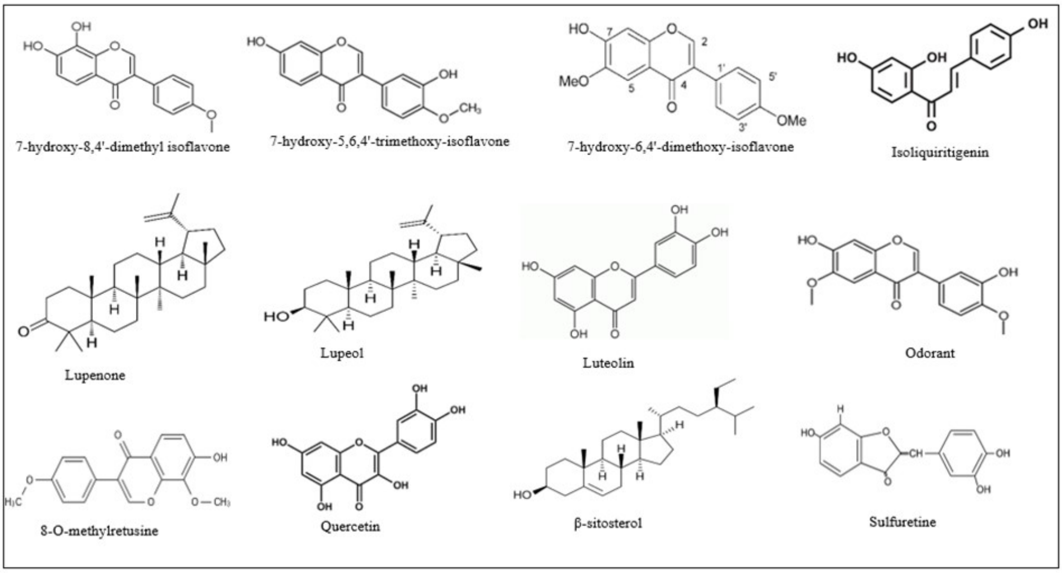


Figure 8. Chemical structures of compounds found in different parts of the baru - part 5.

spheroid human colorectal cancer cell lines (Oliveira-Alves et al., 2020), while the hydroethanolic extract from the pulp+peel inhibited the growth of cervical cancer cell lines (SiHa and C33A) (Campidelli et al., 2022).

Considering that several plants are used as medicines in traditional communities, evaluating the safety of medicinal plants is essential. Recently, a review revealed evidence that many species and compounds from Cerrado plants, despite having high cytotoxicity against tumour cells, showed low toxicity, genotoxicity, and mutagenicity against nontumor cells and no toxic effects on murine models of acute and chronic treatments (Rocha et al., 2022).

3.11.2. Antimicrobial and leishmanicidal activities (ALAs)

Hydroalcoholic extracts from baru exhibited moderate antimicrobial potential, showing minimum inhibitory concentrations (620 to > 1000 µg.mL^{-1}) and minimum microbicidal concentrations (620 to > 1000 µg.mL^{-1}) against *Staphylococcus aureus* and *Escherichia coli*. Interestingly, the peel (2.6 to 3.3) and pulp (4.0) extracts displayed greater inhibition zones for *S. aureus* than did the almond (Santos et al., 2017). However, the authors did not investigate the chemical composition of the extracts to clarify this difference.

Hexanic extracts of the leaves of baru were as effective as amphotericin B (IC_{50} = 0.08 µg.mL^{-1}) and were more

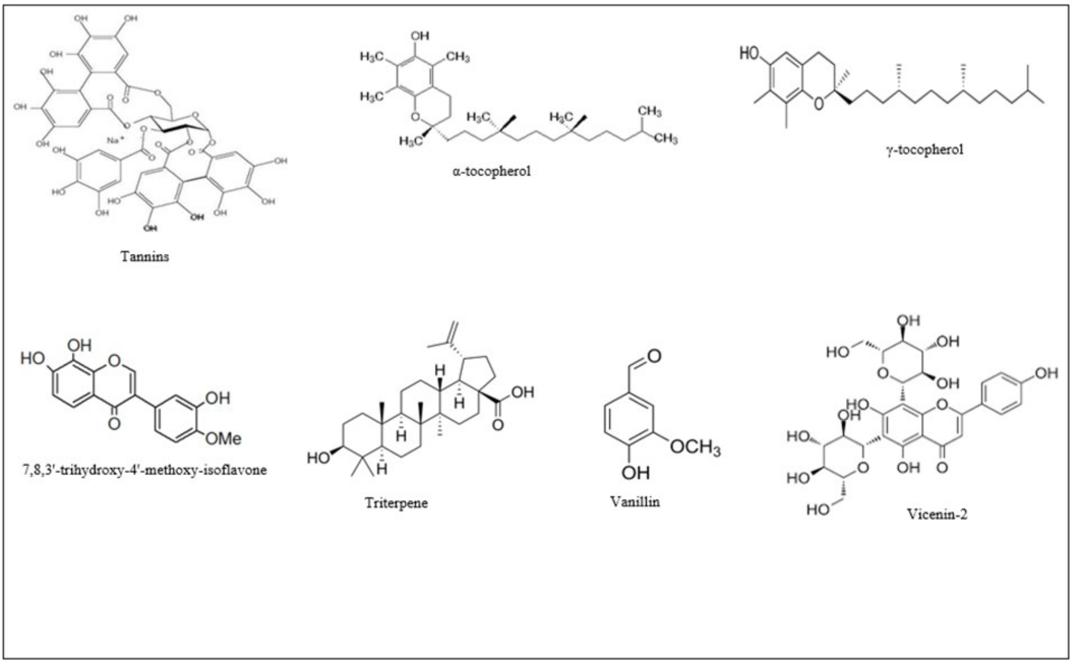


Figure 9. Chemical structures of compounds found in different parts of the baru - part 6.

effective than extracts from 15 other Brazilian plants of the genera *Campomanesia*, *Cecropia*, *Diospyros*, *Syzygium*, *Eugenia*, *Hymenaea*, *Jacaranda*, *Licania*, *Vernonia* and *Melancium* against leishmaniasis (IC_{50} = 4.69-199.4 µg.mL^{-1}) (Ribeiro et al., 2014). In addition, the inhibitory effect against *Leishmania amazonensis* promastigotes internalized by macrophages occurred in a dose-dependent manner (up to 95%) (Ribeiro et al., 2014). As suggested by researchers, the leishmanicidal potential may be related to the presence of phenolic and terpene compounds (Garcia et al., 2019; Shilling et al., 2020).

Microbial resistance is a global public health problem (WHO, 2021b), similar to leishmaniasis, which is a neglected tropical disease with more than one million new cases each year and up to 30,000 deaths (WHO, 2022). Both conditions motivate the search for treatments that can replace antibiotics (Santos et al., 2017) and are effective against parasites (Gervazoni et al., 2020). Several species from the Cerrado contain bioactive compounds with antimicrobial and leishmanicidal potential (Rocha et al., 2022). Studies suggest that baru extracts can be used to develop antimicrobial and antiparasitic products.

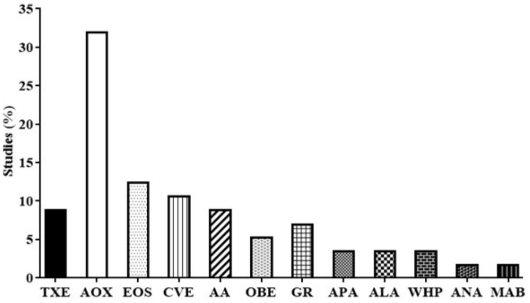


Figure 10. Biological effects category grouped of baru. (TXE) Toxicological evidence, (AOX) antioxidant activity, (EOS) effects on oxidative stress, (CVE) cardiovascular effects, (AA) Antiophidic activity, (OBE) overweight and obesity, (GR) gastrointestinal regulation, (APA) Antiproliferative activity, (ALA) Antimicrobial and leishmanicidal activities, (WHP) Wound Healing potential, (ANA) Anti-inflammatory activity, (MAB) Memory and anxiolytic-like behavior.

3.11.3. Wound Healing potential (WHP)

The ethanolic extract of baru almond improved wound healing in human pulmonary epithelial cell lines (NCI-H441 and A549) (Coco et al., 2021). However, the topical use of ointment with hydroethanolic extracts of almond or bark (10%) for 21 days did not affect the speed of wound closure, quality of reepithelialisation, neovascularization, or collagenization in mice and did not demonstrate its applicability for wound healing (Gouveia et al., 2021). Thus, future studies exploring other forms of administration and doses are needed to elucidate whether baru has wound healing potential, mainly because it is one of the most popular uses of this plant.

3.11.4. Antiophidic activity (AA)

Snakebite envenomation is a neglected tropical disease with a high economic cost, particularly in low- and middle-income countries (WHO, 2019). In Brazil, the limited supply of antivenom for public health (Schneider et al., 2021) has stimulated the discovery of new plants and molecules with antiophidic potential (Trento et al., 2021).

Extracts from the bark of baru were able to reduce the neuromuscular blockade caused by *Bothrops jararacussu* venom in the phrenic nerve-diaphragm. Methanolic extract from the bark had a greater protective effect on neuromuscular capacity (Puebla et al., 2010; Nazato et al., 2010). In addition, the bark reduced myonecrosis (Nazato et al., 2010).

To clarify the possible causes of these effects, some bioactive compounds isolated from the bark were also investigated for their effects on snake venom. 7,8,3'-Trihydroxy-4'-methoxyisoflavone and the triterpenoids betulin, lupeol, lupenone, and 28-OH-lupenone showed a high protective effect against the neuromuscular blockade, and myotoxicity caused by snake venom (Ferraz et al., 2012; Ferraz et al., 2014). In addition, betulin, and lupenone are protective against *Crotalus durissus terrificus* envenomation (Ferraz et al., 2012). Posteriorly, betulin was efficient in attenuating the neuromuscular effects of *B. jararacussu* venom *in vivo* (Ferraz et al., 2015). These studies indicate that the bark of baru has the potential to be applied as an antiophidic product.

3.11.5. Antioxidant activity (AOX)

Various methods of i) radical scavenging, such as 2,2-diphenyl-1-picrylhydrazyl (DPPH) and 2,2-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS+), ii) inhibition of peroxidation as a β-carotene/linoleate bleaching system, iii) ability to reduce an Fe(3) complex to an Fe(2) complex containing 2,4,6-tri(2-pyridyl)-1,3,5-triazine (TPTZ) ligand, as in the ferric reducing antioxidant power method (FRAP), and iv) the elimination of the peroxyl radical generated by the thermal reaction between 2,2'-azobis-(2-methylpropionamidine)-dihydrochloride (AAPH) and atmospheric oxygen (pH 7.4) at 37 °C (Marchi et al., 2022), have been used to evaluate the antioxidant potential and distinguish the mechanism of baru.

Table 7 shows the antioxidant potential of baru almond, pulp, and leaves against different oxidant agents. Was observed that raw almond showed greater antioxidant activity (81, 100, and 157 µMol.TE g^{-1}) than did roasted almond (76, 77, and 136.8 µMol. TE g^{-1}) in the DPPH, ABTS, and FRAP methods, respectively (Santiago et al., 2018). Studies have reported that heat treatment at 100 °C or more can reduce the antioxidant capacity by 36% to 56% and that heat treatment at 65 °C for 30 minutes did not affect the antioxidant capacity compared to that of raw almond (Campidelli et al., 2020a; Silva et al., 2022).

The antioxidant capacity of the raw almond (100 to 473 µM. Trolox g^{-1}) (Santiago et al., 2018; Lima et al., 2021a; Barros et al., 2021) was also greater than that of almond oil (Fetzer et al., 2018) in the ABTS assay. Antioxidant activity can be influenced by the chosen method for the extraction of the sample evaluated. Therefore, Fetzer et al. (2018) evaluated the antioxidant capacity of baru almond oil extracted by different methods. The oil obtained by the supercritical CO_2 method using propane as the solvent showed greater antioxidant activity (96.57 µM. Trolox g^{-1}) than the oil extracted by Soxhlet using hexane (9.98 µM. Trolox g^{-1}). Posteriorly, Peixoto et al. (2022) proposed the extraction of almond oil using the supercritical CO_2 method with water as a cosolvent and showed greater extraction of antioxidant compounds.

The baru pulp flour exhibited weak DPPH free radical scavenging potential (9 to 12 µMol. Trolox g^{-1}) and ABTS (13 to 34 µMol. Trolox g^{-1}) (Silva et al., 2019), while the IC_{50} values for lyophilized pulp were 416.0 ± 28.00 and 2306.33 ± 101.83 µg.mL^{-1} for the ABTS and DPPH methods, respectively (Leite et al., 2020). The hydroethanolic extract also had a low antioxidant effect on the pulp (21.2 to 49 µMol. TE g^{-1}) and to the peel of fruit (45 to 60 µMol. TE g^{-1}) in different methods (Santiago et al., 2018). These findings corroborate the results obtained with different peel+pulp extracts (2 to 29 µMol. TE g^{-1}) evaluated by the DPPH and ORAC methods (Barizão et al., 2021) (Table 7).

The ethanolic and hexanic extracts of the baru leaves demonstrated antioxidant potential (52 to 169 ppm) and effective tyrosinase inhibition (Silvério et al., 2013) (Table 7). Tyrosinase is a key enzyme in skin hyperpigmentation and food browning. Thus, the discovery of natural inhibitors has been of interest to the pharmaceutical, cosmetic, and food industries (Zolghadri et al., 2019). Previous studies have demonstrated that phenolic compounds are effective tyrosinase inhibitors (Nguyen et al., 2012; Sasaki et al., 2018). Thus, at least partially, this inhibitory effect on baru leaves may be associated with the presence of phenolic compounds. However, as the leaves did not show a copper chelating capacity, it is suggested that there are other mechanisms involved (Silvério et al., 2013). In addition, the antioxidant activity of bark has not yet been reported. Some bioactive compounds present in plant species are natural antioxidants capable of maintaining the redox balance in the organism (Carvalho and Conte-Júnior, 2021). Thus, the presence of phenolic compounds and terpenes supports the antioxidant potential showed in baru almond, pulp, and leaves.

3.11.6. Effects on oxidative stress (EOS), overweight/obesity (OBE), and the cardiovascular system (CVE)

Oxidative stress is a biological condition of disbalance between the production of reactive species and antioxidant defense (Maurya et al., 2016). This condition can be responsible for protein damage (Siqueira et al., 2012), lipid peroxidation, and a reduction in endogenous antioxidant defences, such as glutathione peroxidase (GPx) levels and superoxide dismutase (SOD) and catalase (CAT) activities. Consequently, oxidative stress is associated with the development of chronic diseases, such as diabetes, dyslipidaemia (Erukainure et al., 2020), obesity, and metabolic syndrome (Ruiz-Ojeda et al., 2018).

Baru almond and almond oils have been suggested to reduce oxidative stress (Siqueira et al., 2012; Fernandes et al., 2015; Reis et al., 2018b; Souza et al., 2018, 2019). Supplementation of almond in iron-induced oxidative stress in rats was effective in preventing lipid oxidation in the liver and spleen and reducing carbonyl levels in the liver, spleen, and heart (Siqueira et al., 2012). Roasted almond decreased lipid oxidation and increased vitamin E in the liver of hyperlipidaemic rats (Fernandes et al., 2015). Its oil promoted hepatoprotective effects and decreased peroxidation in the aorta of rats (Reis et al., 2018b).

Dietary supplementation with baru almond (30%) improved the antioxidant capacity (FRAP), increased the glutathione reductase content, and reduced the malondialdehyde

Table 7. Antioxidant activity of baru.

Part	Assay	Antioxidant activity	Reference
Raw almond	ABTS	186.64 ± 3.37 μMol Trolox g^{-1}	Lima et al. (2021a)
		473 ± 20 μMol Trolox g^{-1}	Barros et al. (2021)
		100 ± 4 μMol.TE g^{-1}	Santiago et al. (2018)
	β-Carotene/linoleate	91.72 ± 3.35% protection	Campidelli et al. (2020a)
		66.5 ± 1.9% protection	Barros et al. (2021)
	DPPH	81 ± 0.8 μMol.TE g^{-1}	Santiago et al. (2018)
		100.08 ± 1.44 μMol Trolox g^{-1}	Lima et al. (2021a)
		69.02 ± 2.86%SRL	Campidelli et al. (2020a)
	FRAP	157 ± 3 μMol.TE g^{-1}	Santiago et al. (2018)
		357 ± 21.5 FeSO4 μMol.g^{-1}	Barros et al. (2021)
	ORAC	4.06 ± 0.76 μM g^{-1}	Campidelli et al. (2020a)
Roasted almond	ABTS	77 ± 0.6 μMol.TE g^{-1}	Santiago et al. (2018)
		1,179 ± mg.GAE Kg^{-1}	Cruz et al. (2019)
		170.72 μMol.TE g^{-1}	Silva et al. (2020)
	β-Carotene/linoleate	0.6 and 6.0% g^{-1}	Siqueira et al. (2012)
		86.10 to 89.94% protection	Campidelli et al. (2020a)
	DPPH	67.00 ± 6.31 μMol.TE g^{-1}	Siqueira et al. (2015)
		76 ± 1 μMol.TE g^{-1}	Santiago et al. (2018)
		8,342 ± 11.0 mg.GAE kg^{-1}	Cruz et al. (2019)
		0.6 and 0.8 μMol.TE g^{-1}	Siqueira et al. (2012)
		79.68 to 84.38%SRL	Campidelli et al. (2020a)
		0.18 to 0.42 mg.mL^{-1} (EC50)	Borges et al. (2014)
		259.10 μMol.TE g^{-1}	Silva et al. (2020)
	FRAP	1.2 and 8.3 FeSO4 μMol.g^{-1}	Siqueira et al. (2012)
		126.8 ± 0.6 μMol.TE g^{-1}	Santiago et al. (2018)
		144.49 μMol.TE g^{-1}	Silva et al. (2020)
	ORAC	2.96 to 3.43 μM.g^{-1}	Campidelli et al. (2020a)
		88.71 ± 0.51 μMol.TEAC g^{-1}	Oliveira-Alves et al. (2020)
Oil from almond	ABTS	9.98 to 96.57 μM.Trolox g^{-1}	Fetzer et al. (2018)
pulp	ABTS	13 to 34 μMol Trolox g^{-1}	Silva et al. (2019)
		49 ± 2.0 μMol.TE g^{-1}	Santiago et al. (2018)
		416.0 ± 28.00 μg.mL^{-1}	Leite et al. (2020)
		4.1 ± 0.2 μM.g^{-1}	Almeida et al. (2019)
	DPPH	9 to 12 μMol.Trolox g^{-1}	Silva et al. (2019)
		21.2 ± 0.1 μMol.TE g^{-1}	Santiago et al. (2018)
		23.91 ± 0.82 μMol.TE g^{-1}	Alves-Santos et al. (2023)
		2,306.33 ± 101.83 μg.mL^{-1}	Leite et al. (2020)
		68.6 ± 4.1% of discoloration	Almeida et al. (2019)
		1,021 ± 86.8 g.Kg^{-1} (EC50)	Siqueira et al. (2013)
		31.60 ± 1.85 μMol.TE g^{-1}	Araujo et al. (2013)
	FRAP	24.2 ± 0.2 μMol.TE g^{-1}	Santiago et al. (2018)
Peel	ABTS	60 ± 2 μMol.TE g^{-1}	Santiago et al. (2018)
	DPPH	45 ± 2 μMol.TE g^{-1}	
	FRAP	50 ± 0.2 μMol.TE g^{-1}	
pulp with peel	DPPH	6.70 ± 0.23 μMol.TE g^{-1}	Barizão et al. (2021)
	ORAC	28.7 ± 4.5 μMol.TE g^{-1}	
Leaves	DPPH	52.9 to 169.1 ppm	Silverio et al. (2013)
Bark	ND	ND	ND

EC50, Effective concentration forinhibit 50%; GAE, Gallic acid equivalents; ND, not determined; %SRL, percentage of free radical sequestration; ppm, Parts per million; TEAC, trolox equivalents antioxidant capacity; TE, Trolox equivalent.

(MDA) content in the rat liver (Campidelli et al., 2022). Daily consumption of 20 g of almond increased GPx activity and serum copper levels but did not improve MDA or cytokine levels in overweight or obese women (Souza et al., 2019). The intake of the same serving of almond by mildly hypercholesterolaemic individuals also did not promote changes in SOD activity, thiobarbituric acid reactive substance concentration, or serum antioxidant status (Bento et al., 2014).

Baru pulp promoted the control of oxidative stress and increased the expression of SOD and the nuclear translocation of DAF-16, resulting in an increase in life expectancy in the nematode *Caenorhabditis elegans* (Leite et al., 2020).

Bioactive compounds that are present in almond and pulp can be responsible for their antioxidant potential. Phenols are known for their ability to scavenge reactive species (Yu et al., 2021). Phytic acid can prevent tissue protein damage (Siqueira et al., 2012). Ascorbic acid reduces lipid peroxidation and restores the levels of liver enzymes, kidney function, and glutathione (Shotop and Al-Suwiti, 2021). Tocopheryl acetate (a-tocopherol) and PUFA (n-3) reduce lipid peroxidation in different tissues, and PUFA (n-3) increases GPx activity (Mattioli et al., 2021).

The use of native Brazilian foods and plants with antioxidant and protective effects against oxidative stress can improve human health in the face of various metabolic diseases (Carvalho and Conte-Junior, 2021). Considering the ethnopharmacological applications of this species, several studies have investigated the effects of the consumption of baru almond and almond oils on metabolic diseases.

The consumption of a dessert made with the almond (14%) for two weeks reduced triglyceride (TG) and very low-density lipoprotein (VLDL-c) levels and increased high-density lipoprotein-cholesterol (HDL-c) levels in rats (Cruz et al., 2019). The intake of a hyperlipidic diet supplemented with almond (30%) for 35 days prevented the increase in total cholesterol (TC) and low-density lipoprotein cholesterol. In addition, HDL-c levels were similar to those in the control group (Campidelli et al., 2022). Almond diet supplementation (35%) for 63 days reduced the serum TC and TG levels in rats fed a high-fat diet (Fernandes et al., 2015). A similar intake (20 to 40%) of baru almond for 40 days reduced the serum TG, LDL-c, VLDL-c, and alanine aminotransferase levels and increased the HDL-c level in rats (Fiorini et al., 2017). However, almond oil did not alter the lipid profile in hypercholesterolaemic rats (Reis et al., 2018b).

Supplementation with 20 g of baru almond for six weeks reduced TC and LDL-c in mildly hypercholesterolaemic individuals (Bento et al., 2014). The same serving of almond for eight weeks reduced the serum TC, TG, LDL-c, and non-HDL-c levels and increased the HDL-c level in overweight or obese women (Souza et al., 2018). The intake of baru oil (7.2 $mL.kg^{-1}$) for ten days exerted an antithrombotic effect, reduced platelet aggregation, decreased reactive oxygen species production, and improved vascular function in rats, suggesting its use in the prevention and treatment of cardiovascular conditions (Silva-Luis et al., 2022).

The effects of baru almond on the lipid profile may be related to its chemical and nutritional composition. The intake of soluble and insoluble dietary fiber (Wu et al., 2020; Liu et al., 2021) and phytosterols (Salehi et al., 2021) promotes cholesterol adsorption and decreases TC levels. Moreover, unsaturated fatty acids, such as oleic (Piccinin et al., 2019) and linoleic acids (Maki et al., 2018), are already well described in the literature as bioactive compounds that contribute to improving lipid profiles and preventing cardiovascular diseases.

Preclinical and clinical studies have reported normal body weight gain or a reduction in adiposity after the consumption of baru almond. After nine weeks, the consumption of almond (15% lipids) promoted less body weight gain and TC and TG levels than did the consumption of Brazil nut (15% lipids) in rats (Fernandes et al., 2015). Araújo et al. (2017) reported a reduction in body weight and glycaemic levels in obese mice fed 8% almond in food for eight weeks. These effects may be related to the presence of alpha-amylase inhibitors in baru almond (Bonavides et al., 2007). Consistent with these findings, the consumption of 20 g of almond per day for eight weeks increased HDL-c and reduced abdominal adiposity in obese women (Souza et al., 2018).

Obesity is a chronic disease that can be the cause and/or consequence of other metabolic disorders, such as dyslipidaemia and glycaemic dysregulation (Safaei et al., 2021). Different nutritional and functional interventions can mitigate obesity and associated metabolic disorders. Several bioactive compounds have been isolated from the baru almond and pulp, and their synergistic effects can explain the nutritional and functional benefits already observed for this species.

Soluble fiber can absorb water and form a mucilage that promotes satiety, regulates gut microbiota function (Soukoulis et al., 2018), and reduces the bioaccessibility of total lipids, cholesterol, and bile salts simultaneously (Tamargo et al., 2020). Furthermore, it inhibits β-amylase and reduces blood glucose (Liu et al., 2021). Insoluble fiber promotes less body weight gain, decreases serum TC and LDL-c concentrations, improves glucose homeostasis, and is able to modulate the gut microbiota, preventing high-fat diet-induced obesity in rats (Chang et al., 2017).

The fats in the diet can influence adipokine levels (Nasir et al., 2021). Leptin, an adipokine produced by adipose tissue, regulates energy intake and metabolism. In individuals with obesity, excess circulating leptin leads to resistance (Mishra et al., 2017). In this case, leptin plays a role as a proinflammatory adipokine (Pérez-Pérez et al., 2017). The intake of PUFAs, eicosapentaenoic acid, and docosahexaenoic acid (DHA) reduces circulating leptin levels (Paz et al., 2021). Moreover, increased DHA intake by obese women was associated with low levels of retinol-binding protein 4 (Nasir et al., 2021), an adipokine related to the development of inflammation and insulin resistance (Majerczyk et al., 2016).

Supplementation with polyphenol-rich pulp prevented inflammatory pathway activation, body weight gain, and liver damage in rats (Santamarina et al., 2019a). These anti-inflammatory effects were subsequently confirmed in a placebo-controlled, randomized, double-blind trial with obese adults (Santamarina et al., 2019b).

Thus, we believe that the antioxidant and dyslipidaemic properties mediated by the nutritional and phytochemical composition of baru, especially almond, seem to favour obesity and glycaemic control by reducing the activation of inflammatory pathways.

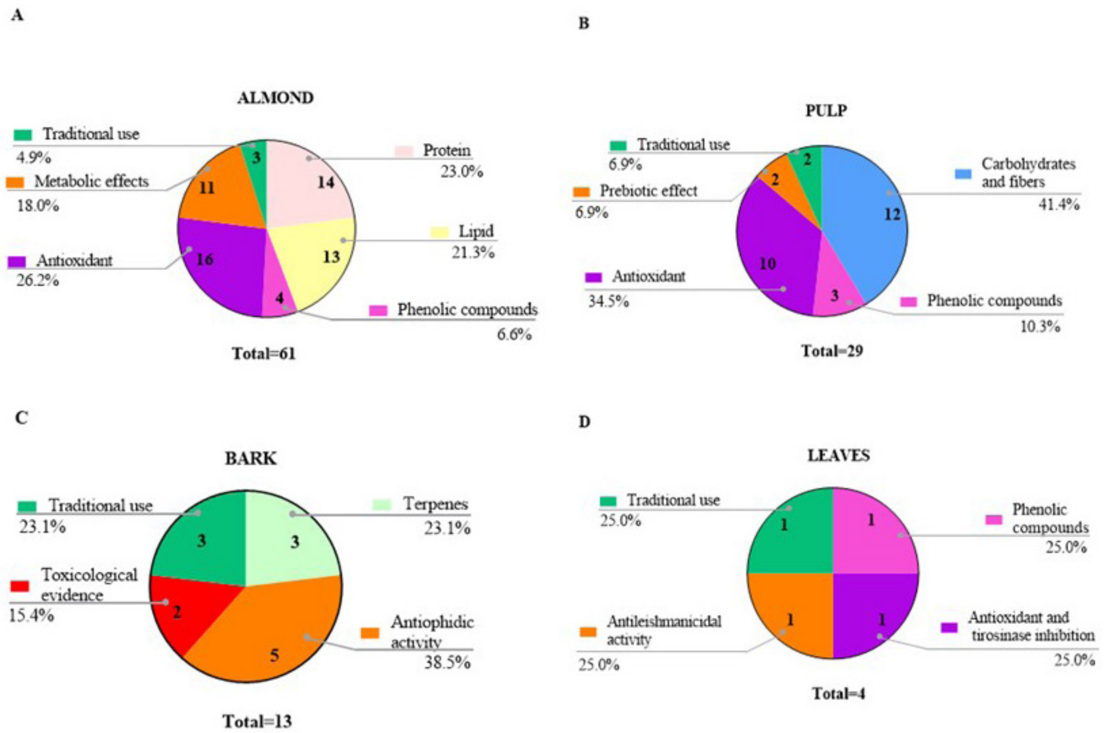


Figure 11. Frequency of indication in popular use and main nutrients, chemical class, and biological activity reported for each part of the plant (number of articles). (A) almond; (B) pulp; (C) bark; (D) leaves.

3.11.7. Gastrointestinal regulation (GR)

The consumption of a dessert made with almond (14%) for two weeks reversed gastrointestinal effects caused by high milk consumption (>40% in the diet), promoting slowed gastric emptying and preventing the delay of intestinal transit time in healthy rats (Cruz et al., 2019). Bidô et al. (2023) demonstrated beneficial modulation of the faecal microbiota with a reduction in the abundance of the pathogenic genus Clostridia_UFC-014. In another study, a supplementation diary of 5 g of oil for 12 weeks improved bowel habits and reduced the force required for evacuation in haemodialysis patients (Schincaglia et al., 2021). These data demonstrate that baru almond and oil seem to modulate the gastrointestinal system, preventing gastrointestinal disorders caused by dairy desserts (Cruz et al., 2019) and improving the quality of life of haemodialysis patients (Schincaglia et al., 2021). It is suggested that the high fiber content present in baru pulp can favour the modulation of the intestinal microbiota (Silva et al., 2021b). However, to date, no studies have investigated which compounds or compounds are responsible for this effect.

Recently, the prebiotic potential of the pulp was reported. The growth of the probiotic strains was observed. Furthermore, pulp increased the abundance of *Lactobacillus-Enterococcus*, *Bifidobacterium*, and *Bacteroides-Prevotella* and improved the production of lactate and metabolites derived from the fermentation of nondigestible carbohydrates, such as propionate, butyrate, and acetate, in the human colonic microbiota (Alves-Santos et al., 2023).

3.11.8. Anti-inflammatory activity (ANA) and memory and anxiolytic-like behaviour (MAB)

Rats fed an elaborate hyperlipidic diet supplemented with baru almond (30%) showed reduced levels of cyclooxygenase-2 in the brain, suggesting that this diet is an effective neuroprotector (Campidelli et al., 2022). In a randomized, double-blind, 12-week placebo-controlled clinical study, the intake of baru almond oil (5 g/day) decreased the level of ultrasensitive C-reactive protein in haemodialysis patients (Schincaglia et al., 2020). Recently, the consumption of baru almond (2 g) alone or in combination with goat milk whey (mix) increased the deposition of MUFAs, PUFAs, and oleic acid in the brains of elderly animals, improving memory and anxiolytic-like behaviour in rats during ageing (Bidô et al., 2023). Considering that few studies have explored the anti-inflammatory and behaviour modulator potential of these compounds, additional studies need to be performed to confirm these effects.

4. Conclusion

In summary, almond and bark are the parts most commonly used in traditional medicine for various ailments. However, a large number of studies have focused on almond as a hypolipidaemic agent and bark for the treatment of snakebites (Figure 11). In this sense, we observed that several indications of popular use have not yet been investigated, leaving an important field to be explored in future studies, mainly regarding other parts of the plant, such as the pulp, flowers, and leaves.

Research and incentives for baru bioprospecting could favour the discovery and development of new products that benefit human nutrition and health.

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Supplementary Material

Supplementary material accompanies this paper.

Table S1 - Baru studies included in this review.

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