REVIEW

Chemistry and biology of *piquiá*: Review

Diana França de Souza[1], Cristiana Nunes Rodrigues[1], Pâmella Buenos Aires Domingues[2*], Klenicy Kazumy de Lima Yamaguchi[1], Valdir Florêncio da Veiga Júnior[3], Fábio Alessandro Pieri[2]

[1]Federal University of Amazonas, Estrada Coari Itapeua, 69460-000, Coari, Brazil
[2]Federal University of Juiz de Fora, Avenida Moacir Paleta, 35020-360, Governador Valadares, Brazil
[3]Military Institute of Engineering, Square Gen. Tiburcio, 22290-270, Rio de Janeiro, Brazil
**Corresponding author: fabio.pieri@ufjf.br*

ABSTRACT
The Amazon biome is rich in plant species that have essential physicochemical, nutritional, and pharmacological properties that guarantee health benefits. The genus *Caryocar* spp. stands out for having native exotic fruits, including *C. villosum*, *C. brasiliense*, and *C. coriaceum*. These are the most studied species, with a nutritional source and rich in fatty acids, mainly oleic and palmitic acids, and phenolic compounds. Therefore, the objective of this review is to present the reported chemical properties and biological activities of fruits of the most common species of the genus *Caryocar* in Brazil. The main chemical compounds found in *Caryocar* species are phenolic, among them gallic acid, ellagic acid, and HDDP-Glucose; and carotenoids as antheraxanthin and zeaxanthin. This rich composition of the fruits shows important biological activities such as anti-inflammatory, antioxidant, and antimicrobial. In addition to adding economic value to different biotechnological and industrial applications, which have been drawing the attention of different branches of industries, valuing natural products and suggesting new alternatives for users that allow the generation of biotechnological products that can contribute to economic, social, and technological development. of all those involved in this process.

Keywords: medicinal plants, essential oils, natural products, phenolic, carotenoids

INTRODUCTION

Brazil has one of the largest native forests in the world, in which the Amazon Forest stands out for covering a large green area of plants. The Amazon biome is rich in oilseed plant species that have essential physicochemical, nutritional, and pharmacological properties that guarantee health benefits. In addition to adding economic value to different biotechnological and industrial applications, which have been drawing the attention of different branches of industries (Ibiapina et al. 2021).

The genus *Caryocar* spp. stands out for having native exotic fruits, including *C. villosum* (Aubl.) Pers., *C. brasiliense* A.St.-Hil., and *C. coriaceum* Wittm. These are the most studied species, with a nutritional source (lipids 51.51%, proteins 25.27%, carbohydrates 8.33%, and fibers 2.2%) and rich in fatty acids, mainly oleic and palmitic acids, and phenolic compounds. The chemical properties arouse the interest of research groups due to the biomolecules capable of modulating important effects on cellular metabolism that have been shown to have various effects such as anti-inflammatory, antioxidant and healing (Miranda et al. 2019; Yamaguchi and Souza 2020).

Consumers are increasingly opting for natural and sustainable products, attracting the attention of the food, pharmaceutical, and cosmetic industries as low-cost alternative sources. Rich in bioactive compounds, the fruits have shown promising potential for the production of antioxidant dietary supplements (Roxo et al. 2020).

Several phytochemical and pharmacological studies of Amazonian fruits have been conquering the national and international markets, which indicate substances with biological properties present in their extracts (Yamaguchi and Souza 2021). The oils from these fruits show antimicrobial, antioxidants and anti-inflammatory properties (Ibiapina et al. 2021). When compared with other 18 tropical fruits (nine

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of them from the Amazon region), the species *C. villosum* showed the highest values of total phenolic substances, flavonoids, and antioxidant activity (Barreto et al. 2009).

Caryocar spp. it is widely used in the cuisine of people in some regions of the Brazil and is widely used for therapeutic purposes. In traditional Brazilian medicine, *Caryocar* fruits have anti-inflammatory, antipyretic, and analgesic properties. It has been used to treat various ailments such as respiratory infections, skin disorders, and gastrointestinal problems. The fruit also contains high levels of carotenoids, which have antioxidant properties and may be beneficial for cardiovascular health.

Several studies have investigated the medicinal properties of the *Caryocar* species. In a study published in the Journal of Ethnopharmacology, researchers found that extracts from the fruit had anti-inflammatory and analgesic effects in animal models (Junior et al. 2020). Another study published in the Journal of Medicinal Food found that the fruit had antioxidant and anti-inflammatory effects in human volunteers (Torres et al. 2020).

This knowledge about the potential of these species from the experience, customs, and way of life provides an exchange subsidizing the discovery of various riches of these plants, in addition to enabling the practice of strategies so that the trees are conserved to provide such resources (Miranda et al. 2019).

Although they have a similar popular nomenclature, commonly called *pequi* or *piquiá*, depending on the region, the species *C. villosum, C. brasiliense,* and *C. coriaceum* are distinct species with peculiar characteristics (Nascimento-Silva and Naves 2019; CNCFlora 2012). This review aims to present the reported chemical properties and biological activities of fruits of the most common species of the genus *Caryocar* in Brazil, namely, *C. villosum, C. brasiliense,* and *C. coriaceum*. The areas of occurrence of the species, their morphological and phytochemical characteristics, and their potential biological activities and applications in industries will be highlighted, to add economic and scientific value to these fruits and identify the characteristics that can differentiate these species.

RESEARCH METHODOLOGY

This review presents a bibliographic survey on the differentiation and chemical and morphological characterization of species of the genus *Caryocar* spp, which are *C. villosum*, *C. brasiliense, and C. coriaceum*, as well as industrial use.

The searches were conditional on scientific databases such as Science Direct, SciELO, Pubmed, Capes Periodicals, CAS SciFinder, and EMBRAPA, as well as on specialized websites with publications in English and Portuguese, using the keywords used for research, *Caryocar,* C*aryocar villosum*, *Caryocar brasiliense*, *Caryocar coriaceum*, *bioactive compounds*, and *antioxidant activities*, separately and in combinations. The years of publications were not estimated, nor was the number of articles researched due to the scarcity of literature on the investigated species. Articles related to the chemical composition and morphological aspects of the analyzed species were considered, as well as the use of their constituents and biological activities.

GENRE *Caryocar*

The genus *Caryocar* spp. has 16 known species spread across South and Central America, as shown in figure 1.

The genus *Caryocar* spp. is predominant in the Amazon region and the Brazilian northeast. *C. villosum*, is commonly known in northern Brazil as *pequiá*, *C. brasiliense* is abundant in the Brazilian *cerrado*, known in its region as *pequi* (Afonso et al. 2014; Miranda et al. 2019), and *C. coriaceum* also found in the Brazilian *cerrado* and northeast (CNCFlora 2012; Flora e Funga do Brasil 2023), as can be seen in Figure 2.

Occurrence area

The *C. villosum* is a tree that predominates in the Central Amazon, it is widely distributed in some regions of Brazil, mainly in the North states (Amazonas, Amapá, Pará, Rondônia, Roraima), Northeast (Maranhão), and Center-West (Mato Grosso). Economically, it is one of the most valued forest products and its importance is due to the quality of the wood that is widely used by traditional peoples to manufacture furniture (Martins and Gribel, 2007; Leal et al. 2016; Conceição et al. 2017; Yamaguchi et al. 2016; 2017; Roxo et al. 2020; Prance and Pirani 2020).

The *C. brasiliense,* native to the Brazilian ecosystem, is one of the trees of great importance in the *cerrado* for being one of the food sources. With confirmed occurrences in the North (Pará, Tocantins), Northeast (Bahia, Maranhão, Piauí), Midwest (Federal District, Goiás, Mato Grosso do Sul, Mato Grosso), Southeast (Minas Gerais, São Paulo), and South (Paraná) states. It is found in the Amazon, *Caatinga*, Atlantic Forest and also in several countries in South America and Central America (Guedes et al. 2017; Nascimento-Silva et al. 2019; Silva et al. 2020).

The species *C. coriaceum* is present in the Northeast (Ceará, Bahia, Maranhão, Piauí, Tocantins, and Pernambuco), more abundant in Ceará due to environmental protection areas (Almeida-Bezerra et al. 2022) and Central-West (Goiás) of Brazil, in the *Caatinga* and *Cerrado* biomes (CNCFlora 2012).

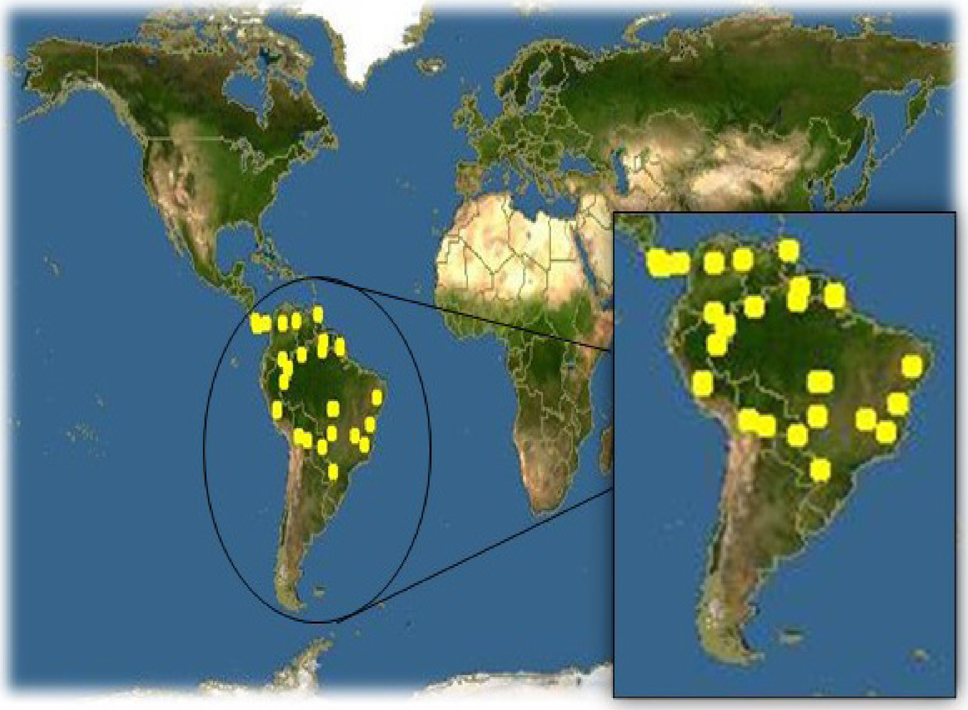

Figure 1. Geographical distribution of the genus *Caryocar.* Source: http://www.discoverlife.org

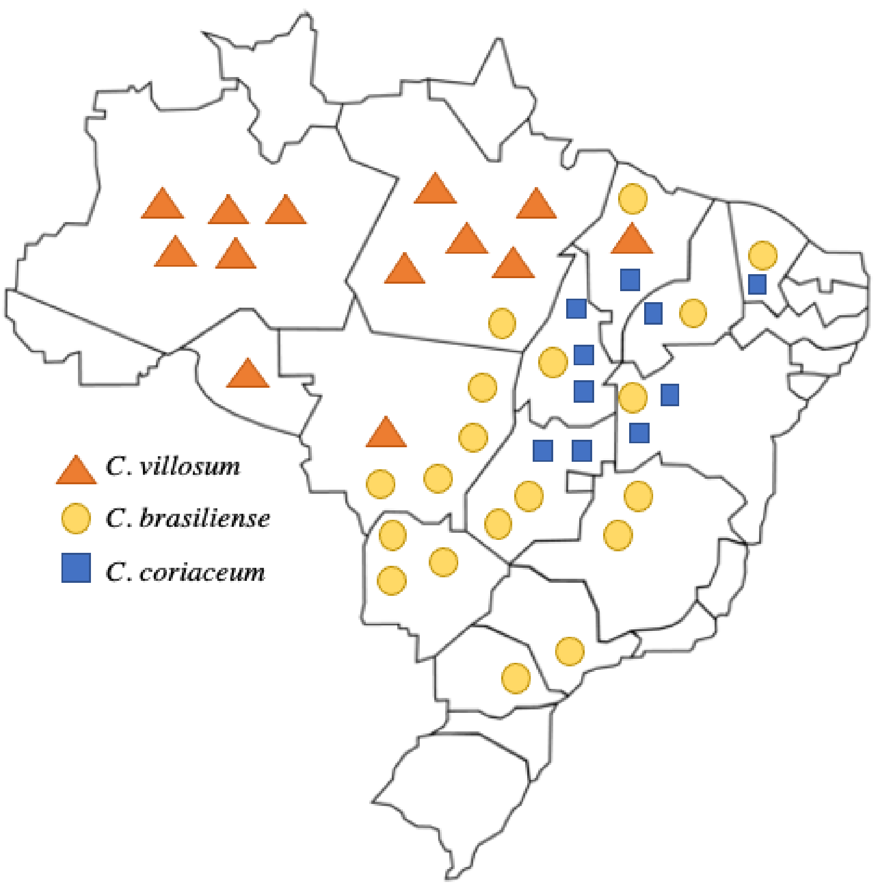

Figure 2. Area of occurrence of *Caryocar* species. Source: Primary data (2022).

Botanical characteristics
Nomenclature
Kingdom: Plantae
Family: Caryocaraceae Voigt
Genre: *Caryocar* L.
Species: *Caryocar villosum* (Aubl.) Pers.
Caryocar brasiliense A.St.-Hil.
Caryocar coriaceum Wittm. Stem

C. villosum is a large tree ranging from 40 to 50 m in height, typical of a primary forest. Piquiazeiro stems are cylindrical and can reach 2.5 m in diameter, or a squeegee greater than 5 m, the rhytidome (bark) is rough and has no aroma, and its crown is robust, standing out in the forest (Shanley and Medina 2005; Rabelo et al*.* 2012; Prance and Pirani 2020). *C. brasiliense has a* medium-sized stem, which varies from 7 to 12 m in height, is usually twisted, and can grow sideways, sometimes close to the ground (Afonso et al*.* 2014). *C. coriaceum* are arboreal, and the stem length varies between 5 to 15 m in height. The trunk has a thick bark and can reach up to 35 cm in diameter, and a wood density of 0.78 g/cm (Almeida-Bezerra et al. 2022).

Leaves

C. villosum show leaves with apexes and leaflets acuminate, serrated and create**,** while *C. brasiliense* show leaves with rounded leaflet apex and crenate margins (Prance and Pirani 2020). The leaves can be very dark when dried (Araújo et al. 2007), very similar to *C. coriaceum* (Carvalho 2009). The leaves present a petiole, near 1.5 to 4 cm long. The margins of the leaves can be serrated or crenate, the leaflets measure 3.7 to 7 cm in length and 5 to 10 cm in width and are short petiolate, with a rounded oval blade with a slightly rectilinear apex (Almeida-Bezerra et al. 2022).

Flowers and inflorescence

The flowers of *C. villosum* have a “stamen brush” shape, with five petals (Almeida-Bezerra et al. 2022) that are yellowish and are exposed above the crown, in terminal inflorescences. They have nocturnal anthesis, last only one night, and secrete about 750 mL of nectar per night (Martins and Gribel 2007).

Inflorescence raceme uniflorous, tomentel to puberty and glabrescent: peduncle 5-13 cm; rachis 3-4 cm; chalice ca. 1.5 mm; petals ca. 2.5 cm, oblong-elliptical, light yellow; stamens ca. 300: globose ovary, 4 locular (Prance and Pirani 2020).

The inflorescence of the species *C. coriaceum* appears in a terminal raceme. Each bunch contains from 10 to 30 flowers, actinomorphic, with a long pedicel, formed by a calyx with 5 green or reddish sepals and a light yellow corolla surrounding with 5 petals with an elliptical base and a rounded apex, measuring 2 to 4 cm in length (Muniz 2017; Almeida-Bezerra et al. 2022).

Fruits

The fruits of *piquiá* show similar characteristics, with a peculiar smell and taste. They have a thick mesocarp and a yellow pulp, rich in lipids. According to Oliveira et al. (2009), its fruits are mainly composed of peel, followed by stone and pulp. The seed of the species has a thorn that makes the genus can be easily recognized within the botanical family. The popular names originating from these three species refer to the indigenous word meaning “thorny cover” (Torres et al*.* 2018). It is verified that in the three investigated species there is approximately 7-12% of edible pulp and about 6-70% of rind (exocarp and external mesocarp).

Harvest

Due to the climatic characteristics of each region, the harvest period tends to be different according to the environment in which the species are inserted. For example, a native *piquiá* tree, present in a forest, does not normally produce fruit every year. Informal popular reports cite that the trees “rest” one year and produce the next.

In general, it is mentioned in the literature that the species *C. villosum* produces flowers from August to October, and fruits from February to April (Shanley and Medina 2005). The collection of fruits takes place manually from the ground when the fruit reaches its maturation (Araújo et al. 2007). In the Amazon region, the crop is commonly associated with the rainy season, in which flowering occurs in the dry season (from July to November) with fruiting in the rainy season (from March to May) (Chisté et al*.* 2012). *C. brasiliense* presents a later harvest, in which the fruit collection period occurs from September to February. The *C. coriaceum harvest* takes place from January to March, and is an activity that represents great economic importance for families in the region due to the collection of fruits (Oliveira et al. 2009).

Chemical and biological characteristics

The fruit of *C. villosum* has the pulp of its fruit consumed by local inhabitants in Amazonian cuisine to prepare regional dishes with rice and edible oil, which is used as a substitute for butter (Clay et al. 2000). In addition to cooking, *C. villosum* is traditionally used in the treatment of some diseases by the native peoples of this region, rich in fix oils, proteins and carotenoids (Conceição et al*.* 2017; Torres et al. 2018). This oil is used by rural families in Northeast Brazil for the treatment of dermatophytoses, such as ringworm (*Tinea capitis*) and fungal skin diseases (“athlete’s foot”) (Grenand et al. 2004). In French Guiana, the pulp and bark of this species are traditionally used by the inhabitants as a fish poison. In the study carried out by Magid et al. (2006; 2006a), this property was associated with the presence of isolated saponins. The species of *C. brasiliense* and *C. coriaceum* also have the pulp as the most exploited part of the fruits, being widely used in cooking and folk medicine (Araújo et al*.* 2007; Nascimento-Silva et al. 2019; Silva et al*.* 2020).

In addition to other secondary metabolites essential to plant organs. The compounds present in the species of the genus combine biologically active properties with beneficial effects on human health: antioxidant, anti-inflammatory, healing, photoprotective, and low toxicity. The traditional use of these in the treatment of diseases, combined with scientific knowledge, inspired some researchers to use the bioactive present in various applications (Torres et al. 2018; Miranda et al. 2019; Yamaguchi and Souza 2020; Prance and Pirani 2020).

Through the assay (ORAC) it was possible to identify the antioxidant capacity of the fruit pulp, indicating that it is a great free radical scavenger with biological properties. This characteristic is associated with the presence of phenolic compounds, flavonoids, and fatty acids, mainly oleic and palmitic acids. In addition to carotenoids. The fruit contains a high content of vitamin A, which helps to prevent and cure eye disorders (blurred vision), vitamin C and B vitamins, as well as phytosterols: sitosterol, stigmasterol, and lanosterol (Araújo et al. 2007; Chisté and Mercadante 2012; Leal et al. 2016; Morais et al. 2020).

It is evident in the three species of the genus *Caryocar,* numerous biological effects pointed out in scientific research, as shown in Table 1. Among the biological activities, the antioxidant capacity to neutralize free radicals that can cause biological imbalance, such as cancer, skin aging, and cardiovascular diseases (Silva et al. 2020), appears as recurrent in the three species analyzed in this review.

Table 1. Biological activity of *Caryocar villosum, Caryocar brasiliense*, and *Caryocar coriaceum.*

Specie	Biological activity	Biological assay	Reference
Caryocar villosum	Anti-inflammatory action	*In vitro,* with *piquiá* hydroethanolic extracts 6,25; 12.5; 25, and 50 µg/ml cells were incubated for 24 h with LPS (1 µg/ml) at 37 °C in 50% incubator.	Yamaguchi et al. 2017
		in vivo, topical administration of *C. vilosum* (100, 200, and 500 mg/kg) of fixed oil for six days in the formation of granulomatous tissue in rats.	Xavier et al. 2011
	Antigenotoxic	*In vivo*, *piquiá* pulp (75, 150 or 300 mg/kg bw) was administered into organs of Wistar rats for 14 days, and the animals received saline or DXR injection (15 mg/kg bw, ip) 24 h	Almeida et al. 2012
	Cytotoxicity	*In vitro*, hydroalcoholic and ethanolic extracts of *C. villosum* against human tumor (SKMELL19, MCF-7 and HCT116) and non-tumor (MCR-5) cells with doxorubicin 50 µg/ml/72 h (IC_{50}> 50 µg/ml).	Yamaguchi et al. 2017
	Antioxidant effect	*In vitro,* free radical scavenging DPPH; 30 µl of extracts diluted in different concentrations (1-100 µg/ml).	Yamaguchi et al. 2017
		In vitro, free radical scavenging assays DPPH and TEAC (trolox equivalent antioxidant capacity) assessed by ABTS (2,2' - azino-bis(3-ethylbenzothiazoline-6-sulfonic acid decolorization).	Roxo et al. 2020
Caryocar brasiliense	Antibacterial	*In vitro*, aqueous extract of leaves of *Caryocar brasiliense* Cambess. produced zones of inhibition against strains of *E. coli* (Gram-negative bacteria).	Ribeiro et al. 2018
		Aqueous extract of *C. brasiliense* 40 mg/ml against Gram-negative bacteria. 5% of *Caryocar brasiliense* extract obtained by supercritical CO_2 extraction (MICs) against *Escherichia coli*, *Pseudomonas aeruginosa* and *Staphylococcus aureus* were determined by the classic microdilution method.	Amaral et al. 2014

Anti-inflammatory action	*In vivo,* **d**oses of 300, 700, and 1000 mg/kg of *pequi* oil were administered orally (po) to male Swiss mice, and three parameters of inflammation (mechanical hyperalgesia, cold, hyperalgesia and edema).	Junior et al. 2021
	In vivo, free *pequi* oil or pequi-NE (20 mg/kg) was orally administered to A/J mice 16 and 4 h before intranasal exposure to LPS, and analyzes were performed 24 h after LPS challenge.	Coutinho et al. 2020
Anticancer action	*In vivo*, in vivo was evaluating DNA damage in lung tissues and changes in lipid peroxidation and redox antioxidants, previous supplementation with *pequi* oil or its extract (15 µl, 60 days) against DNA damage induced by urethane and oxidative stress in forty male BALB/C mice aged 8-12 weeks.	Columbus et al. 2015
Anticholinesterase action	*In vitro,* by Ellman's colorimetric method. (10, 100, and 300 mg/kg) of the hydroalcoholic extract of leaf prevented memory impairment in mice and inhibited brain lipid peroxidation and acetyl and butyryl-cholinesterase activities and neuroprotective effect.	Oliveira et al. 2018
Biological control of *Aedes aegypti larvae*	*C. brasiliense* leaf extract was prepared by extraction with ethanol (70%). Bioassays with L3 larvae were performed at concentrations of 200, 300, 400, and 500 ppm.	Morais et al. 2020
Antioxidant effect	*In vitro,* based on the oxidation of 2,2'-azino-bis (3-ethylbenzothiazolin-6-sulfonic acid) (ABTS). an extract of *C. brasiliense* obtained by extraction of supercritical CO_2.	Amaral et al. 2014
	In vitro 0.25 ml of *C. brasiliense pulp extract* 2.0 ml of ultrapure water and 0.25 ml of Folin-Ciocalteu. 0.25 ml of sodium carbonate at 37 °C in a water bath for 30 min.	Nascimento-Silva and Naves 2019
	In vitro, by capturing DPPH free radicals from microemulsions with pequi oil at 3% (m/m) distilled water, caprylic/capric triglyceride-polymol 812 (CCT), hydrophilic-lipophilic balance (HLB) = 10.8), sorbitan monooleate -Span 80(SP), HLB = 4.3, Polysorbate 80-Tween 80(TW), HLB = 15.0, and 1-butanol).	Torres et al. 2018
	In vitro, crude hydroalcoholic extract of leaves and OFs (1-500 *µ*g/ml) were pre-incubated for 30 min in the presence of DPPH and electroanalytical assays,	Oliveira et al. 2018
	In vitro, by ABTS methods, (2105.18 µM trolox/g), FRAP, (6292.11 µM ferrous sulfate/g) and β-carotene/linoleic acid system (92.94% protection) of *pequi* peel flour .)	Bemfeito et al. 2020
Antidiabetic	In *vitro,* extracts and fractions of *pequi* peels inhibited the release of cytokines involved in insulin resistance - TNF, IL-1β and CCL2 - by THP-1 cells stimulated by lipopolysaccharides. the tannin-enriched fraction (16C) induced a more potent inhibition of α-glucosidase. pic $_{50}$ = 5.3 ± 0.1).	Caldeira et al. 2021
Analgesic	*In vitro*, *pequi* oil (1.000 mg/kg) blocked mechanical hyperalgesia and reduced carrageenan-induced cold allodynia in the paw (P<0.05). administered orally (po) to male Swiss mice.	Junior et al. 2020

Caryocar coriaceum	Anti-inflammatory action	*In vivo,* fixed oil of *C. coriaceum* (OFCC), treatment of mouse paw edema (induced by carrageenan) and myeloperoxidase (MPO), in polymorphonuclear cultured cells, was reduced at all dose levels.	Figueiredo et al. 2016
	Antioxidant action	*In vitro, C. coriaceum* using the free radical DPPH (2,2-diphenyl-1-picrylhydrazyl), aqueous extract of leaves, IC_{50} µg/ml (Extract/Oil) 2.70.	Duavy et al. 2012
		In vitro, *C. coriaceum* using the free radical DPPH (2,2-diphenyl-1-picrylhydrazyl), ethanolic extract, IC_{50} µg/ml (Extract/Oil) 26.37.	Duavy et al. 2017
		In vitro, from C. *coriaceum* using the free radical DPPH (2,2-diphenyl-1-picryl-hydrazyl), ethanolic extract of *pequi* peels and pulp, IC_{50} µg/ml (Extract/Oil) 49.40.	Alves et al. 2017
		In vitro, fixed oil from C. *coriaceum pulp* using the free radical DPPH (2,2-diphenyl-1-picrylhydrazyl).	Oliveira et al. 2017
	Leishmanicidal action	*In vivo,* leaf extracts of *C. coriaceum* EAC and MET ethyl acetate (EAC) and methanol (MET) showed antipromastigote effect after 24, 48, and 72 h, by apoptosis and intracellular amastigotes by Nrf2/HO-1/ferritin dependent response and iron depletion.	Tomiotto-Pellissier et al. 2018
	Antifungal	*In vitro*, extracts from leaves of *C. coriaceum*. Six strains were tested (3 *Malassezia* spp.: MA239, MA276 and MA355; 3 *Microsporum canis*: MC017/15, MC029/15 and MC115/15), isolated from infected domestic animals.	Alves et al. 2017
	Antibacterial	*In vitro*, oil from the pulp of *C. coriaceum* Wittm. with fatty acid content: inhibited the antibacterial growth of *Salmonella cholerasuis* (MIC < 1.25%), *Staphylococcus aureus* (MIC 1.25%), *Pseudomonas aeruginosa* (MIC 1 .25%) and *Streptococcus pneumoniae* (MIC 5%).	Costa et al. 2011
		In vitro, C. coriaceum pulp oil – CCFO), (CIM) from CCFO. Test with *Escherichia coli* and *Staphylococcus aureus strains* by microdilution assay. CCFO, MIC of 512 µg/ml against *E. coli* and *S. aureus* resistant strains.	Saraiva et al. 2011
	Gastroprotective	*In vivo*, oil from the *pulp of C. coriaceum*, evaluated for cytoprotective activity in the formation of ethanol-induced ulcers in mice. EOCZ, EOVA, OCC and ESR were administered doses of 200 and 400 mg/kg and LDH, in the same way, at 0.2 and 0.4 ml/animal (n=8). After 60 min, mice received 0.2 ml of ethanol (96%).	Leite et al. 2009
	Hypolipidemic	*In vivo* , fixed oil of *C. coriaceum* (OFCC); on lipid profiles of healthy mice, on tyloxapol -induced dyslipidemia . At doses of 500, 1000, and 2000 mg/kg OFCC, no behavioral, physical changes or deaths were observed in the experimental groups. There was no significant weight gain in the animals.	Figueiredo et al. 2016

Source: primary data, 2022.

The cited species present a composition rich in phenolic substances, carotenoids, and terpenes. Some of the substances detected can be seen in figure 3.

C. brasiliense is a fruit that carries in its pulp and almond a high content of lipids, with energy levels of 269 kcal/100 g (seed) and 16/100 g pulp), with a greater predominance of monounsaturated and saturated fatty acids, high concentration of carotenoids (47 µg/g) and polyphenols. The peel represents most of the fruit, being rich in fiber and phenolic compounds, mainly gallic acid, ellagic acid, and quercetin (Nascimento-Silva et al*.* 2019; Bemfeito et al. 2020 and 2021). The studies by Roxo et al. (2020), analyzed the phytochemical profile of *C. brasiliense pulp* and detected the presence of tannins, phenolics, and flavonoids. Oliveira et al. (2018) associated antioxidant and anticholinesterase activity, the presence of phenolic compounds in dried leaves, and the presence of gallic acid with antioxidant action as well. The hydroalcoholic extract of *C. brasiliense leaves* also presented phenolic compounds as the main ones, among them quercetin, violaxanthin, myricetin3-*O*-hexoside, methyl ellagic acid-3-arabinose, and isoquercitrin. The authors suggest that the combination of these substances affected the development of *Aedes aegypti* larvae*,* preventing their development into mosquitoes (Morais et al. 2020). In the study conducted by Oliveira et al. (2012), the hydroalcoholic extract also had quercetin as a major compound, with important antioxidant action in potential use for pathological conditions such as hypertension and atherosclerosis. In addition to phenolic compounds, *pequi* is also rich in monounsaturated fatty acids, including oleic acid, with anti-inflammatory activity (Coutinho et al. 2020)

In the studies by Yamaguchi et al. (2017), with the different parts of *C. villosum* (peel, pulp, and seeds), bioactive substances were found, such as phenolics, ellagic acid, gallic acid, oleic acid, proteins, and carotenoids. This species is considered an important nutritional source (lipids 51.51%, proteins 25.27%, carbohydrates 8.33%, and fibers 2.2%) in addition to a therapeutic purpose (Conceição et al*.* 2017; Torres et al. 2018; Yamaguchi and Souza 2020).

The so-called polar components of the ethanolic extract of *C. brasiliense* were revealed by direct infusion electrospray ionization mass spectrometry (ESI-MS) and the presence of bioactive substances widely reported as potent antioxidants such as gallic acid, quinic acid, quercetin, and quercetin 3-*O*-arabinose justify its high antioxidant activity (Roesler et al. 2008).

In addition to these studies, the chemical composition of the bark of *C. villosum* is mentioned, as rich in hydrolyzable tannins and triterpenoid saponins, which can be used for the production of paints, net dyes, and soap. The oil extracted from the pulp of C. villosum is rich in carotenoids and phenolic substances (Leal et al. 2016; Roxo et al. 2020).

In addition to pulp, in studies carried out by Chisté and Mercadante (2012) and Chisté et al. (2012) related to *C. villosum*, phenolic substances were detected: gallic acid, ellagic acid and ellagic acid deoxyhexoside rhamnoside (HDDP-Glucose), and the carotenoids: lutein and zeaxanthin as major compounds. In the stem bark, glycosylated phenolics, triterpene saponins, and flavonoids were found. From the methanolic extract, five triterpene saponins were isolated (β-D-glucuronic acid, β-D-galactose, α-L-rhamnose, β-D-glucose, Gallate (gallic acid salt)). Triterpene saponins were also isolated from the pulp, including β-D-glucose, β-D-galactose, β-Dxylose and the flavonoid glycosides, β-D-glucopyranose, 3',4',5'-trimethoxyphenyl, galloyl (Magid et al. 2006; 2006a; 2008).

Pulp oil has large amounts of substances that characterize consistency, color and, biological properties. The fatty acids present in *piquiá* oil were quantified by Polinni et al. (2012) through gas chromatography. The results showed a higher content of linolenic acid, followed by oleic acid and palmitic acid. Previously, the main fatty acid esters of methyl hexadecanoic, methyl octadecanoic, and methyl (*E*)-octadecenoate were identified in the works of Xavier et al. (2011).

In the works of Yamaguchi and Souza (2020) they demonstrated that the different parts of the *piquiá*: *piquiá* peel, pulp, and seed are sources of raw material in cosmetic applications. Among the 7 physical-chemical tests carried out, they corroborated for the *piquiá* fruit to be used in full in cosmetic products. Among the tests carried out, the phytochemical prospection showed the presence of biologically active substances such as saponin, phenolic compounds, flavanones, chalcones and, anthocyanins that are secondary metabolites beneficial to health. The results shown motivated the production of an exfoliating soap for the skin.

The fruits of *C. coriaceum* also have important nutritional value. Pulp oil, according to Costa et al. (2011) is rich in fatty acids, namely oleic, palmitic, heptadecenoic, linoleic, stearic, eicosenoic, and palmitoleic. In addition to the pulp oil, the kernel is also rich in this macronutrient (Torres et al. 2020). The composition of *C. coriaceum* kernel oil is composed of more than 50% lipids, followed by proteins and carbohydrates (Araújo et al. 2018; Torres et al. 2020).

Phenolics compounds

Gallic acid Ellagic acid HDDP-Glucose

Carotenoids

Antheraxanthin Zeaxanthin

Figure 3. Major chemical substances detected and/or isolated from *Caryocar*. Draw for ACD/ChemSketch version 2022.

In recent years, advanced analytical techniques have been sought in the identification of chemical compounds. In mass spectrometry, it is possible to identify the chemical profile of compounds present. Being one of the most used techniques for the study of biomolecules with high molecular weight and other compounds.

Applications in Industry

The characterization of oils from fruits provides important information, being potential ingredients of a variety of products. Their sustainable use can have considerable economic potential (Jaramilo et al. 2019). The potentialities attributed to these fruits are promising in the cosmetics and nutraceuticals industries since their uses are recommended in healthy diets (Silva et al. 2020a).

Oil extracted from the pulp or “almond” (seed) has a high local socioeconomic impact and is associated with nutritional and therapeutic benefits (Torres et al. 2018). They have biological action for different purposes, in favor of human health, as shown in Table 1. *Caryocar* species are commonly used in cooking and medicinal use by local communities, which generates all empirical knowledge about the pharmacological potential of this genus (Miranda et al. 2019).

In the Amazon region, only *C. villosum* is present, and the nutritional sources of *piquiá* draw the attention of consumers, its pulps are cooked with rice or in regional dishes, consumed by the community, as well as being applied in the cosmetics industries in the production of soaps and moisturizers for the skin (Yamaguchi and Souza 2020).

Bioactive substances such as antioxidant activity have aroused increasing interest and are considered potentially useful for the cosmetic, pharmaceutical, and nutraceutical industries as their use is recommended in healthy diets (Leal et al. 2016; Lamarão et al. 2020; Silva et al. 2020a).

Piquiá is used empirically and popularly in the production of skin creams and lotions, soaps, bath oils, and emulsions, in which the compounds present in the extracts provide hydration and firmness to the skin. Studies indicate the benefits of incorporating *piquiá* oil into shampoo formulations, increasing hair shine and improving combability (Araújo et al. 2007).

In the studies by Roxo et al. (2020) *piquiá* shells were indicated as potential candidates for nutraceutical applications. The *pequi* from the *Cerrado* is also a promising source of application in industries, as seen in the work of Bemfeito et al. (2020), in which *pequi* peel flour because it has high levels of dietary fiber and phenolic compounds, can be used to develop healthier foods for the population. As in the studies by Leão et al. (2017) and Cangussu et al. (2021) from the physicochemical characterization, the content of total phenolics and proanthocyanidins of flours prepared from *pequi* fruit by-products, showed favorable results for application in the food industry, promising prospects for the exploitation of *pequi* peel as a source fiber potential and natural antioxidants, which makes the product commercially attractive, in addition to generating value for an agro-industrial residue.

FINAL CONSIDERATIONS

Species of the genus *Caryocar* have been showing excellent results for biological activities, being rich in biomolecules and widely used in Brazilian regions in the culinary area and as an alternative for medicinal use. Among the species, *C. brasiliense,* has the largest number of studies, and given the analysis of the composition and application of *C. coriaceum* and *C. villosum,* they present great similarity, encouraging more studies of these species and use in the regions where they are found. Through the research carried out, it appears that the industrial applications involving the species are related to the use in the wood industry and timidly and punctually, despite the great potential.

In this way, this bibliographic review highlights the benefits of these species to present the potential and encourage studies that enable the use of these raw materials, valuing them and suggesting new alternatives for use that allow the generation of biotechnological products that can contribute to the economic, social and technological development of all those involved in this process.

AUTHORS' CONTRIBUTIONS

All authors contributed to the study. Conceptualization, D.F.S., C.N.R., P.B.A.D.; investigation, D.F.S., C.N.R., P.B.A.D.; methodology, D.F.S., C. N.R., P.B.A.D.; project administration, K.K.L.Y. and F.A.P.; supervision, K.K.L.Y. and F.A.P.; validation, D.F.S., C.N.R., P.B.A.D., K.K.L.Y., V.F.V.J. and F.A.P.; visualization, D.F.S., C.N.R., P.B.A.D., K.K.L.Y., V.F.V.J. and F.A.P.; writing - original draft, D.F.S., C.N.R., P.B.A.D.; writing - review & editing, D.F.S., C.N.R., P.B.A.D., K.K.L.Y., V.F.V.J. and F.A.P. All authors read and approved the final manuscript.

CONFLICT OF INTERESTS

The authors have no conflicts of interest to declare.

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