GRASAS Y ACEITES 69 (2)
April-June 2018, e257
ISSN-L: 0017-3495
https://doi.org/10.3989/gya.1222172

Bioactive compounds and functional potential of pequi (*Caryocar* spp.), a native Brazilian fruit: a review

L.R.O. Torres[a,b,✉], F.C. Santana[a], F.B. Shinagawa[a] and J. Mancini-Filho[a]

[a]Department of Food Science and Experimental Nutrition, University of São Paulo, Av. Prof. Lineu Prestes, 580, Bloco 14, Cidade Universitária, 05508-900, São Paulo, Brazil.
[b]Federal Institute of Education, Science, and Technology of Maranhão, Rodovia MA 349 (Caxias/Aldeias Altas), Km 2, s/n, Gleba Buriti do Paraíso, Povoado Lamego, Zona Rural, 65.600-970, Caixa Postal 77, Caxias, Maranhão, Brazil.

✉Corresponding author: lucillia.rabelo@ifma.edu.br

Submitted: 06 December 2017; Accepted: 09 March 2018

SUMMARY: Pequi is an indigenous word that means "thorny covering" and is used to describe fruits from the *Caryocar* spp. These fruits are widely consumed as food and used in traditional medicine by Brazilians in the savannah (*Cerrado* biome) and the Amazon region. The fruit is rich in lipids, mainly oleic acid, and other bioactive substances including carotenoids, phenolics, and tocopherols. The oil extracted from the pulp or "almond" (seed) has a high local socioeconomic impact and is associated with nutritional and therapeutic benefits. A wide array of health benefits such as antioxidant, anti-inflammatory, antitumor, and antimicrobial effects, improved cardiac function, as well as an increased lymphocyte-dependent immunity have been attributed to the pequi fruit, especially its pulp. This review provides a comprehensive overview on the edible parts of pequi fruits (pulp and almond), more specifically the oil produced from these parts, as a source of functional compounds with biological activity. Moreover, it considers the differences among the three more commercially-important species from the genus *Caryocar*.

KEYWORDS*: Bioactive compounds; Caryocaraceae; Fruit; Health benefits; Oleic acid*

RESUMEN: ***Compuestos bioactivos y funcionalidad potencial del pequi (*Caryocar spp.*), fruta nativa brasileña. Revisión***. Pequi es una palabra indígena que significa "piel espinosa" y es utilizada para describir los frutos de *Caryocar* spp. Estos frutos son ampliamente consumidos como alimentos y son utilizados en la medicina popular por los brasileños ubicados en el *Savannah* (bioma *Cerrado*) y en la región amazónica. La fruta es rica en grasas, ácido oleico y otros bioactivos, incluyendo carotenoides, fenoles y tocoferoles. El aceite procedente de la pulpa o de la almendra (semilla) tiene un importante impacto socioeconómico local y está asociado con beneficios nutricionales y terapéuticos. Una amplia gama de beneficios para la salud tales como antioxidante, antiinflamatorio, antitumoral, antimicrobiano, mejora de la función cardíaca, así como el aumento de la inmunidad linfocitaria han sido atribuidas a la fruta, especialmente a su pulpa. Esta revisión proporciona una descripción exhaustiva sobre las partes comestibles de la fruta del pequi (pulpa y almendra), más específicamente del aceite producido a partir de estas partes, como una fuente de compuestos funcionales con actividad biológica. Además se consideran las diferencias encontradas entre las tres especies comerciales más importantes del género *Caryocar*.

PALABRAS CLAVE*: Ácido Oleico; Caryocaraceae; Compuestos Bioactivos; Fruta; Saludables*

ORCID ID: Torres LRO https://orcid.org/0000-0002-4563-8353, Santana FC https://orcid.org/0000-0002-8545-6570, Shinagawa FB https://orcid.org/0000-0001-5147-9398, Mancini-Filho J https://orcid.org/0000-0002-9863-8920

Citation/Cómo citar este artículo: Torres LRO, Santana FC, Shinagawa FB, Mancini-Filho J. 2018. Bioactive compounds and functional potential of pequi (*Caryocar* spp.), a native Brazilian fruit: a review. *Grasas Aceites* **69** (2), e257. https://doi.org/10.3989/gya.1222172

1. INTRODUCTION

Fruits and vegetables are important components of a diversified and healthy diet due their numerous bioactive components such as carotenoids, polyphenols, fibers, hydrosoluble vitamins, and minerals. Those components are associated with improved overall health and the prevention of several major chronic and neurodegenerative diseases and cancers (Yuan *et al*., 2015; Kishimoto *et al*., 2013; Pérez-Jiménez *et al*., 2010; Dauchet *et al*., 2009; WHO, 2003).

The mechanisms of action of bioactive compounds are not totally elucidated and vary between cells and organisms, but in general, they are associated with antioxidants as well as anti-inflammatory, antitumor, antigenotoxic, and antimicrobial properties (Li *et al*., 2016). Since an increased consumption of fruits is one of the strategies to promote a healthy nutrition and beneficial eating habits, it is crucial that information about the dietary composition and specific benefits is available not only for the most frequently consumed foods, but also for those farmed and consumed in small communities scattered around the world, as is the case of the pequi fruit.

The pequi belongs to the Caryocaraceae family, which is widely distributed throughout Central and South America and comprises 25 species divided into two genera (*Caryocar* and *Anthodiscus*) (Ascari *et al*., 2013). According to De Oliveira *et al*. (2008), several species of the genus *Caryocar* are known as pequi and other derivatives such as piqui, piquiá, and piqui-vinagreiro. However, other authors describe pequi as a popular denomination for the fruits of *C. brasiliense*, which grows in the Central-West Region of Brazil and the western part of the state Minas Gerais; while "piqui" would be considered the fruits of *C. coriaceum*, which grows in northeastern Brazil; and "pequiá" the fruits of *C. villosum*, which grows in the Amazon Region (Geocze *et al*., 2013; Costa *et al*., 2011; De Oliveira *et al*., 2010; Lima *et al*., 2007; Segall *et al*., 2006; Marx *et al*., 1997). These three species represent the main source of income for many small communities in Brazil (Leite *et al*., 2017; Guedes *et al*., 2017; Figueiredo *et al*., 2016; Costa *et al*., 2011; De Moraes Cardoso *et al*., 2013; Marx *et al*., 1997).

The *C. brasiliense* is a drupaceous, spherical, and green fruit, presenting one to four segments (pyrenes). Its structure is composed of a green epicarp (very thin peel), an external mesocarp (non-edible), and an internal mesocarp (edible, light-yellow, pulpy, rich in oil), which includes a layer of thin and rigid endocarp (approximately 2−5 mm) with spines and a white kernel (also called seed, nut, or almond) (Faria-Machado *et al*., 2015) (Figure 1). Although sparsely described, the fruits from other species are structurally similar to those of *C. brasiliense* (Marx *et al*., 1997).

The external mesocarp makes up the largest part of the pequi fruit, but it is usually thrown away since it is non-edible (Ascari *et al*., 2010). Both the internal mesocarp (pulp) and the almond are an excellent sources of lipids and proteins, appreciated in culinary applications as color and flavoring agents. The pulp can be used in the preparation of juices, ice cream, jelly, jam and liquors, for fresh consumption, or for the preparation of typical meals; the almond is used as a culinary ingredient in a tamale-like cake or in condiments or is consumed fresh (Torres *et al*., 2016b; Ascari *et al*., 2013; Ascari *et al*., 2010; Roesler *et al*., 2008; Segall *et al*., 2006). The pulp and the almond are often used as a source of edible oil, generating income for the communities involved (Roesler *et al*., 2008; Afonso *et al*., 2015). In this way, both pulp and almond are routinely used for therapeutic purposes by the regional population to treat e.g. tumors, respiratory diseases, wound lesions, gastric and inflammatory diseases, muscle pain, and

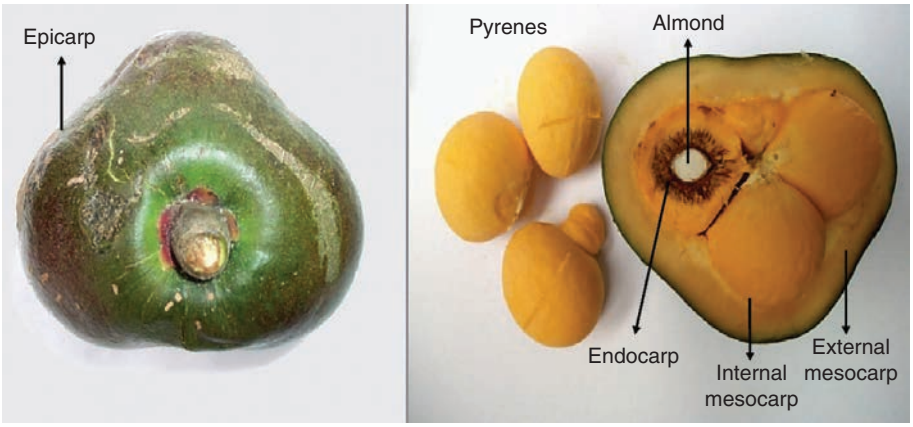

FIGURE 1. Pequi fruit (*Caryocar brasiliense*) and its parts. Adapted from Cardoso *et al*. (2013).

chronic arthritis (Miranda-Vilela *et al*., 2014; Costa *et al*., 2011; Da Silva Quirino *et al*., 2009; Miranda-Vilela *et al*., 2008).

Pequi presents some beneficial biological properties, such as wound-healing and anti-inflammatory activities, antimicrobial activity, and protection against genomic and oxidative damage, among others (Colombo *et al*., 2015; Costa *et al*., 2011; De Oliveira *et al*., 2010; Da Silva Quirino *et al*., 2009; Passos *et al*., 2002). These biological properties, along with the nutritional and health benefits, are mainly attributed to the presence of monounsaturated fatty acids (MUFA) and phytochemicals (Aguilar *et al*., 2011; Roesler *et al*., 2008).

Overall, there is a lack of published and detailed information about the phytochemical composition and the potential for the use of the fruits of the genus *Caryocar*, especially concerning the species *C. coriaceum* and *C. villosum* with negative repercussions for the improvement of the current system of exploitation (Barreto *et al.,* 2009; De Oliveira *et al.,* 2008). Thus, the objective of this review is to highlight the potential of pequi (pulp and almond), more specifically the oil produced from these parts, as a source of functional compounds by presenting the differences found amongst the three more commercially-important species from the genus *Caryocar*. In addition, an attempt was made to evaluate new findings on biological activities. In each of the following sections, the information was ordered first in terms of species: *C. brasiliense*, *C. coriaceum,* and *C. villosum*, and then for data from the pulp and almond, when available.

2. NUTRITIONAL COMPOSITION

Caryocar spp. is a good source of MUFA, fiber, minerals, and bioactive compounds (Ramos and Souza, 2011; Lima *et al.,* 2007; Marx *et al*., 1997), although there is a lack of information in the literature about the macronutrient contents and minor compounds, mainly from the almonds of the species *C. coriaceum* and *C. villosum*. The contents of these components vary according to the species, environmental conditions, and type of analysis, as shown in Table 1.

Both edible parts of *C. brasiliense*, the pulp and the almond, are primarily a source of vegetable oils (Ascari *et al*., 2013; Aguilar *et al*., 2011). The *C. brasiliense* pulp contains lipids, water, carbohydrates, proteins, and minerals, along with a high fiber content (Table 1) (Macedo *et al*., 2011; Vera *et al*., 2007; Lima *et al*., 2007). Additionally, *C. brasiliense* pulp is a potential source of potassium (K) (560 mg/100 g), magnesium (Mg) (174 mg/100 g), copper (Cu) (0.9 mg/100 g), and manganese (Mn) (1.4 mg/100 g) and contains zinc (Zn) (2.5 mg/100 g), calcium (Ca) (161 mg/100 g), phosphorus (P) (162 mg/100 g), iron (Fe) (1679 mg/100 g), and nitrogen (N) (1148 mg/100 g) (data expressed on dry basis) (db) (Mariano-da-Silva *et al*., 2009).

The lipid content in the almond of *C. brasiliense* is higher (30–40%) compared to that in the pulp. In addition, the almond seems to contain more protein (80%) and minerals (80%) (Table 1) (Macedo *et al*., 2011; Lima *et al*., 2007) and is rich in Mg (452.1 mg/100 g), selenium (Se) (0.0014 mg/100 g), and Zn

TABLE 1. Nutritional composition of *Caryocar* spp. pulp and almond (expressed on wet basis)

	C. brasiliense		*C. coriaceum*		*C. villosum*	
Nutritional Composition (%)	**Pulp** [a]	**Almond** [b]	**Pulp** [c]	**Almond** [d]	**Pulp** [e]	**Almond**
Water	41.5–54.3	8.7–31.7	25.2–55.6	35.0–53.2	51.7	n.a.
Protein	3.0–3.9	20.8–25.3	2.0–3.6	23.9–33.8	3.7	n.a.
Minerals	0.5–0.6	3.0–4.0	0.6–3.2	2.3–3.4	1.1	n.a.
Carbohydrates	11.4	8.3–10.9	18.0–59.9	14.6–26.9	18.0	n.a.
Fiber	3.7–10.0	1.0–2.2	4.2–6.4	1.8–3.7	n.a.	n.a.
Lipids	18.7–33.4	32.5–51.5	23.0–38.1	34.0–55.1	25.5	n.a.
Fatty acids (% of total)*						
Linoleic (C18:2)	0.6–2.2	3.9–7.3	1.8–2.3	2.4–4.2	0.5	n.a.
Oleic (C18:1)	48.6–62.2	43.6–60.1	55.8–64.2	47.9–57.1	29.5	n.a.
Palmitic (C16:0)	32.5–46.3	28.1–43.8	31.6–34.2	35.5–44.4	33.5	n.a.
Palmitoleic (C16:1)	0.5–1.4	0.4–1.2	0.3	n.d.	0.1	n.a.
Stearic (C18:0)	0.7–3.5	1.5–3.5	1.8	4.0	0.6	n.a.

[a] (Faria-Machado *et al*., 2015; Macedo *et al*., 2011; Mariano *et al*., 2009; Garcia *et al*., 2007; Lima *et al*., 2007; Vera *et al*., 2007; Facioli and Gonçalves, 1998); [b] (Torres *et al*., 2016b; Faria-Machado *et al*., 2015; Macedo *et al*., 2011; Lima *et al*., 2007); [c] (Ramos and Souza, 2011; Saraiva *et al*., 2011a; Oliveira *et al*., 2010; Da Silva Quirino *et al*., 2009; Figueiredo *et al*., 1989); [d] (Ramos and Souza, 2011; De Oliveira *et al*., 2010; Oliveira *et al.*, 2010; Figueiredo *et al*., 1989); [e] (Chisté and Mercadante, 2012; Marx *et al*., 1997); n.a: not available; n.d: not determined; * fatty acids expressed on dry basis.

(7.4 mg/100 g) (db). The amount of Zn present in the roasted *C. brasiliense* almond is higher than that of any other almond or nut reported in the literature, reaching 67% of the dietary reference intake for adults (De Oliveira Sousa *et al*., 2011).

The pulp of *C. coriaceum* contains water, lipids, carbohydrates, protein, fiber, and minerals (Table 1) including K (140.3–460.4 mg/100 g), Mg (36.1–124.6 mg/100 g), Cu (0.2–7.2 mg/100 g), Mn (1.1–2.5 mg/100 g), Zn (0.7–2.2 mg/100 g), Ca (30.8–102.0 mg/100 g), P (17.3–83.5 mg/100 g), Fe (0.4–3.1 mg/100 g), and Na (1.2–4.7 mg/100 g) (data expressed on a wet basis) (wb) (Ramos and Souza, 2011; Oliveira *et al*., 2010). Furthermore, the *C. coriaceum* almond contains more protein (90%), minerals (30%) and lipids (30%) compared to the pulp (Table 1). The mineral contents of the almond are as follows: Ca (51.7–163.6 mg/100 g), K (374.1–965.7 mg/100 g), Mg (301.1–560.0 mg/100 g), Cu (0.5–2.9 mg/100 g), Mn (2.0–4.8 mg/100 g), Fe (0.9–3.7 mg/100 g), P (391.2–1008.4 mg/100 g), and Zn (2.3–6.0 mg/100 g) (wb) (Ramos and Souza, 2011; Oliveira *et al*., 2010).

According to Chisté and Mercadante (2012), *C. villosum* pulp contains water, lipids, carbohydrates, proteins, and ashes (Table 1). Marx *et al*. (1997) found the minerals Ca (83.0 mg/100 g), Mg (52.0 mg/100 g), P (41.0 mg/100 g), Se (0.7 mg/100 g), Fe (0.6 mg/100 g), Zn (0.5 mg/100 g), and Mn (0.3 mg/100 g) (db). No detailed descriptions were found regarding the nutritional composition of *C. villosum* almond.

Comparing the average values of the pulps of the different species presented in Table 1, *C. coriaceum* pulp has higher amounts of minerals (70%), carbohydrates (70%), and linoleic acid (30%), while *C. brasiliense* pulp appears to present more fiber (20%) and protein (18%). The *C. coriaceum* almond appears to be richer in moisture (50%), carbohydrates (50%), fiber (40%), and protein (20%) than the *C. brasiliense* almond, which appears to contain more minerals (18%) and linoleic acid (40%).

2.1. Fatty acids

The pulp and almond of the *Caryocar* species are rich in lipids, as seen in the previous section, and have a similar fatty acid (FA) composition, with a predominance of unsaturated fatty acids (UFA) (Aguilar *et al*., 2011).

The *C. brasiliense* pulp has a high content of MUFA, with oleic acid (C18:1) as the main component, followed by linoleic acid (C18:2) and palmitoleic acid (C16:1). Saturated fatty acids (SFA) are also present in high amounts, mainly in the form of palmitic acid (C16:0), followed by stearic acid (C18:0) (Mariano *et al*., 2009; Garcia *et al*., 2007; Lima *et al*., 2007; Facioli and Gonçalves, 1998). All values are presented in Table 1.

Therefore, the *C. brasiliense* almond and pulp are composed primarily of oleic and palmitic acids, with minor amounts of linoleic, stearic, myristic, palmitoleic, and linolenic acids (Torres *et al*., 2016b; Lima *et al*., 2007). According to Faria-Machado *et al*. (2015), despite similarities in the major FA, it is possible to distinguish pequi pulp oil from pequi almond oil based on the content of linoleic acid. This statement could be confirmed by the data stated in Table 1, showing that the average linoleic acid values of the almonds of both *C. brasiliense* and *C. coriaceum* are higher (70 and 38%, respectively) when compared to their respective pulps.

The fatty acid profiles of *C. coriaceum* and *C. villosum* pulps are similar to those observed for *C. brasiliense* (Saraiva *et al*., 2011a; De Oliveira *et al*., 2010; Da Silva Quirino *et al*., 2009; Marx *et al*., 1997; Figueiredo *et al*., 1989). In addition, *C. coriaceum* almonds have a similar oleic and palmitic acid-rich composition (Table 1) (De Oliveira *et al*., 2010; Figueiredo *et al*., 1989). The chemical structures of the main FAs found in pequi are shown in Figure 2.

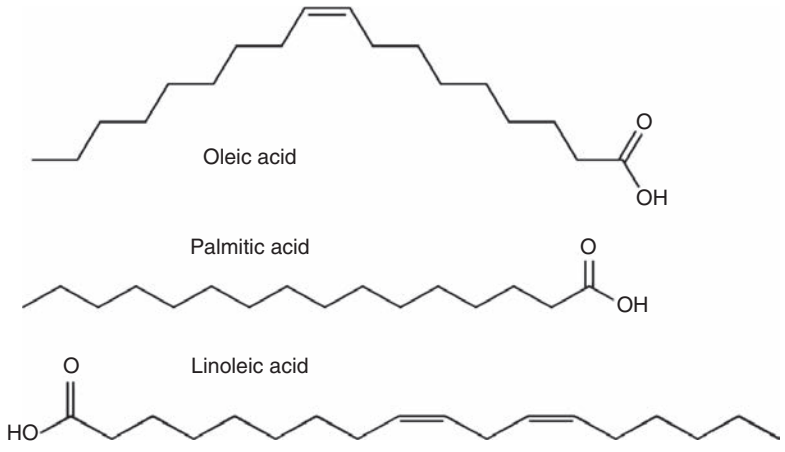

FIGURE 2. Main fatty acids present in pequi (*Caryocar* spp.) pulp and almond.

The distributions of FAs in terms of triacylglycerol (TAG) molecules have been described previously. Segall *et al*. (2006) used a mixture of pulp and almond oils (*C. brasiliense*) for the evaluation of the TAG composition by liquid chromatography-mass spectrometry (LC-MS) and found three major peaks: trioleoyl glycerol (OOO), palmitoyl dioleoyl glycerol (POO), and dipalmitoyl oleoyl glycerol (POP). Other TAGs, such as dioleoyl stearoyl glycerol (OOS), were present in small amounts. In addition, the authors report that the composition of pequi oil may have potential application in the food industry (i.e., less expensive chocolate substitute upon fractionation) and can be used without fractionation or hydrogenation for frying and cooking because of its low content of polyunsaturated fatty acids and a high content of oleic acid.

Guedes *et al.* (2017) reported that pequi oil is a source of POP, a TAG of great interest in the food industry. Its high contents of C18:1 and C16:0 is interesting for the food industry, either for cosmetic or oleochemical uses, and the TAG composition indicates its potential use as cocoa butter substitute.

3. PHYTOCHEMICAL COMPOUNDS

The literature does not provide complete information on the phytochemical composition of fruits of the *Caryocar* species, specially for the almond, as shown in Table 2. Among the compounds that have been identified in this genus, carotenoids are the most important ones (Torres *et al*., 2016b; Barreto *et al*., 2009; Lima *et al*., 2007; Marx *et al*., 1997).

3.1. Carotenoids

Several studies have identified *C. brasiliense* pulp as a source of carotenoids (Table 2), with amounts being comparable to those in papaya and guava, which are caroteinoid-rich fruits. The carotenoids β-carotene, lycopene, ζ-carotene, cryptoflavin, β-cryptoxanthin, anteraxanthin, zeaxanthin, mutatoxanthin, violaxanthin, lutein, and neoxanthin have already been identified in the fruit pulp (De Moraes Cardoso *et al*., 2013; Machado *et al*., 2013; Ribeiro *et al*., 2012; Lima *et al*., 2007; Oliveira *et al*., 2006; Azevedo-Meleiro and Rodriguez-Amaya, 2004; Ramos *et al*., 2001), see Figure 3.

Beta-carotene, the most important pro-vitamin A found in fruits, is the main carotenoid present in *C. brasiliense* pulp according to Ribeiro *et al*. (2012) and Oliveira *et al*. (2006) (25 mg/100 g oil and 6.3 to 11.4 mg/100 g pulp, respectively). The consumption of 100 g of cooked *C. brasiliense* pulp would supply 57.3 and 66.9% of the recommended dietary allowance (RDA) of vitamin A for adult men and pregnant women, respectively (De Moraes Cardoso *et al*., 2013). However, different findings were observed by Azevedo-Meleiro and Rodriguez Amaya *et al*. (2004), who reported violaxanthin, lutein, and zeaxanthin as the main carotenoids of *C. brasiliense* pulp (values not provided). On the other hand, Ramos *et al*. (2001) reported larger amounts of β–cryptoxanthin (9.4 mg/100 g) and anteraxanthin (7.9 mg/100 g) (wb) and stated that the total pro-vitamin A found in pequi pulp is rather low.

Variations in carotenoid contents can be attributed to environmental conditions during fruit production, to the state of ripeness, and to the extraction procedure, among others (De Moraes Cardoso *et al*., 2013). The contradictions regarding the pro-vitamin A content of *C. brasiliense* pulp indicate that further research is necessary to identify and quantify the amount of the carotenoids present in this fruit from different regions. It is important to mention that additional information, such as sampling methods, fruit origin, and species identification, are factors that must be considered by researchers during the planning and execution of their studies.

With respect to the *C. brasiliense* almond, Lima *et al*. (2007) showed a lower total carotenoid content

Table 2. Phytochemical compounds of *Caryocar* spp. pulp and almond

Bioactive compounds (mg/100 g)	***C. brasiliense***		***C. coriaceum***		***C. villosum***	
	Pulp	**Almond**	**Pulp**	**Almond**	**Pulp**	**Almond**
Carotenoids	8.1–23.1 (wb) [a]	0.3 (wb) [b]	n.a.	n.a.	1.7–6.9 (db) [c]	n.a.
Phenolics	209.0 (wb) [b]	122.0 (wb) [b]	n.a.	n.a.	58.9–236.2 (db) [c]	n.a.
Vitamin E	n.a.	n.a.	n.a.	n.a.	1.2 (db) [d]	n.a.
Vitamin C	6.6 (wb) [e]	n.a.	n.a.	n.a.	5.9 (wb) [f]	n.a.
Phytosterols	n.a.	73.4–96.5 [g,*]	n.a.	n.a.	580.0 (db) [h]	n.a.

[a] (De Moraes Cardoso *et al*., 2013; Ramos *et al*., 2001); [b] (Lima *et al*., 2007); [c] (Almeida *et al*., 2012; Chisté and Mercadante, 2012); [d] (Almeida *et al*., 2012); [e] (Machado *et al*., 2013); [f] (Barreto *et al*., 2009); [g] (Torres *et al*., 2016b); [h] (Marx *et al*., 1997); [*] values found for almond oil; n.a.: not available; wb: wet basis; db: dry basis.

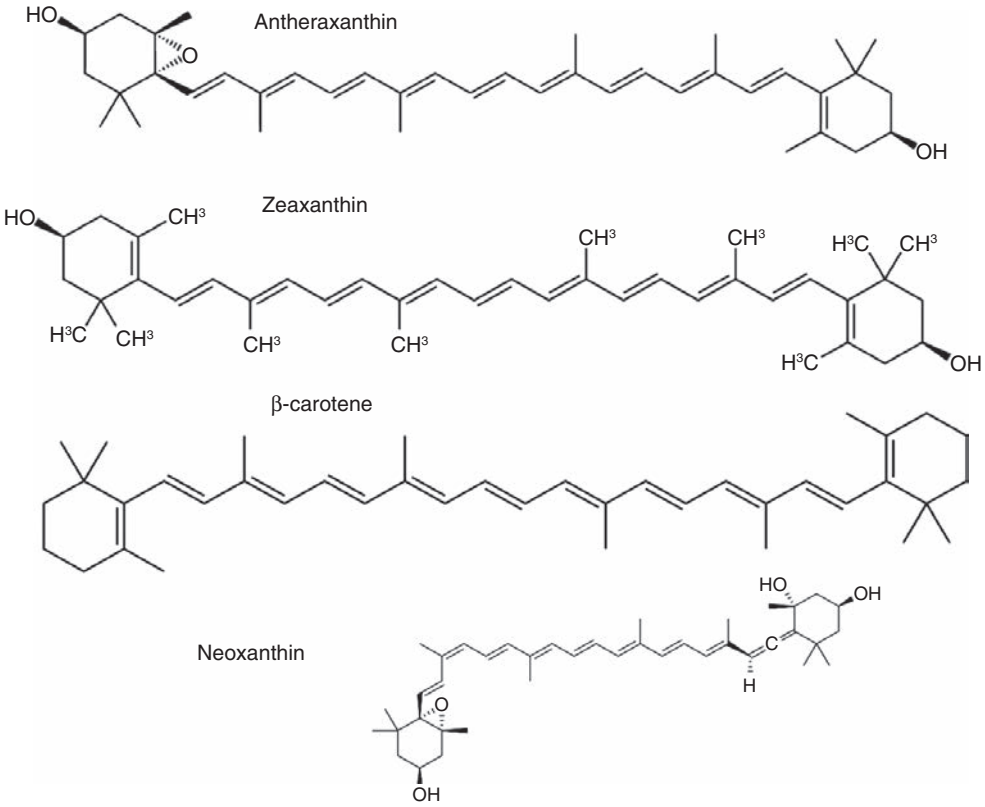

FIGURE 3. Example of most important carotenoids present in *Caryocar spp.* pulp.

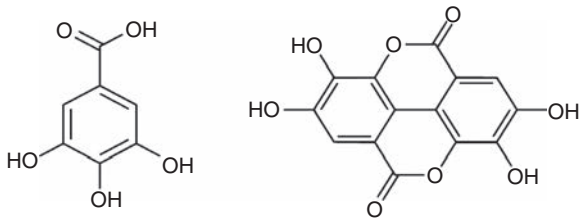

FIGURE 4. Main phenolics found in the pulp of *Caryocar* spp.

when compared to the pulp (Table 2). This result was in agreement with Torres *et al*. (2016b) for *C. brasiliense* almond oil (up to 0.3 mg/100 g).

No descriptions were found regarding the carotenoid composition of the *in natura C. coriaceum* pulp or almond. However, Souza *et al*. (2013) found carotenoid values of 0.3 mg/100 g pulp (wb) for *C. coriaceum* pulp cut into slices and packaged under vacuum.

Several studies have shown the presence of carotenoid in *C. villosum* pulp, as presented in Table 2. (Almeida *et al*., 2013; Almeida *et al*., 2012; Chisté *et al*., 2012; Chisté and Mercadante, 2012; Barreto *et al*., 2009). Chisté and Mercadante, (2012) reported that the main identified carotenoids in *C. villosum* pulp were all-trans-antheraxanthin (3.4 mg/100 g pulp), followed by all-trans-zeaxanthin (2.9 mg/100 g pulp) and the lutein-like carotenoid (2.8 mg/100 g pulp) (db). Antheraxanthin and zeaxanthin were the major carotenoids identified in *C. villosum* pulp by Almeida *et al*. (2012), corresponding to 24 and 19% (db) of the total carotenoid content, respectively.

3.2. Phenolics

Regarding the total phenolic compounds in *C. brasiliense*, the levels were higher in the pulp than in the almond (Lima *et al*., 2007) (Table 2). Besides that, the almond oil, according to Torres *et al*. (2016b), contains higher values (up to 392.0 mg gallic acid equivalents (GAE) per 100 g of oil).

The phenolic composition of the *in natura C. coriaceum* pulp and almond is not described in the scientific literature, but Souza *et al*. (2013) found 69.6 mg/100 g pulp (wb) of phenolic compounds in *C. coriaceum* pulp cut into slices and packaged in vacuum-sealed bags.

Chisté and Mercadante (2012) and Almeida *et al.* (2012) found 58.9 and 236.2 mg/100 g pulp (db) of phenolics, respectively, in *C. villosum* pulp (Table 2). Characterization of the phenolic compounds in *C. villosum* pulp showed gallic and ellagic acids as the main ones (Figure 4) (Yamaguchi *et al*., 2017; Almeida *et al*., 2013; Almeida *et al*., 2012; Chisté

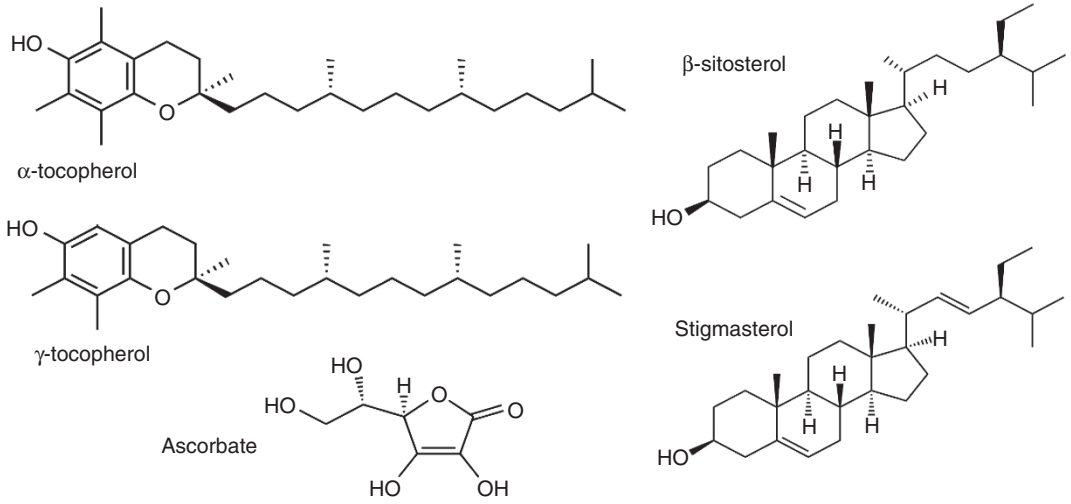

FIGURE 5. Ascorbic acid, the main tocopherols, and phytosterols found in the *Caryocar* spp.

et al., 2012; Chisté and Mercadante, 2012), with values of 73.2 and 40.1 mg/100 g pulp (db), respectively, corresponding to 31 and 17% of the total amount of phenolic acids (Almeida *et al*., 2012).

3.3. Vitamin E

Studies determining vitamin E levels in *Caryocar* spp. are scarce. De Morais Cardoso *et al*. (2013) found vitamin E in cooked *C. brasiliense* pulp (0.2 mg/100 g pulp) (wb), with values being higher than that found in banana but lower than for kiwi and avocado, which are high in vitamin E. The isomers identified by these authors were α-tocopherol (0.06 mg/100 g), α-tocotrienol (0.05 mg/100 g), γ-tocopherol (0.04 mg/100 g), and γ-tocotrienol (0.02 mg/100 g).

Previous investigations revealed the presence of tocopherols in *C. brasiliense* almond oil (13.3 to 19.2 mg/100 g oil), with α-tocopherol and γ-tocopherol accounting for 67 and 48% of the total tocopherols, respectively (Torres *et al*., 2016b) (Figure 5).

According to Almeida *et al*. (2012), *C. villosum* pulp contains 1.2 mg tocopherols/100 g pulp (db) (Table 2), with α-tocopherol accounting for 100%.

3.4. Vitamin C and phytosterols

According to Machado *et al*. (2013) and Barreto *et al*. (2009), *C. brasiliense* and *C. villosum* pulps have a vitamin C (ascorbic acid or ascorbate) content of 6.6 and 5.9 mg ascorbic acid/100 g (wb), respectively (Table 2). However, cooked *C. brasiliense* pulp presented a vitamin C content greater than that found in the fresh pulp of pequi (14.3 mg/100 g) (wb) (De Moraes Cardoso *et al*., 2013). The authors suggest that the differences may be related to fruit origin.

Caryocar brasiliense almond oil has up to 96.5 mg phytosterols/100 g (Table 2), which is within the range of most oils (100 to 500 mg/100 g) (Torres *et al*., 2016b; Gunstone and Padley, 1997). The main phytosterols found in this oil were stigmasterol (48.2–65.3 mg/100 g), β-sitosterol (20.5–27.9 mg/100 g), and campesterol (4.8–3.8 mg/100 g) (Torres *et al*., 2016b) (Figure 5).

According to Marx *et al*. (1997), the total phytosterol content in *C. villosum* pulp is 580 mg/100 g pulp (db) (Table 2), with 7, 25-stigmastadienol (195.7 mg/100 g), β-sitosterol (129.7 mg/100 g), stigmasterol (80.2 mg/100 g), and squalene (63.8 mg/100 g) being the main compounds.

Based on these findings, pequi fruits have considerable amounts of nutrients and bioactive compounds that are associated with protection in many biochemical processes underlying the development of diseases. Therefore, this review also focusses on studies that have shown the main biological effects of these compounds after fruit intake.

4. BIOLOGICAL EFFECTS OF *CARYOCAR* FRUIT CONSUMPTION

Scientific evidence for popular knowledge refers to several healthy effects of the consumption of fruits of the *Caryocar* spp. Commonly, *C. brasiliense* fruits are used to treat several diseases, including tumors, several respiratory diseases, and ophthalmic problems (Miranda-Vilela *et al*., 2014; Miranda-Vilela *et al*., 2008), while fruits of *C. coriaceum* are popularly used to treat many types of afflictions, such as wound lesions, gastric and inflammatory diseases, respiratory tract infections, muscle pain, and chronic arthritis (Costa *et al*., 2011; Da Silva Quirino *et al*., 2009). As stated earlier, most of these

TABLE 3. Studies on the biological effects of *Caryocar* spp.

Biological effects	Sample Specification	Treatment	Experimental model	Reference
C. brasiliense				
Antitumor	*C. brasiliense* pulp oil extracted by cold maceration and chloroform (Brasilia, Central-West region)	30 mg/day for 10 days before tumor induction	Swiss mice, Ehrlich solid tumor	Miranda-Vilela *et al.*, 2011
Antitumor **↑ Lymphocyte-dependent immunity** **↓ Adverse side effects associated with doxorubicin**	*C. brasiliense* pulp oil extracted by cold maceration and chloroform (Brasilia, Central-West region)	30 mg/day for 10 days before tumor induction or continuous (10 days before and 15 days after), orally	Swiss mice, Ehrlich solid tumor, doxorubicin	Miranda-Vilela *et al.*, 2014
Antitumor **Lymphocyte-dependent immunity**	*C. brasiliense* pulp oil extracted by cold maceration and chloroform (Brasilia, Central-West region)	30 mg/day for 10 days, orally before tumor induction plus intratumoral injection of dextran-functionalized magnetic fluid and exposure to a current magnetic field for three days	Swiss mice, Ehrlich solid tumor	Miranda-Vilela *et al.*, 2013
Hepatoprotective **Anticancer**	*C. brasiliense* pulp oil extracted by pressing (Brasilia, Central-West region)	100–400 mg/day for 25 weeks after administration of diethylnitrosamine, orally	BALB/C mice, diethylnitrosamine-induced carcinogenesis	Palmeira *et al.*, 2016
Antigenotoxic	*C. brasiliense* pulp oil or pulp extracted with ethanol (Brasilia, Central-West region)	30 mg/day of oil or 15 mL of extract for 60 days after administration of urethane, orally	BALB/C mice, urethane-induced lung carcinogenesis	Colombo *et al.*, 2015
Anticlastogenic **Antiproliferative**	*C. brasiliense* pulp extracted with water (Brasilia, Central-West region)	1 mL/kg/bw for 10 days before administration of bleomycin or cyclophosphamide, orally	Swiss mice, bleomycin or cyclophosphamide *In vitro* CHO-K1 chromosome aberration assay	Khrouri *et al.*, 2007
Antigenotoxic	*C. brasiliense* pulp extracted with water or chloroform (Brasilia, Central-West region)	0.5–1 mL/kg/bw for 10 days before administration of bleomycin or cyclophosphamide, orally	Swiss mice, bleomycin or cyclophosphamide	Miranda-Vilela *et al.*, 2008
Genotoxic	*C. brasiliense* pulp extracted with water (Brasilia, Central-West region)	5 mL of extract at 1–10%	*Drosophila melanogaster,* SMART	Castro *et al.*, 2008
↓ AST and ALT **↓ DNA damage** **↓ Lipid peroxidation**	*C. brasiliense* pulp oil extracted by cold maceration and chloroform (Brasilia, Central-West region)	400 mg/day by 14 days	Runners, Comet assay, TBARS	Miranda-Vilela *et al.*, 2009a
Improving anisocytosis **↑ Blood oxygen-carrying capacity**	*C. brasiliense* pulp oil extracted by cold maceration and chloroform (Brasilia, Central-West region)	400 mg/day by 14 days	Runners	Miranda-Vilela *et al.*, 2010
Anti-inflammatory **↓ Serum TC and LDL** **↓ Arterial pressure**	*C. brasiliense* pulp oil extracted by cold maceration and chloroform (Brasilia, Central-West region)	400 mg/day by 14 days	Trained runners	Miranda-Vilela *et al.*, 2009b
Anti-inflammatory **Antioxidant**	*C. brasiliense* pulp oil handmade or cold-pressed extraction (western part of Minas Gerais state)	3 mL–6 mL/kg/bw for 21 days before induction	*Wistar* rats, CCl_4-induced	Torres *et al.*, 2016a
Antibacterial **Antioxidant** **Cytotoxic**	*C. brasiliense* pulp oil commercially purchased obtained by cooking in water (western part of Minas Gerais state)	10 mg/mL 0.05 – 50 mg/mL	*Artemia nauplii* test *In vitro* DPPH	Ferreira *et al.*, 2011

Continued

TABLE 3. *(Continued)*

Biological effects	Sample Specification	Treatment	Experimental model	Reference
↑ Total lipids (liver) ↓ Serum TAG and TC ↓ TBARS and oxLDL and ROS by macrophages ↑ Lesions in aorta ↑ Lesions in aorta root	*C. brasiliense* oil (undefined) commercially purchased incorporated in diet (western part of Minas Gerais state)	7% diet of oil over six weeks	$LDLr^{-/-}$, isogenic (C57BL/6 background) knockout mice fed with cholesterol (1.25%)	Aguilar *et al*., 2012
↑ Cardiac function ↓ liver TAG	*C. brasiliense* oil (undefined) commercially purchased and incorporated in diet (western part of Minas Gerais state)	Addition of 50% (2.2 g/100 g) in the lipid chow content of the diet over 15 weeks, orally	*Wistar* rats	Oliveira *et al*., 2017
Antioxidant ↓ liver TAG and TC ↑ fecal TAG ↑ intestinal structure	Pulp extracted with different solvents *C. brasiliense* pulp incorporated in diet (western part of Minas Gerais state)	Addition of 50% (3.3 g/100 g) in the lipid chow content of the diet over 15 weeks, orally	*In vitro* DPPH and FRAP *Wistar* rats	Moreno *et al*., 2016
↑ serum HDL ↓ liver lipids	*C. brasiliense* pulp incorporated in diet (western part of Minas Gerais state)	Addition in diet of 10% of lard plus pequi pulp (400 or 600 mg/25 g of diet) over four weeks, orally	*Wistar* rats, high fat diet	Teixeira *et al*., 2013
↑ Serum HDL ↑ TAG liver	*C. brasiliense* pulp or almond incorporated in diet (western part of Minas Gerais state)	33% diet of pequi almond or pulp over six weeks	Swiss mice	Aguilar *et al*., 2011
Antioxidant	*C. brasiliense* almond or pulp extracted with ethanol (Goiás, Central-West region)	1–50 mg/mL	*In vitro* TBARS	Roesler *et al*., 2008
Antioxidant	*C. brasiliense* almond + pulp extracted with water or ethanol (Goiás, Central-West region)	1–2,000 mg/mL	*In vitro* DPPH	Roesler *et al*., 2007
Antifungal	*C. brasiliense* almond oil commercially purchased or leaf extracts (western part of Minas Gerais and Goiás - Central-West region)	15.6–1,000 mL/mL	Agar diffusion method	Passos *et al*., 2002
Antifungal	*C. brasiliense* almond or leaf essential oils (western part of Minas Gerais and Goiás - Central-West region)	62.5–1,000 mL/mL	Agar diffusion method	Passos *et al*., 2003
C. coriaceum				
Anti-inflammatory	*C. coriaceum* pulp oil extracted with ethyl acetate and Soxhlet (Ceará, Northeast region)	8–13 mg/ear, topical	Swiss mice, ear edema croton oil-, arachidonic acid- or phenol-induced	Saraiva *et al*., 2011b
Anti-inflammatory	*C. coriaceum* pulp oil extracted with ethyl acetate and Soxhlet (Ceará, Northeast Region)	100–400 mg/kg over seven days, orally	*Wistar* rats, acute arthritis in knees zymosan-induced	De Oliveira *et al*., 2015
↓ Serum TAG and TC ↑ Serum HDL Hypolipemic Anti-inflammatory	*C. coriaceum* pulp oil obtained by cooking in water (Ceará, Northeast region)	500-2,000 mg/kg/bw over 7, 15, or 30 days, orally 500–1,000 mg/kg/bw over 15 days before administration of Tyloxapol, orally 500-2,000 mg/kg/bw over 7, 15, or 30 days, orally	*Wistar* Rats *Wistar* Rats, dyslipidemia induced by Tyloxapol *Wistar* Rats, Carrageenan-induced paw edema	Figueiredo *et al*., 2016
Healing potential Gastroprotection	*C. coriaceum* pulp oil extracted with hexane and Soxhlet (Ceará, Northeast region)	200–400 mg/kg before ethanol induction, orally	Swiss mice, gastric damage induced by ethanol or aspirin	Da Silva Quirino *et al*., 2009
Anti-inflammatory	*C. coriaceum* almond oil commercially purchased (Ceará, Northeast region)	50 mL (6–100% in 0.9% NaCl), topical	Swiss mice, ear edema xylene-induced	De Oliveira *et al*., 2010

Continued

TABLE 3. *(Continued)*

Biological effects	Sample Specification	Treatment	Experimental model	Reference
Antibacterial	*C. coriaceum* pulp oil extracted with hexane and Soxhlet (Ceará, Northeast region)	20 mL of oil solution at 1.2–10%	Agar diffusion method	Costa *et al*., 2011
Antibacterial	*C. coriaceum* pulp oil extracted with ethyl acetate and Soxhlet (Ceará, Northeast region)	32 mg/mL oil with or without aminoglycosides	Microdilution assay	Saraiva *et al*., 2011a
C. villosum				
Antigenotoxic	*C. villosum* pulp (Pará, Amazon Region)	75–300 mg/kg/bw over 14 days before administration of doxorubicin, orally	*Wistar* rats, doxorubicin	Almeida *et al*., 2012
Cytotoxic	*C. villosum* pulp extracted with methanol (Guyana, Amazon region)	10–1,000 mg/mL	*Artemia salina* test	Alabdul Magid *et al*., 2006
Antioxidant	*C. villosum* pulp extracted with methanol/water (Manaus, Amazon region and Ceará, Northeast region)	1 mL of extract	*In vitro* TEAC	Barreto *et al*., 2009
Antioxidant	*C. villosum* pulp extracted with water, ethanol or ethyl acetate (Pará, Amazon region)	Up to 833 mg/mL	*In vitro* ROS and RNS-scavenging assays	Chisté *et al*., 2012
Anti-inflammatory **Cytotoxicity** **Antioxidant**	*C. villosum* pulp extracted with ethanol and ethanol:water (Amazonas, Amazon region)	6.2–50 µg/mL 0.8–50 µg/mL 1–100 mg/mL	$NO^{\bullet}$ production in J774 cells Tumor strains test *In vitro* ABTS, DPPH and ROS assay	Yamaguchi *et al*., 2017
Anti-edematogenic **Anti-inflammatory**	*C. villosum* pulp oil extracted with hexane and Soxhlet (Amapá, Amazon Region)	531 mg/kg, topical 100–500 mg/kg over six days, topical	Carrageenan-induced paw edema *Wistar* rats, granuloma assay	Xavier *et al*., 2011

TC: total cholesterol; LDL: low density lipoprotein; HDL: high density lipoprotein; TAG: triacylglycerols; SMART: Somatic mutation and recombination test; TBARS: thiobarbituric acid reactive substances; CCl_4: carbon tetrachloride; oxLDL: oxidized LDL; ROS: reactive oxygen species; DPPH: 2,2-diphenyl-1-picrylhydrazyl; FRAP: ferric reducing antioxidant power; ALT: alanine aminotransferase; AST: aspartate aminotransferase; DNA: deoxyribonucleic acid; TEAC: trolox equivalent antioxidant capacity; RNS: reactive nitrogen species; ABTS: 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulphonic acid); NaCl: sodium chloride; $NO^{\bullet}$: nitric oxide; bw: body weight.

effects are attributed to the oil that is extracted from the pulp of the *Caryocar* spp. due to the fact that it is routinely used for therapeutic purposes, but some studies have also reported positive effects of both the pulp and the almond (Aguilar *et al*., 2011; Roesler, *et al*., 2007) (Table 3).

4.1. Anticancer activity

Evidence suggests that cancer cells are under increased oxidative stress compared with normal cells, and this is associated with oncogene-induced transformation, increased metabolic activity, mitochondrial malfunction, and increased generation of reactive oxygen species (ROS) (Miranda-Vilela *et al*., 2014). Many cancer-chemopreventive agents possess antioxidant potential, and biological antioxidants contain bioactive phytochemicals that may play a vital role in protecting cells from oxidative stress (Miranda-Vilela *et al*., 2011). Animal studies have demonstrated that the administration of pequi could improve the antioxidant system and consequently decrease the advance of carcinogenesis (Miranda-Vilela *et al*., 2014; Almeida *et al*., 2012; Miranda-Vilela *et al*., 2011).

Previous results for Ehrlich solid tumor-bearing mice demonstrated that the administrations of *C. brasiliense* pulp oil before tumor inoculation or in continuous and concurrent administration with doxorubicin (DXR, an antitumor agent) were effective in inhibiting tumor growth and in increasing lymphocyte-dependent immunity, thereby reducing the adverse side effects associated with DXR-induced oxidative damage to normal cells (Table 3). This indicates that at least for DXR, pequi pulp oil instead of the vitamins C and E would be a relevant

option to reduce its adverse effects (Miranda-Vilela *et al*., 2014; Miranda-Vilela *et al*., 2011).

Miranda-Vilela *et al*. (2013) stated that the preventive use of *C. brasiliense* pulp oil could increase the efficiency of magnetic hyperthermia therapies mediated by dextran-coated maghemite nanoparticles in cancer treatment. The authors showed effective action of the oil against the advance of the carcinogenesis process after the second week, acting to control tumor growth and promoting lymphocyte-dependent immunity.

Palmeira *et al*. (2016) showed that *C. brasiliense* pulp oil exerts a hepatoprotective effect against the diethylnitrosamine-induced development of preneoplastic lesions and adenoma in BALB/C mice. The total volume of lesions and adenomas was reduced by 51% in the group treated with the carcinogen and pequi oil. In addition, some mice supplemented with the oil did not develop lesions, demonstrating the potential of this oil for the prevention of liver cancer.

In another study, *C. brasiliense* pulp oil and an ethanolic extract of the pulp affected urethane-induced lung cancer in BALB/C mice and restored urethane-mediated conformational changes of deoxyribonucleic acid (DNA), suggesting that pequi may modify the carcinogenic process either by blocking the development of early lesions or by inhibiting the progression to invasive cancer (Colombo *et al*., 2015).

Khouri *et al*. (2007) and Miranda-Vilela *et al*. (2008) suggested that *C. brasiliense* pulp, as chloroform or aqueous extract, has anticlastogenic and antimutagenic potentials, being able to inhibit cyclophosphamide (CP)- and bleomycin (BLM)-induced DNA damage in mice. They also demonstrated antiproliferative activity when tested *in vitro* in hamster cells, possibly due to its antioxidative properties (Khouri *et al*., 2007). On the other hand, Castro *et al*. (2008), using somatic mutation and recombination test (SMART) with *Drosophila melanogaster*, found a genotoxicity attributed to *C. brasiliense* pulp aqueous extract which was attributed to the higher extract concentrations (1, 5, and 10%), with elevated contents of phytochemicals acting as prooxidants on the DNA of exposed larvae.

The findings from Almeida *et al*. (2012) suggest that *C. villosum* pulp has protective effects against DXR-induced DNA damage in rats. The results demonstrated that the pulp was not genotoxic and inhibited the genotoxicity induced by DXR.

Although the exact mechanism of the anti-carcinogenic action of pequi has not been thoroughly elucidated, it is suggested that the effects are caused by the presence of bioactive compounds. When combined, these compounds can act as preventive agents in cancer, scavenging free radicals, improving the antioxidant defense system, and increasing the activities and expression of antioxidant enzymes at the protein and genomic level, thus reducing oxidative stress and its consequences. Therefore, further investigations are required to elucidate the role of each active constituent of pequi to determine the molecular mechanisms involved and to develop targeted therapies for cancer treatment (Colombo *et al*., 2015; Miranda-Vilela *et al*., 2014; Almeida *et al*., 2012; Miranda-Vilela *et al*., 2011; Khouri *et al*., 2007).

4.2. Anti-inflammatory activity

Inflammation is a key component of the immune response to certain tissue injuries. This response occurs as an attempt to neutralize and/or eliminate the source of this injury, restoring tissue function. A change in the magnitude, control or duration of the inflammatory response can cause major tissue damage and contribute to the emergence of diseases (Shinagawa *et al*., 2015).

Miranda-Vilela *et al*. (2009b) reported that *C. brasiliense* pulp oil produced anti-inflammatory effects in athlete runners who were supplemented with 400 mg of oil after races for 14 days, which led to a higher reduction in the values of high-sensitivity C-reactive protein (hs-CRP), an acute-phase reactant and a sign of inflammation, implying that inflammation decreased. These findings are in agreement with those found using *C. brasiliense* almond oil, in which there was a decrease in inflammation in the serum and hepatic tissue of rats induced by carbon tetrachloride (CCl_4) (Torres *et al*., 2016a).

Currently, most studies on *C. coriaceum* deal with its anti-inflammatory activity, gastroprotective effects, and topical wound-healing properties (Saraiva *et al*., 2011b; Batista *et al*., 2010; De Oliveira *et al*., 2010; Da Silva Quirino *et al*., 2009; Saraiva *et al*., 2008). Saraiva *et al*. (2011b), for example, demonstrated the topical anti-edematous effects of *C. coriaceum* pulp oil in mouse ear edema induced by different agents (croton oil, arachidonic acid (AA), and phenol). This oil exhibited a similar profile of topical anti-inflammatory activity as the drugs that classically modulate the production of AA metabolites and significantly reduced or inhibited the edema when compared to the control group. Consistent with these results, De Oliveira *et al*. (2015) found that *C. coriaceum* pulp oil had anti-nociceptive and anti-inflammatory effects in a model of acute arthritis induced by zymosan in rat knees, suggesting its possible application in the treatment of inflammatory joint diseases.

Da Silva Quirino *et al*. (2009) showed that *C. coriaceum* pulp oil reduced gastric damage induced by ethanol, at least in part, by mechanisms that involve α2-receptors, endogenous prostaglandins, nitric oxide ($NO^{\bullet}$), and ATP-sensitive potassium (K^{+}-ATP) channels.

Similarly, *C. villosum* pulp oil was also related to both the observed topical anti-inflammatory activity and a reduction in granulomatous tissue formation (Xavier *et al*., 2011). In another study, the anti-inflammatory activity observed by the inhibition of $NO^{\bullet}$ production, cytotoxicity in tumor strains, and antioxidant activity (ABTS: 2,2'-azino-bis (3-ethylbenzothiazoline-6-sulphonic acid), DPPH: 2,2-diphenyl-1-picrylhydrazyl and ROS assays) were also observed for shell, pulp, and seed extracts of *C. villosum* (Yamaguchi *et al*., 2017).

The exact mechanism of anti-inflammatory action is still subject of debate; however, these effects may correlate with the properties of carotenoids and FA, such as oleic acid, present in the *Caryocar* spp., probably by reducing the concentration and expression of inflammatory mediators at protein and genomic levels via the production of anti-inflammatory eicosanoids, inhibition of cyclooxygenase (COX) and lipoxygenase (LOX) enzymes, or by the improvement of the antioxidant defense system (Yamaguchi *et al*., 2017; Torres *et al*., 2016a; De Oliveira *et al*., 2015; Saraiva *et al*., 2011b; De Oliveira *et al*., 2010; Miranda-Vilela *et al*., 2009b; Da Silva Quirino *et al*., 2009).

4.3. Effects on lipid profile and cardiovascular diseases

The oleic acid-rich FA composition of the *Caryocar* spp. provides nutritional value, since oleic acid consumption is related to a decrease in low density lipoprotein (LDL) and the maintenance of HDL cholesterol (high-density lipoprotein) levels in humans and animals and, consequently, a reduction in coronary disease risk (Ramadan *et al*., 2012; Katan *et al.,* 1994). However, palmitic acid, a SFA, is also found in large amounts in *Caryocar* spp., whose pro-atherogenic and cytotoxic effects are well known (Moreno *et al*., 2016; Aguilar *et al*., 2012). Because of this, the challenge of researchers is to evaluate whether the proportion of the cardiovascular protection compounds present in pequi is adequate to neutralize the effects of SFA on blood lipids.

In a recent study on rats, Oliveira *et al.* (2017) indicated that *C. brasiliense* oil (type undefined) was able to reduce hepatic TAG by activating catabolic pathways and increasing fat oxidation. In addition, there was an increase in the *ex vivo* cardiac function via increasing cardiac relaxation and contractility. The reduced heart rate and the increased SERCA2a/PLB (cardiac sarcoplasmic reticulum Ca_2 + −ATPase isoform 2/ phospholanban) ratio in the pequi oil group were important changes that can explain this effect.

Teixeira *et al*. (2013) found a higher concentration of serum HDL and lower contents of total lipids in the livers of rats fed with a high-fat diet supplemented with *C. brasiliense* pulp. Moreno *et al*. (2016) indicated that pequi pulp intake (15 weeks) by rats minimized liver fat deposition by increasing fecal outputs and improving the intestinal structure, which could account for a reduction in the cardiometabolic risk in rats. Other *in vivo* studies carried out in human athletes (runners) detected a general tendency for total cholesterol (TC) and LDL to decrease over age, mainly for men, after *C. brasiliense* pulp oil intake (Miranda-Vilela *et al*., 2009a).

Aguilar *et al*. (2012) found that risk factors for atherosclerosis, such as oxidized LDL (oxLDL), oxidative stress, and macrophage liberation of free radicals, were reduced in mice receiving a cholesterol-rich diet supplemented with 7% *C. brasiliense* (undefined) oil, suggesting that pequi oil confers an important antioxidant effect, thereby reducing oxidative stress, including oxLDL antibodies. Moreover, pequi oil reduced atherosclerotic lesions in the aorta, which is a more relevant atherosclerotic site for humans than the aortic valve. However, these authors paradoxically found a poorer serum lipid profile (increase in total and non-HDL cholesterol), lesions in the aortic root, and higher concentrations of total lipids in the animals' livers.

Aguilar *et al*. (2011) evaluated the effects of a diet containing either *C. brasiliense* pulp or almond on the lipid profile and hepatic histology of healthy mice. The results demonstrated that the consumption of a pequi pulp- or almond-supplemented diet could increase serum HDL without changing the serum atherogenic fraction. However, accumulation of TAG in the liver was also caused by the higher fat intake associated with the pequi diets. The results reported by Aguilar *et al*. (2011; 2012) showed that the contradictory effects of *Caryocar* spp. on the lipid profile might be due to an experimental bias; i.e., the amount consumed was not sufficient to evaluate the outcome.

Figueiredo *et al*. (2016) evaluated the effects of *C. coriaceum* pulp oil on the lipid profile of healthy mice, on dyslipidemia induced by tyloxapol, and on its anti-inflammatory effects both *in vivo* and *in vitro*. The results revealed significant reductions in TC and TAG and an increase in HDL levels. In addition, the authors noted that paw edema (induced by carrageenan) and myeloperoxidase activity (in polymorphonuclear culture cells from human blood) were reduced at all dose levels.

In general, the majority of *Caryocar* spp. effects were related to improvements in the lipid profile and in cardiovascular risk factors in rats and humans, such as the reductions in hepatic and serum lipids and in oxidative stress, a key factor in the genesis of atherosclerosis. The researchers proposed that MUFA and/or carotenoids would increase fat oxidation rates by increasing fecal

outputs and improving the intestinal structure, by inhibiting the 3-hydroxy-3-methyl-glutaryl (HMG)-CoA reductase, a cholesterol biosynthesis limiting enzyme, or by activating the LPL (lipoprotein lipase), an enzyme related to very low-density lipoprotein (VLDL) triglyceride hydrolysis (Figueiredo *et al*., 2016; Moreno *et al*., 2016; Aguilar *et al*., 2012; Aguilar *et al*., 2011). Taken together, these findings suggest that further studies should be conducted on the cardiovascular effects of *Caryocar* spp.

4.4. Antibacterial and antifungal effects

Bacteriostatic effects of pequi oil have been reported in some studies. The *C. brasiliense* pulp oil displayed antibacterial activity against *Pseudomonas aeruginosa* (Ferreira *et al*., 2011), while *C. coriaceum* pulp oil showed, *in vitro* assays, activity such as a growth inhibitor for *Salmonella choleraesuis, Staphylococcus aureus*, and *Escherichia coli* (Costa *et al*., 2011; Saraiva *et al*., 2011a). Saraiva *et al*. (2011a) showed a significant synergistic antibiotic effect of pequi oil when combined with aminoglycosides (class of clinically important antibiotics).

An antifungal activity of the essential and fixed oil of *C. brasiliense* almonds has been reported by Passos *et al*. (2003) and Passos *et al*. (2002), respectively, against *Cryptococcus neoformans* and *Paracoccidioides brasiliensis*.

Alabdul Magid *et al*. (2006) evaluated the methanolic extract of the pulp of the *C. villosum* fruit for toxicity in a brine shrimp (*Artemia salina*) assay. The samples showed good larvicidal activity, and the results suggested that the toxicity of the *C. villosum* fruit was due to the presence of saponins; this study revealed the potential pesticidal and antitumor actions of the fruit.

4.5. Other biological effects of pequi

The pulp of *C. brasiliense* contributes to the improvement of both exercise-induced anisocytosis in athletes (runners) and the oxygen-carrying capacity of the blood. The best results with pequi pulp oil were achieved in subjects carrying the manganese superoxide dismutase (MnSOD) Val/Val genotype, catalase (CAT) AA, or CAT AT genotypes and Glutathione peroxidase (GPX)1 proalelle (Miranda-Vilela *et al*., 2010). The oil was also efficient in reducing tissue injuries evaluated for aspartate aminotransferase (AST) and alanine aminotransferase (ALT) and in reducing lipid peroxidation and DNA damage in athletes (runners), suggesting protective effects of pequi pulp oil against exercise-induced oxidative stress and damage (Miranda-Vilela *et al*., 2009a). Miranda-Vilela *et al*. (2009b) also suggested that pequi pulp oil can have a possible hypotensive effect in athletes (runners); however, this presumption requires further investigation.

Roesler *et al*. (2007) demonstrated the scavenging activity of aqueous and ethanolic extracts of *C. brasiliense* against the free radical DPPH, and Roesler *et al*. (2008) reported an antioxidant activity of the ethanolic extract (pulp plus almond), using an *in vitro* model of lipid peroxidation in rat liver microsomes. Ferreira *et al*. (2011) demonstrated an antioxidant activity for *C. brasiliense* pulp oil by the DPPH assay (half maximal inhibitory concentration - IC_{50} -15.5 mg/mL). However, the same authors found cytotoxicity for pequi oil, with an oral lethal dose (LD_{50}) of 827.6 µg/mL, in comparison to oils of buriti (*Mauritia flexuosa*), babaçu (*Attalea* spp.), and passion fruit, suggesting that pequi oil should be used carefully.

Traesel *et al*. (2016) showed low toxicity in acute and sub-chronic tests with *C. brasiliense* pulp oil in rats that received, orally and respectively, a single dose of 2,000 mg/kg/body weight (bw) of oil (14 days) or repeated doses of 125, 250, 500, or 1,000 mg/kg/bw of the oil (28 days). The LD_{50} was established as greater than 2,000 mg/kg/bw. In addition, the oil did not elicit systemic toxicity after subchronic exposure; nevertheless, some hematological abnormalities were found. Although these values are within the normal range for the species, a more detailed study is necessary to investigate whether the pequi can affect the circulation or production of blood cells.

In another study, *C. villosum* pulp showed high antioxidant activity, as measured in a trolox equivalent antioxidant capacity (TEAC) assay, and a high *in vitro* scavenging capacity against ROS and reactive nitrogen species (RNS), which were closely related to the phenolic compound content (Chisté *et al*., 2012; Barreto *et al*., 2009).

5. CONCLUSIONS

The pequi fruit, regardless of the species, is high in nutrients and extremely important to the population groups that consume it as food or for therapeutic purposes. The edible parts of *Caryocar* spp. fruits (pulp and almond) are good sources of oleic acid, minerals, and bioactive compounds such as carotenoids and polyphenolic compounds, which present significant health-promoting properties.

The fruits show anticancer and antimicrobial activity, effects against inflammatory diseases, and positive impacts on the cardiovascular system, amongst others; the health-promoting benefits are mainly attributed to the oil. The exact mechanisms of action are still under debate and need further studies; however, these effects of pequi may be explained by the presence of MUFA, mainly oleic acid, and of bioactive compounds, which

are capable, for example, of stimulating angiogenesis for the production of anti-inflammatory eicosanoids, inhibiting COX and LOX enzymes. They also increase fat oxidation and fecal output and inhibit HMG-CoA reductase or activate LPL, contributing to the improvement of the lipid and the cardiovascular profiles. Its effects also cover an improvement in the antioxidant defense system due to the phytochemicals present in the fruit, increasing the activities and expression of antioxidant enzymes and reducing oxidative stress (Yamaguchi *et al*., 2017; De Oliveira *et al*., 2015; Miranda-Vilela *et al*., 2014; Almeida *et al*., 2012; Miranda-Vilela *et al*., 2011; Saraiva *et al*., 2011b; De Oliveira *et al*., 2010; Da Silva Quirino *et al*., 2009).

The pequi fruit has relevance in nutritional applications and could be a promising source of effective ingredients for nutraceutical and pharmaceutical manufacturers, expanding the commercialization of these underrated fruits. Further investigations are required to expand our knowledge on the nutritional characterization and to elucidate the role of each active phytochemical constituent of pequi, including molecular analysis to determine the exact mechanisms responsible for these beneficial activities.

ACKNOWLEDGMENTS

The corresponding author is grateful to the Coordination for the Improvement of Higher Education Personnel (CAPES) and to the National Council for Scientific and Technological Development (CNPq) for financial support at the University of São Paulo. We are also grateful to The Brazilian Agricultural Research Corporation (EMBRAPA), to Federal Institute of Education, Science and Technology of Maranhão (IFMA) for release to attend the doctoral program and to John Harris for assistance with the English review.

REFERENCES

Afonso SR, Angelo H, de Almeida AN. 2015. Caracterização da produção de pequi em Japonvar, MG. *Floresta* **45**, 49–56.

Aguilar EC, Jascolka TL, Teixeira LG, Lages PC, Ribeiro AC, Vieira EL, Peluzio MC, Alvarez-Leite JI. 2012. Paradoxical effect of a pequi oil-rich diet on the development of atherosclerosis: balance between antioxidant and hyperlipidemic properties. *Braz. J. Med. Biol. Res.* **45**, 601–9. https://doi.org/10.1590/S0100-879X2012007500074

Aguilar EC, Queiroz MdGMN, Oliveira DAd, Oliveira NJFd. 2011. Serum lipid profile and hepatic evaluation in mice fed diet containing pequi nut or pulp (*Caryocar brasiliense* Camb.). *Food Science and Technology* (Campinas) **31**, 879–83. https://doi.org/10.1590/S0101-20612011000400008

Alabdul Magid A, Voutquenne L, Harakat D, Pouny I, Caron C, Moretti C, Lavaud C. 2006. Triterpenoid saponins from the fruits of *Caryocar villosum*. *J. Nat. Prod*. **69**, 919–26. https://doi.org/10.1021/np060097o

Almeida MR, Aissa AF, Ursula Hermogenes Gomes TD, Darin JD, Chisté RC, Mercadante AZ, Antunes LM, Bianchi ML. 2013. *In vivo* genotoxicity and oxidative stress evaluation of an ethanolic extract from piquiá (*Caryocar villosum*) pulp. *J. Med. Food*. **16**, 268–71. https://doi.org/10.1089/jmf.2012.0169

Almeida MR, Darin JD, Hernandes LC, Aissa AF, Chisté RC, Mercadante AZ, Antunes LM Bianchi ML. 2012. Antigenotoxic effects of piquiá (*Caryocar villosum*) in multiple rat organs. *Plant Foods Hum. Nutr*. **67**, 171–7. https://doi.org/10.1007/s11130-012-0291-3

Ascari J, Takahashi JA, Boaventura MAD. 2010. Phytochemical and biological investigations of *Caryocar brasiliense* Camb. *Boletin Latinoamericano y del Caribe de plantas medicinales y Aromaticas* **9**, 20–8.

Ascari J, Takahashi J, Boaventura M. 2013. The phytochemistry and biological aspects of Caryocaraceae family. *Revista Brasileira de Plantas Medicinais* **15**, 293–308. https://doi.org/10.1590/S1516-05722013000200019

Azevedo-Meleiro CH, Rodriguez-Amaya db. 2004. Confirmation of the identity of the carotenoids of tropical fruits by HPLC-DAD and HPLC-MS. *Journal of Food Composition and Analysis* **17**, 385–96. https://doi.org/10.1016/j.jfca.2004.02.004

Barreto GP, Benassi MT, Mercadante AZ. 2009. Bioactive compounds from several tropical fruits and correlation by multivariate analysis to free radical scavenger activity. *Journal of the Brazilian Chemical Society* **20**, 1856–61. https://doi.org/10.1590/S0103-50532009001000013

Batista J, Silva A, Rodrigues C, Costa K, Oliveira A, Paiva E, Nunes F, Olinda R. 2010. Avaliação da atividade cicatrizante do óleo de pequi (*Caryocar coriaceum* wittm) em feridas cutâneas produzidas experimentalmente em ratos. *Arq. Inst. Biol. São Paulo* **77**, 441–7.

Castro AJ, Grisolia CK, de Araújo BC, Dias CD, Dutra ES, Nepomuceno JC. 2008. Recombinogenic effects of the aqueous extract of pulp from pequi fruit (*Caryocar brasiliense*) on somatic cells of Drosophila melanogaster. *Genet. Mol. Res*. **7**, 1375–83. https://doi.org/10.4238/vol7-4gmr515

Chisté RC, Freitas M, Mercadante AZ, Fernandes E. 2012. The potential of extracts of *Caryocar villosum* pulp to scavenge reactive oxygen and nitrogen species. *Food Chem*. **135**, 1740–9. https://doi.org/10.1016/j.foodchem.2012.06.027

Chisté RC, Mercadante AZ. 2012. Identification and quantification, by HPLC-DAD-MS/MS, of carotenoids and phenolic compounds from the Amazonian fruit *Caryocar villosum*. *J. Agric. Food Chem*. **60**, 5884–92. https://doi.org/10.1021/jf301904f

Colombo NB, Rangel MP, Martins V, Hage M, Gelain DP, Barbeiro DF, Grisolia CK, Parra ER, Capelozzi VL. 2015. *Caryocar brasiliense* camb protects against genomic and oxidative damage in urethane-induced lung carcinogenesis. *Braz. J. Med. Biol. Res*. **48**, 852–62. https://doi.org/10.1590/1414-431X20154467

Costa JG, Brito SA, Nascimento EM, Botelho MA, Rodrigues FF, Coutinho HD. 2011. Antibacterial Properties of Pequi Pulp Oil (*Caryocar coriaceum* Wittm.). *International Journal of Food Properties* **14**, 411–6. https://doi.org/10.1080/10942910903207744

Da Silva Quirino G, de Oliveira Leite G, Rebelo LM, da Rocha Tomé A, da Costa JGM, Cardoso AH, Campos AR. 2009. Healing potential of Pequi (*Caryocar coriaceum* Wittm.) fruit pulp oil. *Phytochemistry Letters* **2**, 179–83. https://doi.org/10.1016/j.phytol.2009.06.002

Dauchet L, Amouyel P, Dallongeville J. 2009. Fruits, vegetables and coronary heart disease. *Nature Reviews Cardiology* **6**, 599–608. https://doi.org/10.1038/nrcardio.2009.131

De Morais Cardoso L, Reis BDL, Hamacek FR, Sant'ana HMP. 2013. Chemical characteristics and bioactive compounds of cooked pequi fruits (*Caryocar brasiliense* Camb.) from the Brazilian Savannah. *Fruits* **68**, 3–14. https://doi.org/10.1051/fruits/2012047

De Oliveira Sousa AG, Fernandes DC, Alves AM, De Freitas JB, Naves MMV. 2011. Nutritional quality and protein value of exotic almonds and nut from the Brazilian Savanna compared to peanut. *Food Research International* **44**, 2319–25. https://doi.org/10.1016/j.foodres.2011.02.013

De Oliveira FF, de Araújo JC, Pereira AF, Brito GA, Gondim DV, Ribeiro ReA, de Menezes IR, Vale ML. 2015.

Antinociceptive and anti-inflammatory effects of *Caryocar coriaceum* Wittm fruit pulp fixed ethyl acetate extract on zymosan-induced arthritis in rats. *J. Ethnopharmacol.* **174,** 452–63. https://doi.org/10.1016/j.jep.2015.08.017

De Oliveira MEB, Guerra NB, Barros LDM, Alves RE. 2008. Aspectos agronômicos e de qualidade do pequi. *Embrapa Agroindústria Tropical-Documentos (INFOTECA-E)*.

De Oliveira ML, Nunes-Pinheiro DC, Tomé AR, Mota EF, Lima-Verde IA, Pinheiro FG, Campello CC, de Morais SM. 2010. *In vivo* topical anti-inflammatory and wound healing activities of the fixed oil of *Caryocar coriaceum* Wittm. seeds. *J. Ethnopharmacol*. **129**, 214–9. https://doi.org/10.1016/j.jep.2010.03.014

Facioli NL, Gonçalves LA. 1998. Modificação por via enzimática da composição triglicerídica do óleo de piqui (*Caryocar brasiliense* Camb.). *Quim. Nova* **21**, 16–9. https://doi.org/10.1590/S0100-40421998000100003

Faria-Machado AF, Tres A, van Ruth SM, Antoniassi R, Junqueira NT, Lopes PS, Bizzo HR. 2015. Discrimination of pulp oil and kernel oil from pequi (*Caryocar brasiliense*) by fatty acid methyl esters fingerprinting, using GC-FID and multivariate analysis. *J. Agric. Food Chem*. **63**, 10064–9. https://doi.org/10.1021/acs.jafc.5b03699

Ferreira BS, de Almeida CG, Faza LP, de Almeida A, Diniz CG, da Silva VL, Grazul RM, Le Hyaric M. 2011. Comparative properties of Amazonian oils obtained by different extraction methods. *Molecules* **16**, 5875–85. https://doi.org/10.3390/molecules16075875

Figueiredo R, Maia G, Figueiredo E. 1989. Propriedades físico-químicas e composição dos ácidos graxos da fração lipídica da polpa e amêndoa do pequi (*Caryocar coriaceum* Wittn.). *Ciência Agronômica* **20,** 135–9.

Figueiredo PRL, Oliveira IB, Neto JBS, De Oliveira JA, Ribeiro LB, De Barros Viana GS, Rocha TM, Leal LKAM, Kerntopf MR, Felipe CFB, Coutinho HDM, De Alencar Menezes IR. 2016. *Caryocar coriaceum* Wittm. (Pequi) fixed oil presents hypolipemic and anti-inflammatory effects *in vivo* and *in vitro*. *J. Ethnopharmacol*. **191**, 87–94. https://doi.org/10.1016/j.jep.2016.06.038

Garcia C, Franco P, Zuppa T, Antoniosi Filho N, Leles M. 2007. Thermal stability studies of some cerrado plant oils. *Journal of Thermal Analysis and Calorimetry* **87**, 645–8. https://doi.org/10.1007/s10973-006-7769-x

Geőcze K, Barbosa L, Fidêncio P, Silvério F, Lima C, Barbosa M, Ismail FM. 2013. Essential oils from pequi fruits from the Brazilian Cerrado ecosystem. *Food research international* **54**, 1–8. https://doi.org/10.1016/j.foodres.2013.06.005

Gunstone FD, Padley FB. 1997. *Lipid technologies and applications*: CRC press.

Guedes AMM, Antoniassi R, Faria-Machado AF. 2017. Pequi: a Brazilian fruit with potential uses for the fat industry. *J. Oleo Sci.* **24**, 1–4. https://doi.org/10.1051/ocl/2017040

Katan MB, Zock PL, Mensink RP. 1994. Effects of fats and fatty acids on blood lipids in humans: an overview. *The American Journal of Clinical Nutrition* **60**, 1017S-1022S. https://doi.org/10.1093/ajcn/60.6.1017S

Kishimoto Y, Tani M, Kondo K. 2013. Pleiotropic preventive effects of dietary polyphenols in cardiovascular diseases. *European Journal of Clinical Nutrition* **67**, 532–535. https://doi.org/10.1038/ejcn.2013.29

Khouri J, Resck IS, Poças-Fonseca M, Sousa TM, Pereira LO, Oliveira AB, Grisolia CK. 2007. Anticlastogenic potential and antioxidant effects of an aqueous extract of pulp from the pequi tree (*Caryocar brasiliense* Camb). *Genetics and Molecular Biology* **30**, 442–8. https://doi.org/10.1590/S1415-47572007000300024

Leite GLD, Veloso RVSV, Zanuncio JC, Azevedo AM, Silva JL, Wilcken CF, Soares MA. 2017. Architectural diversity and galling insects on *Caryocar brasiliense* trees. *Scientific reports* **7**, 16677.

Li Y, Zhang J-J, Xu D-P, Zhou T, Zhou Y, Li S, Li H-B. 2016. Bioactivities and Health Benefits of Wild Fruits. *International Journal of Molecular Sciences* **17**, 1258. https://doi.org/doi:10.3390/ijms17081258

Lima A, Silva AO, Trindade RA, Torres RP, Mancini-Filho J. 2007. Composição química e compostos bioativos presentes na polpa e na amêndoa do pequi (*Caryocar brasiliense*, Camb.). *Revista Brasileira de Fruticultura* **29**, 695–8. https://doi.org/10.1590/S0100-29452007000300052

Macedo A, Santos R, Pantoja L, Santos A. 2011. Pequi cake composition, hydrolysis and fermentation to bioethanol. *Brazilian Journal of Chemical Engineering* **28**, 9–15. https://doi.org/10.1590/S0104-66322011000100002

Machado MT, Mello BC, Hubinger MD. 2013. Study of alcoholic and aqueous extraction of pequi (*Caryocar brasiliense* Camb.) natural antioxidants and extracts concentration by nanofiltration. *Journal of Food Engineering* **117**, 450–7. https://doi.org/10.1016/j.jfoodeng.2012.12.007

Mariano RGdB, Couri S, Freitas SP. 2009. Enzymatic technology to improve oil extraction from *Caryocar brasiliense* camb. (Pequi) Pulp. *Revista Brasileira de Fruticultura* **31**, 637–43. https://doi.org/10.1590/S0100-29452009000300003

Mariano-da-Silva S, Brait JDdA, Faria FPd, Silva SMd, Oliveira SLd, Braga PF, Mariano-da-Silva FMd. 2009. Chemical characteristics of pequi fruits (*Caryocar brasiliense* Camb.) native of three municipalities in the State of Goiás-Brazil. *Food Science and Technology* (Campinas) **29**, 771–7. https://doi.org/10.1590/S0101-20612009000400011

Marx F, Andrade EHA, Maia JG. 1997. Chemical composition of the fruit pulp of *Caryocar villosum*. *Zeitschrift für Lebensmitteluntersuchung und-Forschung A* **204**, 442–4. https://doi.org/10.1007/s002170050110

Miranda-Vilela AL, Akimoto AK, Alves PC, Pereira LC, Gonçalves CA, Klautau-Guimarães MN, Grisolia CK. 2009a. Dietary carotenoid-rich pequi oil reduces plasma lipid peroxidation and DNA damage in runners and evidence for an association with MnSOD genetic variant -Val9Ala. *Genet. Mol. Res*. **8**, 1481–95.

Miranda-Vilela AL, Akimoto AK, Alves PC, Pereira LC, Klautau-Guimarães MN, Grisolia CK. 2010. Dietary carotenoid-rich oil supplementation improves exercise-induced anisocytosis in runners: influences of haptoglobin, MnSOD (Val9Ala), CAT (21A/T) and GPX1 (Pro198Leu) gene polymorphisms in dilutional pseudoanemia (sports anemia). *Genet. Mol. Biol*. **33**, 359–67. https://doi.org/10.1590/S1415-47572010005000022

Miranda-Vilela AL, Grisolia CK, Longo JP, Peixoto RC, de Almeida MC, Barbosa LC, Roll MM, Portilho FA, Estevanato LL, Bocca AL, Báo SN, Lacava ZG. 2014. Oil rich in carotenoids instead of vitamins C and E as a better option to reduce doxorubicin-induced damage to normal cells of Ehrlich tumor-bearing mice: hematological, toxicological and histopathological evaluations. *J. Nutr. Biochem*. **25**, 1161–76. https://doi.org/10.1016/j.jnutbio.2014.06.005

Miranda-Vilela AL, Peixoto RC, Longo JP, Silva e Cintra DeO, Portilho FA, Miranda KL, Sartoratto PP, Báo SN, de Azevedo RB, Lacava ZG. 2013. Dextran-functionalized magnetic fluid mediating magnetohyperthermia combined with preventive antioxidant pequi-oil supplementation: potential use against cancer. *J. Biomed. Nanotechnol.* **9**, 1261–71. https://doi.org/10.1007/s13277-013-1447-y

Miranda-Vilela AL, Pereira LC, Gonçalves CA, Grisolia CK. 2009b. Pequi fruit (*Caryocar brasiliense* Camb.) pulp oil reduces exercise-induced inflammatory markers and blood pressure of male and female runners. *Nutr. Res*. **29**, 850–8. https://doi.org/10.1016/j.nutres.2009.10.022

Miranda-Vilela AL, Portilho FA, de Araujo VG, Estevanato LL, Mezzomo BP, Santos MeF, Lacava ZG. 2011. The protective effects of nutritional antioxidant therapy on Ehrlich solid tumor-bearing mice depend on the type of antioxidant therapy chosen: histology, genotoxicity and hematology evaluations. *J. Nutr. Biochem*. **22**, 1091–8. https://doi.org/10.1016/j.jnutbio.2010.09.009

Miranda-Vilela AL, Resck IS, Grisolia CK. 2008. Antigenotoxic activity and antioxidant properties of organic and aqueous extracts of pequi fruit (*Caryocar brasiliense* Camb.) pulp. *Genetics and Molecular Biology* **31**, 956–63. https://doi.org/10.1590/S1415-47572008000500025

Moreno LG, Oliveira LG, Melo DS, Pereira LVC, Costa KB, Miranda JL, Vieira ER, Magalhes FC, Dias-Peixoto MF,

Esteves EA. 2016. *Caryocar brasiliense* fruit intake ameliorates hepatic fat deposition and improves intestinal structure of rats. *Journal of Medicinal Plants Research* **10**, 640–8. https://doi.org/10.5897/JMPR2016.6222

Oliveira LG, Moreno LG, Melo DS, Costa-Pereira LV, Carvalho MM, Silva PH, Alves AM, Magalhães FC, Dias-Peixoto MF, Esteves EA. 2017. *Caryocar brasiliense* oil improves cardiac function by increasing Serca2a/PLB ratio despite no significant changes in cardiovascular risk factors in rats. *Lipids Health Dis*. **16**, 37. https://doi.org/10.1186/s12944-017-0422-9

Oliveira MEBd, Guerra NB, Maia AdHN, Alves RE, Matos NMdS, Sampaio FGM, Lopes MMT. 2010. Chemical and physical-chemical characteristics in pequi from the Chapada do Araripe, Ceará, Brazil. *Ver. Bras. Frutic.* **32**, 114–25. https://doi.org/10.1590/S0100-29452010005000030

Oliveira MD, Gusmão E, Lopes PSN, Simões MOM, Ribeiro L, Souto B. 2006. Estádio de maturação dos frutos e fatores relacionados aos aspectos nutritivos e de textura da polpa de pequi (*Caryocar brasiliense* Camb.). *Ver. Bras. Frutic.* **28,** 380–6. https://doi.org/10.1590/S0100-29452006000300010

Palmeira SM, Silva PR, Ferrão JS, Ladd AA, Dagli ML, Grisolia CK, Hernandez-Blazquez FJ. 2016. Chemopreventive effects of pequi oil (*Caryocar brasiliense* Camb.) on preneoplastic lesions in a mouse model of hepatocarcinogenesis. *Eur. J. Cancer Prev.* ***25***, 299–305. https://doi.org/10.1097/CEJ.0000000000000187

Passos XS, Santos SaC, Ferri PH, Fernandes OeF, Paula TeF, Garcia AC, Silva MoR. 2002. Antifungal activity of *Caryocar brasiliensis* (Caryocaraceae) against Cryptococcus neoformans. *Rev. Soc. Bras. Med. Trop*. **35**, 623–7. https://doi.org/10.1590/S0037-86822002000600013

Passos XS, Castro ACM, Pires JS, Garcia ACF, Campos FC, Fernandes OF, Paula JR, Ferreira HD, Santos SC, Ferri PH. 2003. Composition and antifungal activity of the essential oils of *Caryocar brasiliensis*. *Pharmaceutical Biology* **41**, 319–24. https://doi.org/10.1076/phbi.41.5.319.15936

Pérez-Jiménez J, Neveu V, Vos F, Scalbert, A. 2010. Identification of the 100 richest dietary sources of polyphenols: an application of the Phenol-Explorer database. *European Journal of Clinical Nutrition* **64**, S112-S120. https://doi.org/10.1038/ejcn.2010.221

Ramadan MF, Asker MMS, Tadros M. 2012. Antiradical and antimicrobial properties of cold-pressed black cumin and cumin oils. *European Food Research and Technology* **234**, 833–44. https://doi.org/10.1007/s00217-012-1696-9

Ramos KMC, Souza V. 2011. Características físicas e químico-nutricionais de frutos de pequizeiro (*Caryocar coriaceum* Wittm.) em populações naturais da região Meio-Norte do Brasil. *Revista Brasileira de Fruticultura* **33**, 500–8. https://doi.org/10.1590/S0100-29452011005000072

Ramos MIL, Umaki MCS, Hiane PA, Ramos Filho MM. 2001. Efeito do cozimento convencional sobre os carotenóides pró-vitamínicos" A" da polpa do piqui (*Caryocar brasiliense* Camb). *Boletim do Centro de Pesquisa de Processamento de Alimentos* **19**, 23–32.

Ribeiro MC, Boas V, de Barros EV, Riul TR, Pantoja L, Marinho HA, Santos ASd. 2012. Influence of the extraction method and storage time on the physicochemical properties and carotenoid levels of pequi (*Caryocar brasiliense* Camb.) oil. *Food Science and Technology* (Campinas) **32**, 386–92. https://doi.org/10.1590/S0101-20612012005000053

Roesler R, Catharino RR, Malta LG, Eberlin MN, Pastore G. 2008. Antioxidant activity of *Caryocar brasiliense* (pequi) and characterization of components by electrospray ionization mass spectrometry. *Food Chemistry* **110**, 711–7. https://doi.org/10.1016/j.foodchem.2008.02.048

Roesler R, Malta LG, Carrasco LC, Holanda RB, Sousa CAS, Pastore GM. 2007. Atividade antioxidante de frutas do cerrado. *Ciência e Tecnologia de Alimentos* **27**, 53–60. https://doi.org/10.1590/S0101-20612007000100010

Saraiva RA, Matias EF, Coutinho HD, Costa JG, Souza HHF, Fernandes CN, Rocha JB, Menezes IR. 2011a. Synergistic action between *Caryocar coriaceum* Wittm. fixed oil with aminoglycosides *in vitro*. *Eur. J. Lipid Sc. Technol.* **113**, 967–72. https://doi.org/10.1002/ejlt.201000555

Saraiva RA, Araruna MK, Oliveira RC, Menezes KD, Leite GO, Kerntopf MR, Costa JG, Rocha JB, Tomé AR, Campos AR, Menezes IR. 2011b. Topical anti-inflammatory effect of *Caryocar coriaceum* Wittm. (Caryocaraceae) fruit pulp fixed oil on mice ear edema induced by different irritant agents. *J. Ethnopharmacol*. **136**, 504–10. https://doi.org/10.1016/j.jep.2010.07.002

Saraiva R, Leite G, Oliveira R, Araruna M, Menezes K, Pereira C, Costa J, Campos A, Menezes I. 2008. Topical anti-inflammatory activity of *Caryocar coriaceum* Wittm. (Caryocaraceae) pulp fruit and seed oils. *4th Brazilian Symposium on Medicinal Chemistry-Braz Med Chem*.

Segall SD, Artz WE, Raslan DS, Ferraz VP, Takahashi JA. 2006. Triacylglycerol analysis of pequi (*Caryocar brasiliensis* Camb.) oil by electrospray and tandem mass spectrometry. *J. Sci. Food Agric*. **86**, 445–52. https://doi.org/10.1002/jsfa.2349

Shinagawa FB, Santana FCd, Torres LRO, Mancini-Filho J. 2015. Grape seed oil: a potential functional food? *Food Science and Technology* (Campinas) **35**, 399–406. https://doi.org/10.1590/1678-457X.6826

Souza JP, Alves RE, Brito ES, Nogueira DH, Lima JR. 2013. Estabilidade de produtos de pequi (*Caryocar coriaceum* wittm) sob congelamento em diferentes tipos de embalagens. *Rev. Bras. Frutic.* (Jaboticabal) **35**, 971–976. https://doi.org/10.1590/S0100-29452013000400007

Teixeira TN, Esteves EA, Oliveira LG, Oliveira MLP, Santana RC, Rodrigues AP. 2013. *Caryocar brasiliense* pulp increases serum HDL and reduces hepatic lipid accumulation in rats fed a high fat diet. *Journal of Medicinal Plants Research* **7**, 963–9.

Torres LR, Santana FC, Torres-Leal FL, Melo IL, Yoshime LT, Matos-Neto EM, Seelaender MC, Araújo CM, Cogliati B, Mancini-Filho J. 2016a. Pequi (*Caryocar brasiliense* Camb.) almond oil attenuates carbon tetrachloride-induced acute hepatic injury in rats: Antioxidant and anti-inflammatory effects. *Food. Chem. Toxicol*. **97,** 205–16. https://doi.org/10.1016/j.fct.2016.09.009

Torres L, Shinagawa F, Santana F, Araújo E, Oropeza M, Macedo L, Almeida-Muradian L, Lima H, Mancini-Filho J. 2016b. Physicochemical and antioxidant properties of the pequi (*Caryocar brasiliense* Camb.) almond oil obtained by handmade and cold-pressed processes. *International Food Research Journal* **23**, 1541–51.

Traesel GK, Menegati SE, Dos Santos AC, Carvalho Souza RI, Villas Boas GR, Justi PN, Kassuya CA, Sanjinez Argandoña EJ, Oesterreich SA. 2016. Oral acute and subchronic toxicity studies of the oil extracted from pequi (*Caryocar brasiliense*, Camb.) pulp in rats. *Food Chem. Toxicol*. **97,** 224–31. https://doi.org/10.1016/j.fct.2016.09.018

Vera R, de Souza ERB, Fernandes EP, Naves RV, Júnior MSS, Caliari M, Ximenes PA. 2007. Caracterização física e química de frutos do pequizeiro (*Caryocar brasiliense* Camb.) oriundos de duas regiões no estado de goiás, Brasil. *Pesquisa Agropecuária Tropical (Agricultural Research in the Tropics)* **37**, 93–9.

WHO. World Health Organization. 2003. Report of a joint WHO/FAO expert consultation: *Diet, nutrition and the prevention of chronic diseases*. WHO Technical Report Series **916**.

Xavier WKS, Medeiros BJ, Lima CS, Favacho HA, de Aguiar Andrade EH, Neyva R, Araújo M. 2011. Topical anti-inflammatory action of *Caryocar villosum* oil (Aubl) Pers. *Journal of Applied Pharmaceutical Science* **1**, 62.

Yamaguchi KK, Lamarão CV, Aranha ES, Souza ROS, Oliveira PDA, Vasconcellos MC, Lima ES, Veiga-Junior VF. 2017. HPLC-DAD profile of phenolic compounds, cytotoxicity, antioxidant and anti-inflammatory activities of the amazon fruit *Caryocar villosum*. *Química Nova* **40**, 483–90. https://doi.org/10.21577/0100-4042.20170028

Yuan H, Zhang J, Nageswaran D, Li L. 2015. Carotenoid metabolism and regulation in horticultural crops. *Horticulture Research* **2**, 15036. https://doi.org/10.1038/hortres.2015.36