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Underexploited Brazilian Cerrado fruits as sources of phenolic compounds for diseases management: A review

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ABSTRACT

The Brazilian Cerrado is home to a large number of native and endemic species of enormous potential, among which we can highlight the cagaita, gabiroba, jatobá-do-cerrado, lobeira, and mangaba. In this review, we report the nutritional and phenolic composition, as well as bioactivities of these five Brazilian Cerrado fruits. The compiled data indicated that these fruits have high nutritional, functional, and economic potential and contribute to the daily intake of macro- and micronutrients, energy, and phenolic compounds by inhabitants of the Cerrado region. Phenolic-rich extracts obtained from these fruits have shown several bioactivities, including antioxidant, anti-inflammatory, antidyslipidemic, antidiabetic, analgesic, anticarcinogenic, hepatoprotective, gastrointestinal protective, and antimicrobial properties. Therefore, these fruits can be explored by the food industry as a raw material to develop food products of high value-added, such as functional foods, and can also be employed as plant sources to obtain bioactive compounds for food, cosmetic, and pharmaceutical purposes.

1. Introduction

The Brazilian Cerrado is the second largest biome in Brazil and South America, spanning approximately 2 million km^2, which represents about 23 % of the Brazilian territory and 11 % of the territorial area of South America (Reis & Schmiele, 2019; Rezende-Silva et al., 2019). This biome is considered one of the 25 most biodiverse sites worldwide and the savanna formation that holds the greatest plant diversity. It is estimated that the Brazilian Cerrado is home to about 12,356 naturally occurring species, including herbaceous plants, shrubs, trees, and vines, of which 11,627 species are native and approximately 44 % are endemic (Arruda and de Almeida, 2015). Its species account for about 30 % and 5 % of Brazilian and world biodiversity, respectively. These species have a huge potential for use, since their seeds, flowers, fruits, leaves, roots, trunk bark, latex, and resins are employed in the formulation of food and medicines (more than 220 plant species) (Arruda, 2017; Gonçalves et al., 2019).

The Brazilian Cerrado vegetation has species capable of withstanding extreme environments, such as high temperatures and low availability of water for long periods of the year, soil deficient in nutrients, numerous occurrences of fires, high incidence of UV radiation, and constant attack of insects and pathogenic microorganisms. These factors have led the native plants of Brazilian Cerrado to develop a series of adaptations throughout their evolutionary process to resist the oxidative stress caused by these conditions. Among the adaptations developed by these plants, a higher expression/activity of antioxidant enzymes and a high synthesis of phytochemicals, particularly phenolic compounds, stand out (Arruda, 2017; Reis & Schmiele, 2019). In the human body, these secondary metabolites can play various biological activities, such as antioxidant, antihypertensive, anti-inflammatory, and antimutagenic activities, which can prevent and/or delay the development of several chronic non-communicable diseases (Arruda et al., 2017). Ethnopharmacological studies have shown that Brazilian Cerrado native plants have been used in folk medicine to combat various diseases (Ribeiro et al., 2014). Furthermore, these fruits have been processed to obtain high value-added products, such as oils, nuts, and ready-to-eat food and beverages (Arruda and de Almeida, 2015).

Although the literature introduces relevant data on different Brazilian Cerrado fruits, their benefits to human health still remain scientifically underexplored, or, in some cases, unexplored. Therefore, further research and studies should be carried out to determine the nutritional and phytochemical composition of these fruits, as well as their bioactivities through *in vivo* studies and clinical trials. In this context, this review did not aim to compare these fruits with other traditional fruits,

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but to summarize and present an overview, by a broad compilation of scientific data found in the literature on the phenolic composition and nutritional and bioactive properties of five underexploited Brazilian Cerrado fruits, namely: cagaita (*Eugenia dysenterica* DC.), gabiroba (*Campomanesia adamantium* (Cambess.) O. Berg), jatobá-do-cerrado (*Hymenaea stigonocarpa* Mart. ex Hayne), lobeira (*Solanum lycocarpum* A. St.- Hil), and mangaba (*Hancornia speciosa* Gomes), to elucidate their beneficial effects on health and stimulate the appreciation and preservation of these native species from Brazil. Thus, this review can be a reference material to support other researchers in conducting future studies on Brazilian Cerrado fruits.

2. Search strategy and studies selection

In the current comprehensive review study, electronic searches were carried out using the main repositories of the world's scientific data (Scopus, Google Scholar, Science Direct, Web of Science, and PubMed databases), to identify relevant studies published in high-impact journals from 2001 to the present. In addition, manual searches of the reference lists of studies identified during electronic searches were also undertaken and electronic links to additional related materials were reviewed to identify other studies that were not found in the electronic searches. We used the following terms to perform our bibliographic research: "Cagaita" OR "*Eugenia dysenterica*", "Gabiroba" OR "*Campomanesia adamantium*", "Jatobá-do-cerrado" OR "*Hymenaea stigonocarpa*", "Lobeira" OR "*Solanum lycocarpum*", and "Mangaba" OR "*Hancornia speciosa*". The abovementioned terms were searched on the article title, abstract, and keywords. The search was not restricted to any specific language. The studies that met search criteria were selected for full-text review. Theses, editorials, communications, and conference abstracts were excluded. The inclusion criteria were studies that reported results concerning: 1) nutritional composition, 2) phenolic composition, and 3) biological properties.

3. Botanical characteristics

3.1. Cagaita (Eugenia dysenterica DC.)

Cagaita (Fig. 1**A**), a member of the *Myrtaceae* family, is a berry-like fruit with a globular-flattened shape, pale yellow color, a diameter that can vary from 1 to 3 cm, and a weight between 15 and 20 g, containing 1 to 3 seeds of oval, flattened, or ellipsoid shape that are wrapped by the pulp, which is slightly acidic (Martinotto et al., 2007). Beyond consumption *in natura*, the fruits can be used in the preparation of liqueurs, jams, juices, ice creams, soft drinks, and candies. Its fruits and other parts of the plant are used in folk medicine to treat several diseases (de Cardoso et al., 2011; Chaves et al., 2011; Coelho & Carreiro, 2018). Cagaita fruits have a laxative effect when consumed in excess or when fermented, and such an effect is attributed to the protein fraction of the fruit (Lima et al., 2010).

3.2. Gabiroba (Campomanesia adamantium (Cambess.) O. Berg)

Gabiroba (Fig. 1**B**), belonging to the *Myrtaceae* family, also popularly known as guabiroba, guabiroba-do-campo, and guavira, has a rounded shape, thin skin with a yellow-green color, and a whitish pulp that surrounds some light yellow seeds (Vallilo et al., 2006). The fruit has an average of 22.97 mm in longitudinal diameter, 24.20 mm in transverse diameter, and 6.99 g, and the pulp weighs an average of 3.28 g, with an approximate yield of 46.24 % (Alves et al., 2013). Beyond *in natura* consumption, the fruit can be eaten as candies, ice creams, popsicles, liqueurs, and juices (da Souza et al., 2019).

3.3. Jatobá-do-cerrado (Hymenaea stigonocarpa Mart. ex Hayne)

Jatobá-do-cerrado (Fig. 1**C**), belonging to the *Leguminosae* family, is also known as jutaí, jatobá-capo, jatobá-de-cascafina, jitaí, or jutaicica (Corrêa, 1984; Lorenzi, 1992). The fruit has an elongated pod shape with a rounded or slightly straight apex, a rounded base, and a whole or slightly wavy edge, whose length ranges from 6 to 18 cm and diameter from 3 to 6 cm. The peel is thick, woody, and quite resistant, has a rough texture due to the presence of some scores, and presents a color that can vary from light brown to dark brown (almost black). Its seeds are surrounded by a greenish-yellow pulp, soft, fibrous-farinaceous, sweetish, edible, with a characteristic taste and aroma. The seeds are flattened with an oblong to obovate shape, brownish color, and, on average, 1.90, 1.64, and 1.45 cm in length, width, and thickness, respectively (Botelho et al., 2000; Rizzini, 1971; Silva et al., 1994). The pulp with a

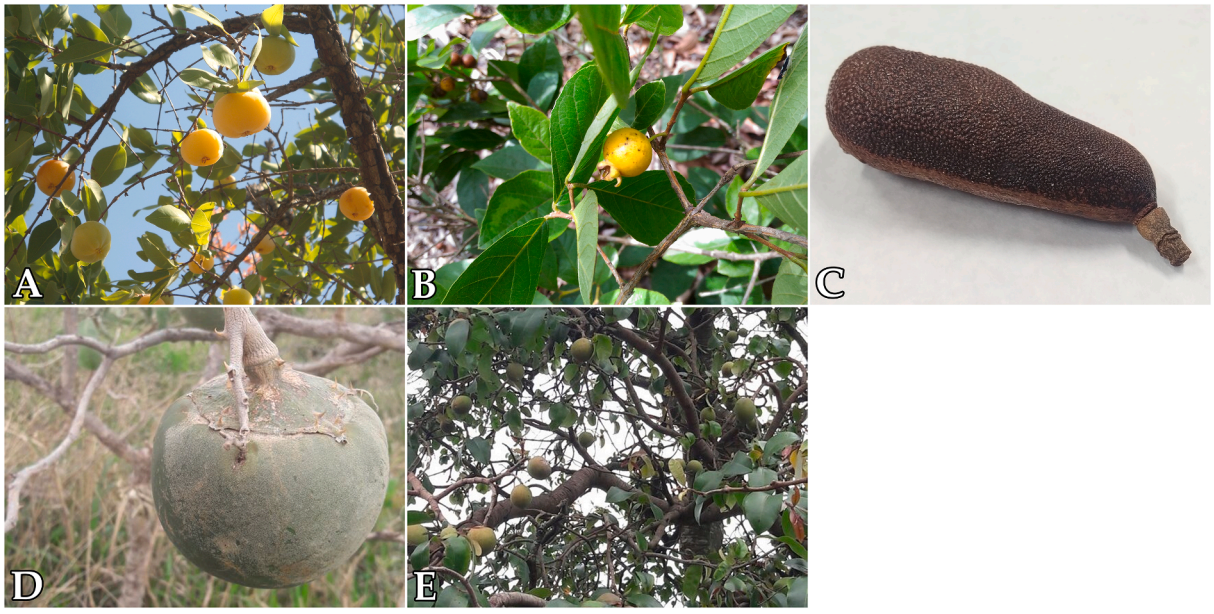

Fig. 1. Cagaita fruit (*Eugenia dysenterica* DC.) (**A**); Gabiroba fruit (*Campomanesia adamantium* (Cambess.) O. Berg) (**B**); Jatobá-do-cerrado fruit (*Hymenaea stigonocarpa* Mart. ex Hayne) (**C**); Lobeira fruit (*Solanum lycocarpum* A. St.-Hil) (**D**); and Mangaba fruit (*Hancornia speciosa* Gomes) (**E**). **Picture authors:** Henrique Silvano Arruda (Pictures A and B), Felipe Tecchio Borsoi (Picture C), and Gabrielle Silvano Arruda (Pictures D and E).

farinaceous texture is consumed *in natura* or used in the formulation of jams, cakes, liqueur, bread, and porridges (Silva et al., 1994).

3.4. Lobeira (*Solanum lycocarpum A. St.-Hil*)

Lobeira (Fig. 1**D**), belonging to the *Solanaceae* family, is also popularly called fruta-de-lobo, jurubebão, juripeba, and baba-de-boi (Dal-l'Agnol & Lino von Poser, 2000). This fruit has a globular shape, is slightly flattened, measuring about 8 to 12 cm in diameter, and can weigh up to 500 g (Corrêa, 1984). The peel is tomentose, has small hairs that shed when touched and green color even after ripening. On the other hand, the pulp has a fairly firm consistency and a white color when unripe, becoming yellow in color with a soft consistency, sweetish taste, and extremely aromatic when fully ripe. The seeds are gray-brown and have an ellipsoid or subdiscoid shape with, on average, 7.04, 5.33, and 1.71 mm in length, width, and thickness, respectively (Castellani et al., 2008; de Oliveira Junior et al., 2004). Lobeira is characterized as an edible and aromatic fruit, used in the preparation of jellies and candies, and can also be added to peaches for the production of peach candy or to quince to obtain quince candy (Corrêa, 1984).

3.5. Mangaba (*Hancornia speciosa Gomes*)

Mangaba (Fig. 1**E**), belonging to the *Apocynaceae* family, is a berry-like fruit that has an elliptical and/or rounded shape with weight, longitudinal diameter, and a transverse diameter ranging between 12.55 and 48.42 g, 3.03 and 4.34 cm, and 2.84 and 4.34 cm, respectively. The peel is yellowish or greenish with or without red pigmentation (Pereira et al., 2006; Silva et al., 2013). The pulp has a yellow-green color, is sweet, aromatic, and has a characteristic taste (Perfeito et al., 2015). Each fruit has, in general, from 2 to 15 discoid, flattened, and light brown seeds, measuring 7 to 8 mm in diameter. Besides *in natura* consumption, the mangaba fruits are used in the production of juices, ice cream, jams, candy, and liqueur (Pereira et al., 2006).

4. Physicochemical and nutritional composition

Table 1 lists the physicochemical and nutritional composition of the five Brazilian Cerrado fruits covered in this review. With exception of the jatobá-do-cerrado, the other fruits show a low pH (3.30–4.87) and total titrable acidity (0.73–1.12 g citric acid/100 g), and high values of total soluble solids (9.12–24.00 °Brix), TSS/TTA ratio (10.52–30.38), and moisture (74.62–91.56 %). These features are extremely desirable for their application in some processed food products, especially jams, yogurts, and sweets (Arruda & Pastore, 2019).

In general, the edible part of the fruits presented high moisture levels (74.62–91.56 %), except the jatobá-do-cerrado, which had only 8.8 % of moisture because it is a fibrous-farinaceous pulp. This characteristic makes jatobá-do-cerrado a very promising fruit for food processing since its low moisture content provides high chemical, enzymatic, and microbiological stability during post-harvest, transport, and storage. Furthermore, the drying process to obtain a flour becomes dispensable as this fruit pulp is naturally dry (8.8 % of moisture; according to Codex Standard 152–1985, the moisture content of a flour cannot be more than 15 %), which can reduce its processing costs (Pereira et al., 2020).

Due to the low moisture content, jatobá-do-cerrado pulp presented the highest contents of proteins (5.6 %), lipids (3.8 %), carbohydrates (34.1 %), ash (3.4 %), and energy (193 kcal/100 g). The other Brazilian Cerrado fruits had reduced levels of lipids (0.55–1.70 %), carbohydrates (2.30–10.97 %), and energy (29.83–72.30 kcal/100 g), demonstrating the potential of their inclusion in restrictive diets (*e.g.,* low-energy diets for obese individuals). On the other hand, the jatobá-do-cerrado shows high dietary fiber content (44.30 %), followed by mangaba (11.60 %). These fruits can be exploited by the food industry for developing functional foods since the daily intake of dietary fiber has been associated with human health and well-being, contributing to the prevention of some diseases, such as obesity, diabetes, cardiovascular and gastrointestinal tract dysfunctions. The World Health Organization (WHO) recommends the daily intake of at least 25 g of dietary fiber (Pereira et al.,

Table 1
Composition of the edible parts of five underexploited Brazilian Cerrado fruits.

Parameter	Unit	Cagaita	Gabiroba	Jatobá-do-cerrado	Lobeira	Mangaba
Physicochemical parameter						
pH	–	3.3[(1)]	3.767[(4)]	5.5 ± 0.2[(7)]	4.87 ± 0.04[(10)]	3.6 ± 0.1[(12)]
TTA	g citric acid/100 g	0.73[(1)]	1.12[(4)]	1.5 ± 0.1[(7)]	0.79 ± 0.00[(10)]	0.8 ± 1.2[(12)]
TSS	°Brix	9.12[(1)]	11.78[(4)]	4.8 ± 0.1[(7)]	24.0 ± 0.00[(10)]	15.1 ± 1.1[(12)]
TSS/TTA ratio	–	12.49[(1)]	10.52[(4)]	3.2[(7)]	30.38[(10)]	18.88[(12)]
Proximate						
Moisture	%	91.56[(1)]	80.87 ± 0.04[(5)]	8.8 ± 1.0[(7)]	74.62 ± 0.11[(10)]	83.0 ± 1.4[(12)]
Proteins	%	0.63 ± 0.09[(1)]	1.06 ± 0.00[(5)]	5.6 ± 0.4[(7)]	1.37 ± 0.07[(10)]	0.8 ± 0.1[(12)]
Lipids	%	0.57 ± 0.05[(1)]	0.55 ± 0.03[(5)]	3.8 ± 1.0[(7)]	0.86 ± 0.22[(10)]	1.7 ± 0.1[(12)]
Carbohydrates	%	5.54 ± 0.65[(1)]	10.00 ± 0.06[(5)]	34.1 ± 3.3[(7)]	10.97 ± 0.57[(10)]	2.3 ± 0.2[(12)]
Dietary fiber	%	1.51 ± 0.20[(1)]	7.10 ± 0.03[(5)]	44.3 ± 2.3[(7)]	4.54 ± 0.43[(10)]	11.6 ± 0.8[(12)]
Ash	%	0.18 ± 0.02[(1)]	0.43 ± 0.02[(5)]	3.4 ± 0.1[(7)]	0.92 ± 0.01[(10)]	0.6 ± 0.1[(12)]
Energy value	kcal/100 g	29.83 ± 3.43[(1)]	49.19[(5)]	193.0 ± 11.9[(7)]	57.1[(10)]	64.8 ± 5.1[(12)]
Minerals						
Iron, Fe	mg/100 g	11.53 ± 1.82[(2)]	1.13 ± 0.05[(6)]	1.1 ± 0.2[(8)]	0.2 ± 0.0[(8)]	0.50 ± 0.04[(3)]
Zinc, Zn	mg/100 g	2.31 ± 0.10[(2)]	0.49 ± 0.01[(6)]	1.0 ± 0.5[(8)]	0.4 ± 0.2[(8)]	0.4 ± 0.2[(8)]
Sodium, Na	mg/100 g	6.63 ± 1.36[(2)]	3.07 ± 0.07[(6)]	–	<LOQ[(9)]	–
Calcium, Ca	mg/100 g	15.35 ± 2.23[(2)]	16.5 ± 0.1[(6)]	850 ± 0[(9)]	6.4 ± 1.3[(8)]	31.01 ± 2.35[(3)]
Magnesium, Mg	mg/100 g	66.00 ± 6.06[(2)]	17.5 ± 0.2[(6)]	3173 ± 9[(9)]	8.43 ± 0.59[(10)]	12.80 ± 1.92[(3)]
Potassium, K	mg/100 g	126.37 ± 3.86[(3)]	130.4 ± 1.9[(6)]	1447 ± 5[(9)]	396.17 ± 13.72[(10)]	161.45 ± 10.82[(3)]
Phosphorus, P	mg/100 g	12.75 ± 0.91[(3)]	17.0 ± 0.3[(6)]	167 ± 5[(9)]	–	9.16 ± 0.36[(3)]
Manganese, Mn	mg/100 g	1.56 ± 0.07[(2)]	0.21 ± 0.02[(6)]	12.7 ± 0.0[(9)]	<LOQ[(10)]	–
Copper, Cu	mg/100 g	0.63 ± 0.02[(2)]	0.19 ± 0.01[(6)]	0.053 ± 0.000[(9)]	0.33 ± 0.06[(10)]	0.0 ± 0.0[(8)]
Vitamins						
Vitamin C	mg/100 g	34.11 ± 1.48[(1)]	234 ± 2[(6)]	8.9 ± 1.9[(7)]	85.12[(11)]	165.82 ± 24.46[(12)]
Vitamin A	μg RAE/100 g	45.53 ± 2.68[(1)]	–	32.4 ± 9.7[(7)]	–	7.47 ± 0.40[(12)]
Total compounds with Vitamin E activity	μg/100 g	n.d.[(1)]	–	495.5 ± 37.5[(7)]	–	2732.5 ± 77.8[(12)]
Total folates	μg/100 g	25.74 ± 4.64[(1)]	–	53.5 ± 4.2[(7)]	–	98.3 ± 19.6[(12)]

Where: *LOQ:* limit of quantification; *n.d.:* not detected; *RAE:* retinol activity equivalent; *TSS:* total soluble solids; *TTA:* total titratable acidity.
References: (1) de Cardoso et al. (2011); (2) Nascimento et al. (2020); (3) Schiassi et al. (2018); (4) da Souza et al. (2019); (5) Alves et al. (2013); (6) Vallilo et al. (2006); (7) de Cardoso et al. (2013); (8) Marin et al. (2009); (9) de Filho et al. (2019); (10) Pereira et al. (2019); (11) de Oliveira Junior et al. (2003); and (12) de Cardoso et al. (2014).

2020). Therefore, the daily intake of 100 g of jatobá-do-cerrado pulp would be sufficient to meet the WHO recommendations, while the intake of 100 g of mangaba pulp would contribute with approximately 50 % of the WHO recommendations.

According to the Food and Drug Administration (FDA), a food that provides from 10 to 20 % of the Recommended Daily Intake (RDI) for a nutrient per serving is a "good source", while a food providing at least 20 % is considered an "excellent source in" the nutrient (FDA, 2013). Table 2 shows the nutritional contribution to the RDIs for adults from the consumption of 100 g of the edible part of the Brazilian Cerrado fruits. Cagaita can be considered an excellent source of manganese, iron, vitamin C, and copper, and a good source of magnesium and zinc, since the consumption of 100 g of fruit pulp accounts for 78.00, 64.06, 56.85, 31.50, 16.50, and 15.40 % of RDIs, respectively. Jatobá-do-cerrado is an excellent source of minerals, particularly magnesium (793.25 % RDI), manganese (635.00 % RDI), calcium (85.00 % RDI), and potassium (41.34 % RDI), and a good source of phosphorous (16.70 % RDI), vitamin C (14.83 % RDI), and folates (13.38 % RDI). Mangaba proved to be an excellent source of vitamin C and folates, and a good source of vitamin E whereby the consumption of one serving would correspond to 276.37, 24.58, and 18.22 % of RDIs, respectively. Gabiroba and lobeira are excellent sources of vitamin C providing 390.00 and 141.87 % of RDI in one serving. In addition, gabiroba could be a good source of manganese (10.50 % RDI), while the lobeira would be a good source of copper (16.50 % RDI) and potassium (11.32 % RDI). On the other hand, the sodium contents reported for cagaita (6.63 mg/100 g) and gabiroba (3.07 mg/100 g) were extremely low, accounting for only 0.13–0.28 % of RDIs, which could benefit hypertensive people and reduce the risk for cardiovascular diseases. Thus, the consumption of these Brazilian Cerrado fruits could be a key tool to mitigate food insecurity, malnutrition, and risk for several diseases.

The data presented clearly indicate that these Brazilian Cerrado fruits can contribute to the daily intake of different macro- and micronutrients. Furthermore, the physicochemical and nutritional composition data indicate that such fruits have a great potential to be explored by the food industry in the development of different food products, such as desserts, juices, and even functional foods. It is also important to highlight that these fruits have a significant biological value since they are mainly consumed by individuals from socially vulnerable families living in the countryside, helping to prevent or mitigate problems related to the low intake of vitamins and minerals in these populations.

5. Phenolic compounds composition

Phenolic compounds correspond to a class of organic compounds widely distributed in the plant kingdom where they are produced as secondary metabolites in varying amounts. These phytochemicals are characterized by the presence of at least one aromatic ring with one or more hydroxyl substituents and they can be found both free or associated with carbohydrates, lipids, cell wall components, amines, and organic acids (Arruda et al., 2019). Due to their great structural diversity, thousands of structures of phenolic compounds have been described and categorized into several classes. However, flavonoids, proanthocyanidins, hydroxycinnamic and hydroxybenzoic acids are the classes most frequently found in the human diet (Vuolo et al., 2019). Phenolic compounds have multifaceted biochemical actions and are involved in the modulation of signaling pathways related to inflammation, oxidative damage, autophagy, apoptosis, etc. Therefore, phenolic compounds can be a complementary or alternative tool in the management of chronic non-communicable diseases (*e.g.,* metabolic syndromes, cancers, and neurodegenerative diseases) (Arruda et al., 2020).

As can be seen in Table 3, the Brazilian Cerrado fruits addressed here showed different qualitative and quantitative profiles of phenolic compounds, which could also vary according to the fruit part analyzed (peel, pulp, or seed). Quercetin, kaempferol, myricetin, (*epi*)catechin, caffeic acid, *p*-coumaric acid, ferulic acid, gallic acid, ellagic acid, syringic acid and their derivatives were the most frequently reported phenolic

Table 2
Recommended Daily Intake (RDI) values of macro- and micronutrients (μg/day, mg/day, or g/day) for adults and nutritional contribution to the RDIs (%) relative to a 100 g serving of the edible parts of five underexploited Brazilian Cerrado fruits.

Nutrient	RDI*	Daily values (%)[#]				
		Cagaita	Gabiroba	Jatobá-do-cerrado	Lobeira	Mangaba
Proximate						
Proteins	50 g	1.26	2.12	11.20	2.74	1.60
Lipids	65 g	0.88	0.85	5.85	1.32	2.62
Carbohydrates	300 g	1.85	3.33	11.37	3.66	0.77
Dietary fiber	25 g	6.04	28.40	177.20	18.16	46.40
Energy value	2000 kcal	1.49	2.46	9.65	2.86	3.24
Minerals						
Iron, Fe	18 mg	64.06	6.28	6.11	1.11	2.78
Zinc, Zn	15 mg	15.40	3.27	6.67	2.67	2.67
Sodium, Na	2400 mg	0.28	0.13	–	–	–
Calcium, Ca	1000 mg	1.54	1.65	85.00	0.64	3.10
Magnesium, Mg	400 mg	16.50	4.38	793.25	2.11	3.20
Potassium, K	3500 mg	3.61	3.73	41.34	11.32	4.61
Phosphorus, P	1000 mg	1.28	1.70	16.70	–	0.92
Manganese, Mn	2 mg	78.00	10.50	635.00	–	–
Copper, Cu	2 mg	31.50	9.50	2.65	16.50	–
Vitamins						
Vitamin C	60 mg	56.85	390.00	14.83	141.87	276.37
Vitamin A	900 μg RAE	5.06	–	3.60	–	0.83
Total compounds with Vitamin E activity	15 mg	–	–	3.30	–	18.22
Total folates	400 μg	6.44	–	13.38	–	24.58

*Recommended Daily Intake (RDI) values refer to the amount of each macro-/micronutrient (μg, mg, or g) recommended daily by the Food and Drug Administration (FDA) for adults and children four or more years of age (FDA, 2013).

[#] Daily values (%) are based on a caloric intake of 2000 kcal, for adults and children four or more years of age (FDA, 2013). The daily values (%) shown are based on values of each macro-/micronutrient (μg, mg, or g) present in a serving of 100 g of fresh edible fruit part. Daily values (%) were calculated according to the following equation: $DV(\%) = 100 \times FA/RDI$, where, FA referes to amount of each macro-/micronutrient (μg, mg, or g) present in 100 g of fresh edible fruit part (values presented in Table 1).

Table 3
A summary of studies showing the phenolic composition of edible parts and by-products of five underexploited Brazilian Cerrado fruits.

Fruit	Fruit part	Sample form	Major findings	Ref.
Cagaita	Pulp	Hydromethanolic extract (80 % methanol)	−Ellagic acid, ellagitannins, and quercetin and kaempferol derivatives were found.	(Donado-Pestana et al., 2015)
	Pulp	Hydromethanolic extract (70 % methanol)	−10 compounds were identified: gallic acid (5.76 mg/100 g), caffeic acid (1.57 mg/100 g), vanillic acid (7.03 mg/100 g), epicatechin (75.19 mg/100 g), *p*-coumaric acid (20.92 mg/100 g), syringic acid (2.50 mg/100 g), ferulic acid (0.61 mg/100 g), salicylic acid (17.55 mg/100 g), quercetin (14.97 mg/100 g), and rutin (4.55 mg/100 g).	(Guedes et al., 2017)
	Pulp	Hydromethanolic extract (70 % methanol)	−5 quercetin derivatives were identified totalizing 1.94 mg of quercetin equivalents/100 g.	(Alves et al., 2017)
	Pulp	Hydroethanolic extract (79 % ethanol)	–Quercetin derivatives were identified totalizing 144 μg/g extract.	(Daza et al., 2017)
	Pulp	Clarified fruit juice	–Syringic acid, quercetin derivates, kaempferol derivates, and ellagic acid (3.68, 0.39, 0.67, and 1.95 mg/100 mL juice) were identified.	(Balisteiro et al., 2017)
	Pulp	Several extracts	−10 phenolic compounds were identified: citropten, delphinidin-3-glucoside, caftaric acid, *p*-coumaric acid hexoside, caffeoyl-*D*-glucose, syringic acid hexoside, dimethylellagic acid hexoside, galloylated caffeic acid hexoside, caffeic acid hexoside dimer, and vitexin.	(Silva et al., 2019)
	Pulp	Aqueous and ethanolic extracts	−6 phenolic compounds were identified in the aqueous extract: ferulic acid derivative, myricetin-pentoside, quercetin-galloyl-glucoside, quercetin-pentoside, kaempferol-glucoside, and kaempferol-pentoside; −7 phenolic compounds were identified in the ethanolic extract: gallic acid, ferulic acid derivative, myricetin-pentoside, quercetin-glucoside, quercetin-pentoside, quercetin-rhamnoside, and kaempferol-pentoside.	(Justino et al., 2020)
	Pulp	Crude extract (combination of hydromethanolic extract (50 % methanol) and acetonic extract (70 % acetone))	−18 phenolic compounds were identified: chrysoeriol, pelargonidin-3-rutinoside, delphinidin-3-*O*-glucoside, delphinidin-3-*O*-arabinoside, 5-pyranopelargonidin-3-glucoside, caftaric acid, *p*-coumaric acid hexoside, galloyl glucose, conidendrin, caffeoyl glucose, chlorogenic acid, syringic acid hexoside, vitexin, dicaffeoylquinic acid, 5′-methoxy-demethylpiperitol-4-*O*-glucoside, coumaroyl iridoid isomer 1, caffeic acid hexoside dimer, and synapic acid dihexoside hydroxy benzoyl.	(Silva et al., 2020)
	Seeds	Ethyl acetate fraction from ethanolic extract	−7 phenolic compounds were identified: gallic acid, myricetin-galloyl-glucoside, myricetin-pentoside, quercetin-galloyl-glucoside, quercetin-glucoside, quercetin-pentoside, and quercetin.	(Justino et al., 2022)
Gabiroba	Pulp	Dichloromethane extract	−5 flavonoids were identified: 7-hydroxy-5-methoxy-6-*C*-methylflavanone, 5,7-dihydroxy-6-*C*-methylflavanone, 5,7-dihydroxy-6,8-di-*C*-methylflavanone, 4′,6′-dihydroxy-3′-methyl-2′-methoxychalcone, and 4′,6′-dihydroxy-3′,5′-dimethyl-2′-methoxychalcone.	(Lima e Silva et al., 2018)
	Pulp	Microencapsulated pulp	−7 flavonoids were identified: 3,5,7,3′,4′,5′-hexahydroxy-flavonol, 3,5,7,3′,4′,5′-hexahydroxy-flavonol-3-*O*-α-L-arabinofuranoside, 3,5,7,3′,4′,5′-hexahydroxy-flavonol-3-*O*-α-L-raminopyranoside, 7-dihydroxy-5-methoxyflavanone, 6-methyl-7-hydroxy-5-methoxyflavanone, 2′,4′-dihydroxy-6′-methoxychalcone, and 2′,4′-dihydroxy-5′-methyl-6′-methoxychalcone.	(Viscardi et al., 2017)
	Pulp	Hydromethanolic extract (70 % methanol)	–The flavonoid catechin was found (23.32 mg/100 g).	(Alves et al., 2017)
	Peel	Hydroethanolic extract (70 % ethanol)	−9 flavonoids were identified: myricitrin, quercetin, myricetin, 5,7-dihydroxy-6-*C*-methylflavanone, 5,7-dihydroxy-8-*C*-methylflavanone, 2′,4′-dihydroxy-6′-methoxychalcone, 7-hydroxy-5-methoxy-6-*C*-methylflavavone, 5,7-dihydroxy-6,8-di-*C*-methylflavanone, and 2′,4′-dihydroxy-3′,5′-dimethyl-6′-methoxychalcone.	(de Souza et al., 2017)
	Peel	Methanolic extract	−6 flavonoids were identified: 7-hydroxy-5-methoxy-6-*C*-methylflavavone (129.12 mg/g), 5,7-dihydroxy-6-*C*-methylflavanone (138.34 mg/g), 5,7-dihydroxy-8-*C*-methylflavanone (155.16 mg/g), 5,7-dihydroxy-6,8-di-*C*-methylflavanone (39.17 mg/g), 2′,4′-dihydroxy-5′-methyl-6′-methoxychalcone (54.12 mg/g), and 2′,4′-dihydroxy-3′,5′-dimethyl-6′-methoxychalcone (53.04 mg/g).	(Lescano et al., 2018)
	Whole fruit	Ethyl acetate extract and methanolic fraction from hexane extract	−6 flavonoids were identified: 7-hydroxy-5-methoxy-6-*C*-methylflavanone, 5,7-dihydroxy-6-*C*-methylflavanone, 5,7-dihydroxy-8-*C*-methylflavanone, 5,7-dihydroxy-6,8-di-*C*-methylflavanone, 2′,4′-dihydroxy-6′-methoxychalcone, and 2′,4′-dihydroxy-3′,5′-dimethyl-6′-methoxychalcone.	(Cardoso et al., 2010; Pavan et al., 2009)
	Whole fruit	Ethanolic extract	–The flavonoid cardamonin was found (5.40 ± 13.07 μg/mg).	(Pascoal et al., 2014)
Jatobá-do-cerrado	Pulp	Methanolic extract	–Catechin and gallic acid derivatives were found.	(Orsi et al., 2012)
	Pulp	Crude extract (combination of hydroacetonic extract (70 % acetone) and hydroethanolic extract (60 % ethanol))	−13 compounds were identified: salicylic acid, caffeic acid, gentisic acid, *p*-coumaric acid, 3-*O*-feruloylquinic acid, diphyllin, chrysin, quercetin-3-rhamnoside, kaempferol, elemicin, isoxanthohumol, 7-methyljuglone, and pyrogallic acid.	(da Silva et al., 2019)
	Pulp	Ethanolic and aqueous extracts	–Epicatechin was found in both extracts, while kaempferol-3-*O*-rutinoside was found only in the ethanolic extract.	(Ferreira et al., 2021)

(*continued on next page*)

Table 3 (*continued*)

Fruit	Fruit part	Sample form	Major findings	Ref.
	Peel	Ethanolic extract	–The flavonoid rutin was found (2.802 mg/g).	(Peres et al., 2013)
	Seeds	Methanolic extract	–Gallic acid and myricetin were found (9.593 and 4.326 μg/g, respectively).	(Vagula et al., 2019)
Lobeira	Pulp + seeds	Ethanolic extract	−7 phenolic compounds were identified: 3,5-di-*O*-*E*-caffeoylquinic acid, 4,5-di-*O*-*E*-caffeoylquinic acid, *O*-coumaroyl caffeoylquinic acid, 3,4,5-tri-*O*-*E*-tricaffeoylquinic acid, 2 isomers of *O*-coumaroyl dicaffeoylquinic acid, and *O*-caffeoyl dicoumaroylquinic acid.	(Morais et al., 2020)
	Pulp + seeds	Ethyl acetate and hydroethanolic fractions from ethanolic extract	−16 phenolic compounds were identified: 3-*O*-*E*-caffeoylquinic acid, caffeic acid, 5-*O*-*E*-caffeoylquinic acid, 4-*O*-coumaroylquinic acid, *N*1,*N*10-bis-(dihydrocaffeoyl)spermidine, 5-*O*-coumaroylquinic acid, di-*O*-*E*-caffeoylquinic acid, 3,5-di-*O*-*E*-caffeoylquinic acid, 4,5-di-*O*-*E*-caffeoylquinic acid, 3 isomers of *O*-coumaroyl caffeoylquinic acid, 3,4,5-tri-*O*-*E*-tricaffeoylquinic acid, 2 isomers of *O*-coumaroyl dicaffeoylquinic acid, and *O*-caffeoyl dicoumaroylquinic acid.	(Morais et al., 2022)
	Pulp, peel, and seeds	Hydroethanolic extract (70 % ethanol)	−16 phenolic compounds were identified in fruit parts: caffeoylputrescine, 3-*O*-caffeoylquinic acid, caffeoyl-*O*-glucoside, dihydrocaffeoyl-*O*-glucoside, *p*-coumaroyl-*O*-glucoside, dihydroferulic acid glucoside, *p*-coumaroyl-*O*-frutofuranosylglucose, 5-*O*-caffeoylquinic acid, 1-*O*-feruloylglucose, 1-*O*-sinapoyl-glucoside, *p*-coumaroylquinic acid, sinapoyl-*O*-frutofuranosylglucose, rutin, kaempferol-diglucoside, di-*O*-caffeoylquinic acid, and tri-*O*-caffeoylquinic acid.	(Pereira et al., 2019)
Mangaba	Pulp	Exhaustive extraction (free phenolics were extracted with 50 % methanol followed by 70 % acetone, while the conjugated phenolics were obtained by acid hydrolysis of the remaining residue)	−16 phenolic compounds were identified: gentisic acid (9399.74 mg/100 g), protocatechuic acid (998.41 mg/100 g), salicylic acid (426.52 mg/100 g), myricetin (188.64 mg/100 g), catechin (181.99 mg/100 g), rutin (77.23 mg/100 g), ellagic acid (51.29 mg/100 g), ferulic acid (46.82 mg/100 g), syringic acid (40.45 mg/100 g), quercetin (39.22 mg/100 g), gallic acid (31.30 mg/100 g), *p*-coumaric acid (23.42 mg/100 g), vanillic acid (21.83 mg/100 g), *trans*-cinnamic acid (3.47 mg/100 g), kaempferol (3.36 mg/100 g), and hesperetin (2.98 mg/100 g).	(Dutra et al., 2017)
	Pulp	Hydromethanolic extract (90 % methanol)	−3 phenolic compounds were identified: chlorogenic acid (93.71–131.66 mg/100 g), ferulic acid (0.85–2.27 mg/100 g), and rutin (238.59–442.94 mg/100 g).	(Santos et al., 2021)
	Pulp	Hydromethanolic extract (70 % methanol)	−10 phenolic compounds were identified: gallic acid (0.12 mg/100 g), catechin (1.70 mg/100 g), chlorogenic acid (0.32 mg/100 g), caffeic acid (0.35 mg/100 g), *p*-coumaric acid (0.06 mg/100 g), ferulic acid (0.27 mg/100 g), *m*-coumaric acid (0.13 mg/100 g), quercetin (3.13 mg/100 g), *trans*-cinnamic acid (0.06 mg/100 g), and rutin (0.82 mg/100 g).	(Zitha et al., 2022)
	Pulp	Fermented beverage	−20 phenolic compounds were identified: gentisic acid (19.6–24.8 mg/g extract), gallic acid (12–36 mg/g extract), salicylic acid (2.8–10 mg/g extract), 4-hydroxybenzoic acid (n.d.-6.4 mg/g extract), protocatechuic acid (n.d.-27.2 mg/g extract), caffeic acid (3.0–3.2 mg/g extract), vanillic acid (2.0–4.4 mg/g extract), *p*-coumaric acid (n.d.-0.6 mg/g extract), *trans*-cinnamic acid (n.d.-0.4 mg/g extract), synaptic acid (n.d.-0.6 mg/g extract), rosmarinic acid (0.8–1.2 mg/g extract), syringic acid (0.2–0.8 mg/g extract), rutin (15.6–18 mg/g extract), quercetin (0.6–0.8 mg/g extract), hesperetin (0.2–0.6 mg/g extract), naringenin (n.d-0.6 mg/g extract), catechin (4.8–9.8 mg/g extract), myricetin (n.d.-2.8 mg/g extract), chrysin (1.0–1.2 mg/g extract), and kaempferol (n.d.-0.6 mg/g extract).	(Almeida et al., 2021)
	Whole fruit	Aqueous extract	–Chlorogenic acid and rutin were identified and 1 other unidentified phenolic compound.	(Torres-Rêgo et al., 2016)
	Whole fruit	Methanolic extract	−12 phenolic compounds were identified: *trans*-chlorogenic acid, *cis*-chlorogenic acid, vanillin, *trans*-feruloyquinic acid, quercetin-3-*O*-rhaminogalactoside, rutin, quercetin-3-*O*-galactoside, quercetin-pentoside, quercetin, kaempferol-3-*O*-rutinoside, kaempferol-3-*O*-(*p*-coumaroyl)-rhamnogalactoside, and isorhamnetin-3-*O*-rutinoside.	(Marques et al., 2018)
	Whole fruit	Aqueous extract	−10 phenolic compounds were identified: chlorogenic acid, isochlorogenic acid, 3-feruloylquinic acid, rutin, 5-feruloylquinic acid, quercetin-3-*O*-hexoside, kaempferol-rutinoside, kaempferol-hexoside, isorhamnetin-3-*O*-rutinoside, and quercetin.	(de Yamashita et al., 2020)
	Whole fruit	Aqueous extract	−16 phenolic compounds were identified: 1-*O*-caffeoylquinic acid, protocatechuic aldehyde, gentisic acid, chlorogenic acid, caffeic acid, catechin, orientin, *trans*-*ortho*-coumaric acid, 5-*O*-caffeoylquinic acid methyl ester, phenyl pyruvic acid, rutin, calceolarioside A, [(2R,3R,4S,5R,6R)-6-[2-(3,4-dihydroxyphenyl)ethoxy]-3,5-dihydroxy-4-[(3R,4R,5R,6S)-3,4,5-trihydroxy-6-methyloxan-2-yl]oxyoxan-2-yl]methyl(E)-3-(3,4-dihydroxyphenyl)prop-2-enoate, kaempferol-3-*O*-rutinoside, avicularin, and quercetin.	(Santos et al., 2022)

compounds in these Brazilian Cerrado fruits.

Quercetin and its derivatives were reported in the cagaita pulp (quecetin, rutin, quercetin-galloyl-glucoside, quercetin-pentoside, quercetin-glucoside, and quercetin-rhamnoside) (Alves et al., 2017; Balisteiro et al., 2017; Daza et al., 2017; Donado-Pestana et al., 2015; Guedes et al., 2017; Justino et al., 2020), cagaita seeds (quercetin-galloyl-glucoside, quercetin-glucoside, quercetin-pentoside, and quercetin) (Justino et al., 2022), gabiroba peel (quercetin) (de Souza et al., 2017), jatobá-do-cerrado peel (rutin) (Peres et al., 2013), jatobá-do-cerrado pulp (quercetin-3-rhamnoside) (da Silva et al., 2019), lobeira peel and seeds (rutin) (Pereira et al., 2019), and mangaba pulp (quercetin, rutin, quercetin-3-*O*-hexoside, quercetin-3-*O*-rhaminogalactoside, quercetin-3-*O*-galactoside, quercetin-pentoside, and avicularin) (Almeida et al., 2021; Dutra et al., 2017; Marques et al., 2018; Santos et al., 2021; Santos et al., 2022; Torres-Rêgo et al., 2016; de Yamashita et al., 2020; Zitha et al., 2022). The literature has pointed out the antioxidant, anti-inflammatory, antiproliferative, anticarcinogenic, antidiabetic, antiviral, and anti-plated aggregation properties of quercetin, as well as its use in the treatment of neurodegenerative diseases, cancer, cardiovascular disorders, diabetes, allergic reactions, inflammation, and arthritis (Deepika & Maurya, 2022).

Kaempferol and its derivatives were found in the cagaita pulp (kaempferol, kaempferol-glucoside, and kaempferol-pentoside) (Balisteiro et al., 2017; Donado-Pestana et al., 2015; Justino et al., 2020), jatobá-do-cerrado pulp (kaempferol and kaempferol-3-*O*-rutinoside) (Ferreira et al., 2021; da Silva et al., 2019), lobeira peel and seeds (kaempferol-diglucoside) (Pereira et al., 2019), and mangaba pulp (kaempferol, kaempferol-hexoside, kaempferol-3-*O*-(*p*-coumaroyl)-rhamnogalactoside, and kaempferol-3-*O*-rutinoside) (Almeida et al., 2021; Dutra et al., 2017; Marques et al., 2018; Santos et al., 2022; de Yamashita et al., 2020). Studies have shown that kaempferol improves the antioxidant defense system and acts in the modulation of key components of cellular transduction pathways related to angiogenesis, apoptosis, metastasis, and inflammation, protecting normal cells while inhibiting the proliferation of cancer cells (Chen & Chen, 2013).

Myricetin and its derivatives were identified in the cagaita pulp (myricetin-pentoside) (Justino et al., 2020), cagaita seeds (myricetin-galloyl-glucoside and myricetin-pentoside) (Justino et al., 2022), gabiroba peel (myricitrin and myricetin) (de Souza et al., 2017), jatobá-do-cerrado seeds (myricetin) (Vagula et al., 2019), and mangaba pulp (myricetin) (Almeida et al., 2021; Dutra et al., 2017). Therapeutic investigations have shown that myricetin is an effective gastroprotective, antidiabetic, anti-inflammatory, antiatherosclerotic, antioxidant, hypoglycemic, and cytoprotective agent (Pujari & Mishra, 2021).

Catechin and its isomer epicatechin were found in the cagaita pulp (epicatechin) (Guedes et al., 2017), jatobá-do-cerrado pulp (catechin and epicatechin) (Ferreira et al., 2021; Orsi et al., 2012), and mangaba pulp (catechin) (Almeida et al., 2021; Dutra et al., 2017; Santos et al., 2022; Zitha et al., 2022). High intakes of catechin and/or epicatechin have been associated with a lower risk of developing pancreatic cancer, esophageal cancer, and type 2 diabetes; reduced oxidative stress biomarkers; and lower mortality from cardiovascular disease (Arruda et al., 2018).

Caffeic acid and *p*-coumaric acid and their derivatives were present in the cagaita pulp (caffeic acid, caftaric acid, caffeoyl glucose, dicaffeoylquinic acid, galloylated caffeic acid hexoside, caffeic acid hexoside dimer, *p*-coumaric acid, *p*-coumaric acid hexoside, coumaroyl iridoid isomer 1, and chlorogenic acid) (Guedes et al., 2017; Silva et al., 2019, Silva et al., 2020), jatobá-do-cerrado pulp (caffeic acid and *p*-coumaric acid) (da Silva et al., 2019), pulp, peel and seeds of lobeira (caffeic acid, 3-*O*-caffeoylquinic acid, 5-*O*-caffeoylquinic acid, caffeoyl-*O*-glucoside, dihydrocaffeoyl-*O*-glucoside, 3,5-di-*O*-E-caffeoylquinic acid, 4,5-di-*O*-E-caffeoylquinic acid, di-*O*-E-caffeoylquinic acid, 3,4,5-tri-*O*-E-tri-caffeoylquinic acid, *O*-caffeoyl dicoumaroylquinic acid, caffeoylputrescine,3 isomers of *O*-coumaroyl caffeoylquinic acid, 2 isomers of *O*-coumaroyl dicaffeoylquinic acid, 4-*O*-coumaroylquinic acid, 5-*O*-coumaroylquinic acid, *p*-coumaroyl-*O*-glucoside, *p*-coumaroyl-*O*-fruto-furanosylglucose, *O*-caffeoyl dicoumaroylquinic acid, *p*-coumaroylquinic acid, and *N*1,*N*10-bis-(dihydrocaffeoyl)spermidine) (Morais et al., 2020, 2022; Pereira et al., 2019), and mangaba pulp (*p*-coumaric acid, *m*-coumaric acid, *trans*-chlorogenic acid, *cis*-chlorogenic acid, isochlorogenic acid, 1-*O*-caffeoylquinic acid, caffeic acid, *trans-ortho*-coumaric acid, and 5-*O*-caffeoylquinic acid methyl ester) (Almeida et al., 2021; Dutra et al., 2017; Marques et al., 2018; Santos et al., 2021; Santos et al., 2022; Torres-Rêgo et al., 2016; de Yamashita et al., 2020; Zitha et al., 2022). Caffeic acid exhibits several health benefits related to its antioxidant properties, including the prevention of inflammation, cancers, diabetes and neurodegenerative diseases (Birková, 2020). While *p*-coumaric acid has antimutagenic, antigenotoxic, and antimicrobial activities, inhibits the cellular melanogenesis, regulates the immune system, and reduces LDL-cholesterol peroxidation and the risk of stomach cancer (Kiliç & Yeşiloğlu, 2013).

Ferulic acid and its derivatives were reported in the cagaita pulp (ferulic acid and ferulic acid derivative) (Guedes et al., 2017; Justino et al., 2020), jatobá-do-cerrado pulp (3-*O*-feruloylquinic acid) (da Silva et al., 2019), pulp, peel and seeds of lobeira (dihydroferulic acid glucoside and 1-*O*-feruloylglucose) (Pereira et al., 2019), and mangaba pulp (ferulic acid, *trans*-feruloyquinic acid, 3-feruloylquinic acid, and 5-feruloylquinic acid) (Dutra et al., 2017; Marques et al., 2018; Santos et al., 2021; de Yamashita et al., 2020; Zitha et al., 2022). Ferulic acid is a phytochemical that has several biological activities, including antioxidant, anti-inflammatory, antimicrobial, antiallergic, hepatoprotective, anticarcinogenic, antithrombotic, antiviral, and vasodilatory activities, in addition to having the ability to increase sperm viability and modulate enzymatic activity and gene expression (Kumar & Pruthi, 2014).

Gallic acid and its derivatives were detected in the cagaita pulp (gallic acid, galloyl glucose, galloylated caffeic acid hexoside, and quercetin-galloyl-glucoside) (Guedes et al., 2017; Justino et al., 2020; Silva et al., 2019, Silva et al., 2020), cagaita seeds (gallic acid, myricetin-galloyl-glucoside, and quercetin-galloyl-glucoside) (Justino et al., 2022), jatobá-do-cerrado pulp (gallic acid and pyrogallic acid) (Orsi et al., 2012; da Silva et al., 2019), jatobá-do-cerrado seeds (gallic acid) (Vagula et al., 2019), and mangaba pulp (gallic acid) (Almeida et al., 2021; Dutra et al., 2017; Zitha et al., 2022). Several bioactivities have been attributed to gallic acid, among which the anti-inflammatory, antibiotic, anticarcinogenic, antioxidant, and cardioprotective properties stand out (Salas et al., 2013).

Ellagic acid and its derivatives were identified only in the cagaita pulp (ellagic acid and dimethylellagic acid hexoside) (Balisteiro et al., 2017; Donado-Pestana et al., 2015; Silva et al., 2019) and mangaba pulp (ellagic acid) (Dutra et al., 2017). Antioxidant, antimutagenic, anti-inflammatory, and anticarcinogenic activities have been some of the biological activities attributed to ellagic acid (Vattem & Shetty, 2005).

Syringic acid and its derivatives were found only in the cagaita pulp (syringic acid and syringic acid hexoside) (Balisteiro et al., 2017; Guedes et al., 2017; Silva et al., 2019, Silva et al., 2020) and mangaba pulp (syringic acid) (Almeida et al., 2021; Dutra et al., 2017). Several biological activities have been related to syringic acid such as antioxidant, antimicrobial, anticarcinogenic, anti-inflammatory, antidiabetic, cardioprotective, hepatoprotective, and neuroprotective effects (Srinivasulu et al., 2018).

Gentisic acid, its isomer protocatechuic acid, and their derivatives were reported only in the jatobá-do-cerrado pulp (gentisic acid) (da Silva et al., 2019) and mangaba pulp (protocatechuic acid, protocatechuic aldehyde, and gentisic acid) (Almeida et al., 2021; Dutra et al., 2017; Santos et al., 2022). The literature has noticed that these compounds can act as anti-inflammatory, antigenotoxic, anticarcinogenic, antidiabetic, antihyperlipidemic, antimicrobial, antioxidant, hepatoprotective, and neuroprotective (Abedi et al., 2020; Kakkar & Bais, 2014).

Salicylic acid was found in the pulps of cagaita (Guedes et al., 2017),

jatobá-do-cerrado (da Silva et al., 2019), and mangaba (Almeida et al., 2021; Dutra et al., 2017). Scientific investigations have shown that this phenolic compound is a potent analgesic and anti-inflammatory agent and is widely used in the treatment of rheumatic diseases and the prevention of coronary artery and cerebrovascular thrombosis (Chen et al., 2018).

Many other phenolic compounds were found less frequently in these Brazilian Cerrado fruits. However, they can contribute, to a greater or lesser extent, to the maintenance of general health and well-being and the prevention/treatment of diseases associated with the consumption of these fruits.

Among the Brazilian Cerrado fruits addressed in this review, gabiroba presented the most unique phenolic compounds profile. A number of unusual flavonoids and chalcones have been identified in the edible parts of this fruit, among which we can mention 7-hydroxy-5-methoxy-6-*C*-methylflavanone, 5,7-dihydroxy-6-*C*-methylflavanone, 5,7-dihydroxy-6,8-di-*C*-methylflavanone, 5,7-dihydroxy-8-*C*-methylflavanone, 4′,6′-dihydroxy-3′-methyl-2′-methoxychalcone, 4′,6′-dihydroxy-3′,5′-dimethyl-2′-methoxychalcone, 2′,4′-dihydroxy-6′-methoxychalcone, 2′,4′-dihydroxy-3′,5′-dimethyl-6′-methoxychalcone, 2′,4′-dihydroxy-5′-methyl-6′-methoxychalcone, 3,5,7,3′,4′,5′-hexahydroxy-flavonol, 3,5,7,3′,4′,5′-hexahydroxy-flavonol-3-*O*-α-L-arabinofuranoside, 3,5,7,3′,4′,5′-hexahydroxy-flavonol-3-*O*-α-L-raminopyranoside, 7-dihydroxy-5-methoxyflavanone, and 6-methyl-7-hydroxy-5-methoxyflavanone. These compounds are potent chemoprotective, antiproliferative, analgesic, antioxidant, and anti-inflammatory (Cardoso et al., 2010; de Souza et al., 2017; Lescano et al., 2018; Lima e Silva et al., 2018; Pavan et al., 2009; Viscardi et al., 2017). Moreover, Pascoal et al. (2014) found a chalcone called cardamonin in the gabiroba, which has several pharmacological activities, including anti-inflammatory, antineoplastic, antioxidant, vasorelaxant, hypoglycemic, and anti-infectious activities (Gonçalves et al., 2014).

The lobeira also presented a distinct phenolic compounds profile. Researches conducted by Pereira et al. (2019), Morais et al. (2020), and Morais et al. (2022) demonstrated that lobeira is essentially composed of phenolic acids derived from caffeic acid and *p*-coumaric acid. As pointed out earlier, these phenolic compounds and their derivatives present a series of biological activities.

Recent studies have reported the capacity of phenolic-rich extracts obtained from these Brazilian Cerrado fruits in the prevention, management, and/or treatment of some pathological conditions (see **Section 6** for more details). Therefore, the edible part of these fruits can be a novel functional ingredient for the development of functional foods, while their by-products seem to offer a potential plant raw material for pharmaceutical and cosmetic formulations. Despite this, there is an urgent need for a more in-depth characterization of the phenolic compounds profile present in these Brazilian Cerrado fruits as well as the quantification of each compound individually, since both the profile and the content of these compounds have a great effect on their biological activities.

6. Biological activities

The presence of several phenolic compounds in Brazilain Cerrado fruits (as summarized above) can contribute to a wide variety of health benefits. Brazilian Cerrado plants and fruits have been used for centuries by folk medicine for treating various pathological conditions. Moreover, recent studies have shown that phenolic-rich extracts and/or phenolic compounds isolated from these fruits present several biological activities, as described in the sections below (Table 4).

6.1. Antioxidant and anti-inflammatory activities

Antioxidants are molecules capable of inhibiting, reducing, or slowing oxidative processes in other molecules by sequestering reactive oxygen and/or nitrogen species (ROS/RNS), chelating transition metals, donating hydrogen atoms and/or electrons, inhibiting enzymes involved in oxidative stress, and regulating and/or protecting the endogenous defense system (Arruda et al., 2019; Gülçin, 2012). As can be seen in Table 4, some studies have shown that Brazilian Cerrado fruits and their by-products have a high capacity to inactivate reactive species. Furthermore, recent studies have found that the outcomes obtained for the antioxidant capacity of native Brazilian fruits were highly correlated with their anti-inflammatory activity (Infante et al., 2016; Lazarini et al., 2016; Soares et al., 2019). Several diseases have their origin in inflammatory processes, such as rheumatoid arthritis, multiple sclerosis, psoriasis, asthma, cancer, atherosclerosis, obstructive pulmonary disease, diabetes, cardiovascular diseases, cataracts, macular degeneration, neurodegenerative diseases, etc. (Chisté et al., 2012; Lazarini et al., 2016). This silent inflammatory process is mainly caused by ROS/RNS that trigger an oxidative stress process at both the cellular and subcellular levels, inducing excessive damage to cells and tissues, and ultimately leading to the destruction of normal tissue and chronic inflammation (Rimessi et al., 2016). These ROS/RNS can stimulate important intracellular signaling pathways culminating in the activation of nuclear factors, such as NF-κB. Once activated, this factor initiates the transcription of genes related to inflammation, leading to an increase in the synthesis and release of pro-inflammatory proteins, particularly TNF-α and IL-1β cytokines, CXCL1/KC and CXCL2/MIP-2 chemokines, lipid mediator leukotriene B4, among others (Lazarini et al., 2016; Soares et al., 2019).

In vitro and *in vivo* studies have shown that extracts obtained from different parts of the Brazilian Cerrado fruits have antioxidant and/or anti-inflammatory activity (see Table 4). *In vitro* assays (*e.g.,* DPPH, TEAC, ORAC, FRAP, β-carotene/linoleic acid system, etc.) showed that extracts of cagaita (pulp, peel, and seeds) (Daza et al., 2017; Jorge et al., 2010; Justino et al., 2020, 2022; Roesler et al., 2007; de Siqueira et al., 2013), gabiroba (pulp, peel, and seeds) (Alves et al., 2013; de Fernandes et al., 2015; Lescano et al., 2018; Machate et al., 2020), jatobá-do-cerrado (pulp, peel, and seeds) (Figueiredo et al., 2016; de Filho et al., 2019; de Menezes Filho et al., 2020; Orsi et al., 2014; Peres et al., 2013; da Silva et al., 2014; de Siqueira et al., 2013; Vagula et al., 2019), lobeira (pulp, peel, and seeds) (Morais et al., 2022; Pereira et al., 2019; de Siqueira et al., 2013), and mangaba (pulp and seeds) (da Silva & Jorge, 2020; de Siqueira et al., 2013; Zitha et al., 2022) exert antioxidant activity by the inhibition/scavenging of free radicals and ROS/RNS, chelation of transition metals, and donation of hydrogen atoms and/or electrons. Several bioactive compounds present in these fruits can explain their antioxidant potential, with different phenolic compounds standing out (see Table 3).

Studies in animal models and clinical trials have proven the *in vivo* antioxidant potential of the edible parts and/or by-products of some of these Brazilian Cerrado fruits. Donado-Pestana et al. (2015) observed that the oral administration of a phenolic-rich extract obtained from cagaita pulp (14 mg GAE/kg/day) for 8 weeks was able to improve the antioxidant status of the plasma of mice receiving an HF/HS diet. In another study with cagaita pulp, Balisteiro et al. (2017) reported that the intake of 300 mL of clarified cagaita juice also improved the antioxidant status of the plasma of healthy subjects. Several phenolic compounds have been identified in cagaita pulp and may be related to the antioxidant effects observed, among which we can highlight ellagic acid, ellagitannins, quercetin and kaempferol derivatives, and proanthocyanidins (Balisteiro et al., 2017; Donado-Pestana et al., 2015).

Jatobá-do-cerrado pulp also presented antioxidant properties *in vivo*. The addition of 10 % of jatobá-do-cerrado pulp to the diet of rats with acetic acid-induced gastric and duodenal ulcers was able to prevent glutathione depletion in healing duodenal ulcers within 7 or 14 consecutive days of treatment (Orsi et al., 2012). In another study conducted by the same group, Orsi et al. (2014) have shown that the administration of a diet containing 10 % of jatobá-do-cerrado pulp for 23 days reduced lipid peroxidation and prevented glutathione depletion in the colon of rats with trinitrobenzesulphonic acid-induced colonic

Table 4
A summary of studies showing the biological activities of phenolic compounds from edible parts and by-products of five underexploited Brazilian Cerrado fruits.

Fruit	Fruit part	Bioactivity	Sample form	Method/model	Major findings	Related compounds	Ref.
Cagaita	Pulp	Antioxidant	Ethyl acetate and aqueous extracts	DPPH, FRAP, and β-carotene/linoleic acid system based *in vitro* assays	-Aqueous extract showed higher antioxidant activity than ethyl acetate extract for all assays (72.7 μmol TE/g, 107 μmol Fe_2SO_4/g, and 16.4 % inhibition/g against 21.5 μmol TE/g, 19.6 μmol Fe_2SO_4/g, and 0.6 % inhibition/g).	Phenolic compounds (compounds were not identified)	(de Siqueira et al., 2013)
	Pulp	Antioxidant	Encapsulated and freeze-dried hydroethanolic extract (79 % ethanol)	DPPH, FRAP, and ORAC based *in vitro* assays	-Freeze-dried showed higher antioxidant values for all methods (138, 358, and 273 μmol TE/g for DPPH, FRAP, and ORAC, respectively).	Phenolic compounds, especially quercetin derivatives	(Daza et al., 2017)
	Pulp	Antioxidant	Aqueous and ethanolic extracts	DPPH and ORAC based *in vitro* assays	-Aqueous and ethanolic extracts showed similar antioxidant values for DPPH (IC_{50} 0.24 and 0.22 mg/mL, respectively); -Ethanolic extract showed a higher antioxidant value for ORAC than aqueous extract (0.28 and 0.15 mmol TE/g, respectively).	Phenolic compounds (see Table 3), especially gallic acid, ferulic acid, quercetin, myricetin, and kaempferol derivatives	(Justino et al., 2020)
	Pulp	Antiobesity	Hydromethanolic extract (80 % methanol)	C57BL/6J mice receiving HF/HS diet and 7 or 14 mg GAE/kg b.w. for 8 weeks	-↓body weight gain and fat accumulation induced by HF/HS diet; -↓fasting hyperglycemia, hypertriglyceridemia, and hypercholesterolemia; -↓plasma creatinine; -↓liver TG; -↑plasma antioxidant status; -↑fecal triglycerides excretion.	Phenolic compounds, particularly ellagic acid, ellagitannins, proanthocyanidins, and quercetin and kaempferol derivatives	(Donado-Pestana et al., 2015)
	Pulp	Antiobesity	Hydromethanolic extract (80 % methanol)	HF/HS diet-induced obese C57BL/6J mice receiving 7 or 14 mg GAE/kg b.w. for 8 weeks	-↑carbohydrates oxidation and energy expenditure; -↓adipocyte size; -↓fasting hyperglycemia, hyperinsulinemia, hypertriglyceridemia, and hypercholesterolemia; -↓NEFA and LDL-c levels; -↓serum ALT activity; -↓expression of PCX and TNF-α and phosphorylation of NF-κB in the liver.	Phenolic compounds, particularly ellagic acid, ellagitannins, quercetin and kaempferol derivatives, and proanthocyanidins	(Donado-Pestana et al., 2018)
	Pulp	Antidiabetic	Encapsulated and freeze-dried hydroethanolic extract (79 % ethanol)	*In vitro* α-amylase and α-glucosidase inhibition assays	-↓α-amylase (IC_{50} 9.8–107 and 0.12 mg/mL for freeze-dried and encapsulated extracts, respectively) and α-glucosidase (IC_{50} 5.7–159 and 0.07 mg/mL for freeze-dried and encapsulated extracts, respectively) activities.	Phenolic compounds, especially quercetin derivatives	(Daza et al., 2017)
	Pulp	Antidiabetic	Phenolic compounds obtained by solid-phase extraction using polyamide and C18 cartridges	*In vitro* α-amylase and α-glucosidase inhibition assays	-↓α-amylase and α-glucosidase activities.	Phenolic compounds, particularly syringic acid, quercetin and kaempferol derivatives, ellagic acid, ellagitannins, and proanthocyanidins	(Balisteiro et al., 2017)
	Pulp	Antidiabetic	Aqueous and ethanolic extracts	*In vitro* α-amylase, α-glucosidase, and glycation inhibition assays	-Aqueous and ethanolic extracts had similar antiglycation (IC_{50} 0.381 and 0.341 mg/mL, respectively) and α-glucosidase inhibitory (approximately 80 % inhibition at 10 mg/mL) activities; -The extracts were not effective against α-amylase (<40 % inhibition at 10 mg/mL).	Phenolic compounds (see Table 3), especially gallic acid, ferulic acid, quercetin, myricetin, and kaempferol derivatives	(Justino et al., 2020)
	Pulp	Antidiabetic	Clarified fruit juice	23 healthy subjects (29 ± 6 years old; 17 females and 6 males) ingested 300 mL of juice together with a portion of 50 g of white bread	-↓postprandial glycemia; -↑plasma antioxidant status.	Phenolic compounds, particularly syringic acid, quercetin and kaempferol derivatives, ellagic acid,	(Balisteiro et al., 2017)

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Table 4 (*continued*)

Fruit	Fruit part	Bioactivity	Sample form	Method/model	Major findings	Related compounds	Ref.
						ellagitannins, and proanthocyanidins	
	Pulp	Antidiabetic	Clarified fruit juice	12 dysglycemic females with metabolic syndrome (45 ± 11 years old) ingested 300 mL of juice together with a portion of 50 g of white bread	-↓postprandial glycemia and insulinemia; -↓GIP and C-peptide levels; -Ellagitannins from cagaita were metabolized by gut microbiota to urolithins A and B in their conjugated forms (glucuronides).	Ellagitannins	(de Araujo et al., 2021)
	Pulp, peel, and seeds	Antidiabetic	Ethanolic extract	*In vitro* α-amylase, α-glucosidase, and glycation inhibition assays	-Seed end peel extracts had the best antiglycation activity (IC_{50} 28.9 and 60.7 μg/mL) and inhibitory effect against α-glucosidase (IC_{50} 3.0 and 0.7 μg/mL).	Phenolic compounds, especially gallic acid and quercetin and myricetin derivatives (see Table 3)	(Justino et al., 2022)
	Pulp	Antibacterial	Encapsulated and freeze-dried hydroethanolic extract (79 % ethanol)	*In vitro* antibacterial activity against *Staphylococcus aureus* ATCC 29213, *Escherichia coli* ATCC 8739, *Enterobacter aerogenes* ATCC 13048, *Listeria monocytogenes* ATCC 7644, *Salmonella typhimurium* ATCC 14028, and *Salmonella enteritidis* ATCC 13,076	-↓growth of *S. aureus* (MIC 0.16–4.44 and 0.024 mg/mL for freeze-dried and encapsulated extracts, respectively) and *L. monocytogenes* (MIC 0.16–1.48 and 0.012 mg/mL for freeze-dried and encapsulated extracts, respectively).	Phenolic compounds, especially quercetin derivatives	(Daza et al., 2017)
	Pulp and seeds	Antioxidant	Aqueous and ethanolic extracts	DPPH based *in vitro* assay	-Seeds extracts had the highest values by using both solvents (IC_{50} 14.15 and 247.93 μg/mL for ethanolic and aqueous extracts, respectively); -Ethanolic extracts (IC_{50} 14.15 and 387.47 μg/mL for seeds and pulp extracts, respectively) were more active than aqueous extracts (IC_{50} 247.93 and 879.33 μg/mL for seeds and pulp extracts, respectively).	Phenolic compounds (compounds were not identified)	(Roesler et al., 2007)
	Pulp, peel, and seeds	Antioxidant	Ethanolic extract	DPPH, FRAP, and ORAC based *in vitro* assays	-Seed extract showed higher antioxidant values for ORAC and FRAP methods (1220.0 and 295.1 μmol TE/g, respectively); -Seed and peel extracts had similar DPPH values (IC_{50} 23.8 and 21.5 μg/mL, respectively).	Phenolic compounds, especially gallic acid and quercetin and myricetin derivatives (see Table 3)	(Justino et al., 2022)
	Seeds	Antioxidant	Ethanolic extract	DPPH based *in vitro* assay	-IC_{50} 40.63 μg/mL.	–	(Jorge et al., 2010)
	Seeds	Antioxidant	Hexane, dichloromethane, ethyl acetate, *n*-butanol, and aqueous fractions from ethanolic extract	DPPH, FRAP, and ORAC based *in vitro* assays	-Ethyl acetate fraction showed the highest antioxidant values (5613 and 1548 μmol TE/g for ORAC and FRAP assays, and IC_{50} 33.1 μg/mL for DPPH).	Phenolic compounds, especially gallic acid and quercetin and myricetin derivatives (see Table 3)	(Justino et al., 2022)
	Seeds	Antidiabetic	Hexane, dichloromethane, ethyl acetate, *n*-butanol, and aqueous fractions from ethanolic extract	*In vitro* α-amylase, α-glucosidase, and glycation inhibition assays	-Ethyl acetate fraction showed the best antiglycation activity (IC_{50} 3.5 μg/mL) and inhibitory effect against α-amylase and α-glucosidase (IC50 4.2 and 2.6 μg/mL, respectively).	Phenolic compounds, especially gallic acid and quercetin and myricetin derivatives (see Table 3)	(Justino et al., 2022)
Gabiroba	Pulp	Anti-inflammatory and antinociceptive	Microencapsulated pulp (MPCA)	Swiss mice receiving 100 or 300 mg MPCA/kg b.w.	-↓carrageenan-induced leukocyte migration, licking time, carrageenan- and formalin-induced paw edema, and formalin-induced cold hypersensitivity; -Prevented the CFA-induced mechanical and cold hyperalgesia and knee edema.	Flavonoids (see Table 3)	(Viscardi et al., 2017)
	Pulp and peel	Anticancer	Dichloromethane extract	*In vitro* anticancer activity against tumor cell lines B16-F10, MCF-7, PC-3, 786–0, and HepG2	-Pulp extract showed higher antiproliferative activity than peel extract against all tumor cell lines; -Both extracts had high selectivity; -Dimethylchalcone was the most active compound against B16-F10 cells; -Dimethylchalcone and pulp extract induced	Flavonoids (see Table 3) and champanones C and D	(Lima e Silva et al., 2018)

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Table 4 (*continued*)

Fruit	Fruit part	Bioactivity	Sample form	Method/model	Major findings	Related compounds	Ref.
					apoptosis in B16-F10 cells; -Pulp extract activated caspase-3 in B16-F10 cells and reduced nitrite release in the coculture of B16-F10 cells and murine peritoneal macrophages.		
	Pulp and by-product (peel + seeds)	Antioxidant	Hydromethanolic extract (70 % methanol)	DPPH and TEAC based *in vitro* assays	-By-product (IC_{50} 34 mg/L for DPPH assay and 197.13 μmol TE/g for TEAC assay) showed higher antioxidant activity than pulp (IC_{50} 130.4 mg/L for DPPH assay and 107.96 μmol TE/g for TEAC assay).	Flavonoids (compounds were not identified)	(Alves et al., 2013; de Fernandes et al., 2015)
	Pulp and by-product (peel + seeds)	Hepatoprotective	Hydromethanolic extract (70 % methanol)	HepG2 cells exposed to CCl_4	-↓CCl_4-induced cytotoxicity, cell morphological changes (general and nuclear), and AST and ALT levels; -By-product extract was more effective than pulp extract.	Flavonoids (compounds were not identified)	(de Fernandes et al., 2015)
	Peel	Antioxidant	Methanolic extract	DPPH and TEAC based *in vitro* assays	-IC_{50} 163.70 and 68.38 μg/mL for DPPH and TEAC assays, respectively.	Flavonoids (see Table 3)	(Lescano et al., 2018)
	Peel	Antiplatelet aggregation	Methanolic extract	Human platelet-rich plasma	-↓arachidonic acid-induced platelet aggregation; -↓mobilization of calcium and thromboxane B2 levels in platelets; -↑cAMP and cGMP levels.	Flavonoids (see Table 3)	(Lescano et al., 2018)
	Peel	Anti-inflammatory	Methanolic extract	*In vitro* COX-1 and COX-2 inhibition assays	-↓COX-1 and COX-2 activity.	Flavonoids (see Table 3)	(Lescano et al., 2016, Lescano et al., 2018)
	Peel	Antidiarrheal	Methanolic extract	STa toxin-stimulated T84 cells	-↓STa toxin-induced cGMP accumulation in T84 cells.	Phenolic compounds (compounds were not identified)	(Lescano et al., 2016)
	Peel	Anticancer	Methanolic extract	*In vitro* anticancer activity against colorectal tumor cell line T84	-↓viability and proliferation of tumor T84 cells.	Phenolic compounds (compounds were not identified)	(Lescano et al., 2016)
	Peel	Anti-inflammatory, antinociceptive, and antidepressant	Hydroethanolic extract (70 % ethanol)	Swiss mice (anti-inflammatory test) and Wistar rats (antinociceptive, antidepressant, and oral toxicity tests) receiving 100 or 300 mg extract/kg b.w.	-No clinical signs of toxicity were observed in animals; -↓carrageenan-induced leukocyte migration and protein leakage; -↓SNI-induced mechanical hyperalgesia and SNI-induced cold hypersensitivity; -↓immobility in the forced swim test.	Flavonoids (see Table 3)	(de Souza et al., 2017)
	Whole fruit	Antibacterial	Ethyl acetate extract and its fractions	*In vitro* antibacterial activity against *Mycobacterium tuberculosis*	-↓growth of *M. tuberculosis* (MIC 39–>250 μg/mL); -The flavonoids 5,7-dihydroxy-6,8-di-*C*-methylflavanone and 2′,4′-dihydroxy-3′,5′-dimethyl-6′-methoxychalcone found in extract acted synergistically against *M. tuberculosis*.	Flavonoids (see Table 3), particularly 5,7-dihydroxy-6,8-di-*C*-methylflavanone and 2′,4′-dihydroxy-3′,5′-dimethyl-6′-methoxychalcone	(Pavan et al., 2009)
	Whole fruit	Anticancer	Ethanolic extract and isolated cardamonin	*In vitro* anticancer activity against prostate tumor cell line PC-3	-Extract and cardamonin reduced tumor cell growth (GI_{50} 14.25 and 11.35 μg/mL, respectively); -Cardamonin reduced the NF-κB1 expression, increased DNA fragmentation, and induced apoptosis.	Phenolic compounds, especially the chalcone cardamonin	(Pascoal et al., 2014)
Jatobá-do-cerrado	Pulp and peel	Antioxidant	Ethanolic extract and its fractions hexane, ethyl acetate, and hydroethanolic	DPPH based *in vitro* assay	-Hexane fraction from pulp showed the highest antioxidant value (IC_{50} 5.84 μg/mg); -In the peel, the hydroethanolic fraction was the most antioxidant followed by ethanolic extract and ethyl acetate fraction (IC_{50} 9.57, 26.11, and 30.83 μg/mg, respectively).	Phenolic compounds (compounds were not identified)	(Peres et al., 2013)
	Pulp and peel	Antioxidant		DPPH, FRAP, and ORAC based *in vitro* assays	-Hydroethanolic extracts showed higher values for all antioxidant assays;	Phenolic compounds (compounds were not identified)	(Figueiredo et al., 2016)

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Table 4 (*continued*)

Fruit	Fruit part	Bioactivity	Sample form	Method/model	Major findings	Related compounds	Ref.
			Methanolic and hydroethanolic (70 % ethanol) extracts		-Peel extract was the most active extract in all antioxidant assays (IC_{50} 235.90 μg/mL for DPPH assay, 1716.55 μmol TE/g for FRAP assay, and 0.36 μg TE/g for ORAC assay).		
	Pulp, peel, and seeds	Antioxidant	Hydromethanolic extract (50 % methanol)	DPPH based *in vitro* assay	-Peel and seeds extracts showed similar antioxidant activity (87.13 and 89.27 % inhibition), while pulp extract had a lower value (79.31 % inhibition).	Phenolic compounds and carotenoids (compounds were not identified)	(de Filho et al., 2019)
	Pulp	Antioxidant	Ethyl acetate and aqueous extracts	DPPH, FRAP, ORAC, and β-carotene/linoleic acid system based *in vitro* assays	-Aqueous extract showed higher antioxidant activity than ethyl acetate extract for DPPH and FRAP assays (1.7 μmol TE/g and 5.4 μmol Fe_2SO_4/g against 0.2 μmol TE/g and 0.7 μmol Fe_2SO_4/g); -Both extracts showed the same antioxidant value by β-carotene/linoleic acid assay (0.4 % inhibition/g).	-Phenolic compounds (compounds were not identified)	(de Siqueira et al., 2013)
	Pulp	Antioxidant	Aqueous, hydromethanolic (60 % methanol), and hydroacetonic extracts (60 % acetone)	DPPH, FRAP, ORAC, and Rancimat based *in vitro* assays	-Hydroacetonic extract showed the highest antioxidant values for all methods (IC_{50} 1.44 mg/mL, 106.40 μmol Fe_2SO_4/g, 119.79 μmol TE/g, and 1.05 antioxidant activity index for DPPH, FRAP, ORAC, and Rancimat assays, respectively).	Phenolic compounds (compounds not identified) and carotenoids (particularly lutein and β-carotene)	(da Silva et al., 2014)
	Pulp	Antioxidant	Fruit pulp	*In vitro* $FeSO_4$-induced lipid peroxidation in Wistar rat brain membrane suspension	-↓lipid peroxidation in rat brain membranes (IC_{50} 27.33 μg/mL).	Phenolic compounds such as flavonoids, condensed tannins, and terpenes	(Orsi et al., 2014)
	Pulp	Antidiabetic	Crude extract (combination of hydroacetonic extract (70 % acetone) and hydroethanolic extract (60 % ethanol))	*In vitro* α-amylase and α-glucosidase inhibition assays	-↓α-amylase and α-glucosidase activities.	Several phenolic compounds (see Table 3)	(da Silva et al., 2019)
	Pulp	Antidiabetic	Bread with 10, 20, or 30 % of pulp fruit in replacing to wheat flour	11 healthy females (27.4 ± 2.7 years old) ingested a portion of bread containing 42 g of available carbohydrates	-↓glycemic response.	Several phenolic compounds (see Table 3) and fibers	(da Silva et al., 2019)
	Pulp	Gastrointestinal protection	Fruit pulp	Acetic acid-induced gastric and duodenal ulcers in Wistar rats receiving 10 % of fruit pulp in the diet for 14 days	-No clinical signs of toxicity and no behavior changes were observed in animals; -Improved the gastric and duodenal ulcers healing by decreasing the lesion area; -Prevented the GSH depletion in healing duodenal ulcers.	Catechin and gallic acid derivatives	(Orsi et al., 2012)
	Pulp	Colon protection	Fruit pulp	TNBS-induced colonic damage in Wistar rats receiving 5 or 10 % of fruit pulp in the diet for 23 days	−10 % of pulp reduced the TNBS-induced colon damage, MPO and AP activities, MDA levels, and GSH depletion in the colon.	Phenolic compounds such as flavonoids, condensed tannins, and terpenes	(Orsi et al., 2014)
	Pulp	Antileishmanial	Ethanolic and aqueous extracts	*In vitro* antileishmanial against promastigotes forms of *Leishmania amazonensis* and *L. braziliensis*	-Extracts were highly effective against both protozoans, showed low cytotoxicity in macrophages and human red blood cells, and high selectivity; -Ethanolic extract (IC_{50} 160–170 μg/mL) was more active than aqueous extract (IC_{50} 190–200 μg/mL).	Phenolic compounds, particularly epicatechin and kaempferol-3-*O*-rutinoside	(Ferreira et al., 2021)
	Seeds	Antioxidant	Methanolic extract	DPPH and ORAC based *in vitro* assay	-The seeds showed high antioxidant activities by DPPH and ORAC (1305.72 and 75.74 μmol TE/g, respectively).	Phenolic compounds, particularly gallic acid and myricetin	(Vagula et al., 2019)
Lobeira	Pulp	Antioxidant	Ethyl acetate and aqueous extracts	DPPH, FRAP, and β-carotene/linoleic acid system based *in vitro* assays	-Aqueous extract showed higher antioxidant activity than ethyl acetate extract for FRAP and β-carotene/linoleic acid assays (39.7 μmol Fe_2SO_4/g and 45.1 % inhibition/g against 17.5 μmol Fe_2SO_4/g and no active by β-carotene/	Phenolic compounds (compounds were not identified)	(de Siqueira et al., 2013)

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Table 4 (*continued*)

Fruit	Fruit part	Bioactivity	Sample form	Method/model	Major findings	Related compounds	Ref.
					linoleic acid assay); -Ethyl acetate extract was more active than aqueous extract by DPPH assay (66.8 and 7.9 μmol TE/g, respectively).		
	Pulp, peel, and seeds	Antioxidant	Hydroethanolic extract (70 % ethanol)	ORAC based *in vitro* assay	-The pulp had the highest antioxidant activity followed by seeds and peel (4.14, 3.16, and 2.66 μmol TE/100 mL of extract, respectively).	Several phenolic compounds (see Table 3), particularly caffeic and coumaric acids derivatives	(Pereira et al., 2019)
	Pulp + seeds	Antioxidant	Hexane, ethyl acetate, and hydroethanolic fractions from ethanolic extract	DPPH and FRAP based *in vitro* assays	-Ethyl acetate fraction showed the best antioxidant activity by both assays (IC_{50} 1.02 and 1.48 μg/mL for DPPH and FRAP, respectively).	Phenolic acids (see Table 3), particularly caffeic and coumaric acids derivatives and alkaloids	(Morais et al., 2022)
	Pulp + seeds	Anti-inflammatory and antinociceptive	Ethanolic extract (EE)	Swiss mice receiving 30, 100, or 300 mg EE/kg b.w.	-↓carrageenan-induced paw edema; -↓carrageenan-induced footpads tissue injury and polymorphonuclear infiltration in the dermis; -↓acetic acid-induced nociception (↓abdominal writhes); -↓formalin-induced nociception (↓licking time); -↓hot-induced nociception (↑latency to response in the hot-plate test).	Phenolic acids (see Table 3), particularly caffeic and coumaric acids derivatives and alkaloids	(Morais et al., 2020)
	Pulp + seeds	Anti-inflammatory	Hexane, ethyl acetate, and hydroethanolic fractions from ethanolic extract	Swiss mice receiving 30, 100, or 300 mg extract fraction/kg b.w.	-Hexane and hydroethanolic fractions significantly inhibited carrageenan-induced paw edema.	Phenolic acids (see Table 3), particularly caffeic and coumaric acids derivatives and alkaloids	(Morais et al., 2022)
	Whole fruit	Antibacterial	Ethanolic extract and its fractions hexane, dichloromethane, ethyl acetate, and hydroethanolic	*In vitro* antibacterial activity against *Bacillus cereus* ATCC 11778, *Corynebacterium diphtheriae* ATCC ISP, *Enterococcus faecalis* ATCC 19433, *Listeria monocytogenes* ATCC 15315, *Staphylococcus aureus* ATCC 29213, *Streptococcus mutans* ATCC 25175, *Streptococcus pyogenes* ATCC 19615, *Escherichia coli* EHEC ATCC 43895, *Klebsiella pneumoniae* ATCC 27736, and *Pseudomonas aeruginosa* ATCC 25,853	-Ethanolic extract and its fractions presented high antibacterial activity against *L. monocytogenes* (MIC 31–1000 μg/mL); -Ethanolic extract, hexane, dichloromethane, and hydroethanolic fractions were active against *B. cereus* (MIC 1000–>2000 μg/mL); -Hexane fraction was active against *S. mutans* and *K. pneumoniae* (MIC 500 and 250 μg/mL, respectively); -Dichloromethane fraction was active against *S. aureus* and *E. faecalis* (MIC 1000 μg/mL); -Hydroethanolic fraction was active against *S. pyogenes* (MIC 1000 μg/mL); -Ethanolic extract and its fractions exhibited selective antibacterial activity against Gram-positive bacteria.	Phenolic acids, especially caffeic and chlorogenic acids	(Morais et al., 2015)
Mangaba	Pulp	Antioxidant	Ethyl acetate and aqueous extracts	DPPH, FRAP, and β-carotene/linoleic acid system based *in vitro* assays	-Aqueous extract showed higher antioxidant activity than ethyl acetate extract for DPPH and FRAP assays (8.2 μmol TE/g and 47.2 μmol Fe_2SO_4/g against 4.2 μmol TE/g and 7.4 μmol Fe_2SO_4/g); -Both extracts showed a similar antioxidant value by β-carotene/linoleic acid assay (5.7 and 5.3 % oxidation inhibition/g).	Phenolic compounds (compounds were not identified)	(de Siqueira et al., 2013)
	Pulp	Antioxidant	Crude extract (combination of hydromethanolic extract (50 % methanol) and acetonic extract (70 % acetone))	DPPH, TEAC, and β-carotene/linoleic acid system based *in vitro* assays	-The pulp showed high antioxidant activities by all methods (47.93 and 154.73 μmol TE/g for DPPH and TEAC, respectively, and 86.11 % oxidation inhibition).	Phenolic compounds (see Table 3), particularly quercetin and catechin	(Zitha et al., 2022)
	Pulp	Antimutagenic	Fruit pulp	DXR- and DMH-induced mutagenicity in Swiss mice receiving 10, 20, or 40 mg fruit pulp/kg b.w. for 15 days	-↓DXR- and DMH-induced frequency of MNPCEs in the bone marrow and gut epithelial cells; -↓DXR- and DMH-induced apoptosis in the gut epithelial cells;	Phenolic compounds, particularly gallic acid, catechin, chlorogenic acid, vanillic acid, *o*-coumaric acid, rosmarinic acid, and rutin	(de Lima et al., 2015)

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Table 4 (*continued*)

Fruit	Fruit part	Bioactivity	Sample form	Method/model	Major findings	Related compounds	Ref.
					-↓DXR- and DMH-induced DNA damage in bone marrow cells; -↓DXR- and DMH-induced oxidative stress (↓MDA) in the liver.		
	Pulp	Anticancer	Ethanolic extract	*In vitro* anticancer activity against MCF-7 breast cancer cells co-cultured with blood cells	-↑superoxide release and SOD levels.	–	(de Araújo et al., 2019)
	Pulp	Gastrointestinal protection	Whole fruit pulp	Wistar rats receiving 5, 10, or 15 mL pulp/kg b.w. for 14 days	-laxative effect at 15 mL/kg (↑distance traveled by the charcoal meal, and ↓serum magnesium levels); -anti-inflammatory effect (↓leukocyte concentration in small and large intestines).	Fiber and phenolic compounds (compounds were not identified)	(de Reis et al., 2019)
	Whole fruit	Antidiabetic	Methanolic extract	*In vitro* glycation inhibition assays	-↓formation of advanced glycation end products.	Several phenolic compounds (see Table 3), particularly quercetin derivatives	(Marques et al., 2018)
	Whole fruit	Anti-inflammatory	Aqueous extract (AE)	Xylene-induced ear edema in BALB/c mice receiving 40, 50, or 60 mg AE/kg b.w., carrageenan-induced peritonitis in BALB/c mice receiving 20, 30, or 40 mg AE/kg b.w., and zymosan-induced air pouch in Swiss mice receiving 40, 50, or 60 mg AE/kg b.w.	-↓xylene-induced ear edema; -↓leukocyte migration in both carrageenan-induced peritonitis and zymosan-induced air pouch models; -↓production of proinflammatory cytokines (IL-1β, IL-6, IL-12, and TNF-α).	Phenolic compounds, particularly rutin and chlorogenic acid	(Torres-Rêgo et al., 2016)
	Whole fruit	Treatment of scorpion stings	Aqueous extract (AE)	*Tityus serrulatus* venom-induced acute pulmonary edema in Swiss mice receiving 100 or 200 mg AE/kg b.w.	-↓edema, MPO levels, vascular permeability, and production of cytokines (IL-1β, IL-6, and TNF-α) in lung tissue; -↓nitrite and MDA in renal tissue; -↓serum amylase, lactate dehydrogenase, AST, and creatine kinase.	Several phenolic compounds (see Table 3)	(de Yamashita et al., 2020)
	Whole fruit	Antioxidant and hepatoprotective	Aqueous extract (AE)	ACT-induced hepatotoxicity in Wistar rats receiving 200 mg AE/kg b.w. for 10 days	-↓serum AST, ALT and GGT; -↓serum lipid peroxidation (↓MDA); -↑serum SOD; -↓hepatocellular degeneration.	Phenolic compounds (see Table 3), especially chlorogenic acid and rutin	(Santos et al., 2022)

Where: ↑: increase; ↓: decrease; *786–0:* kidney adenocarcinoma cell line; *ACT:* acetaminophen; *ALT:* alanine aminotransferase; *AST:* aspartate aminotransferase; *b.w.:* body weight; *B16-F10:* murine melanoma cell line; *cAMP:* cyclic adenosine monophosphate; *CFA:* Freund's complete adjuvant; *cGMP:* cyclic guanidine monophosphate; *COX:* cyclooxygenases; *DMH:* 1,2-dimethylhydrazine; *DPPH:* 2,2-diphenyl-1-picrylhydrazyl; *DXR:* doxorubicin; *FRAP:* ferric reducing antioxidant power assay; *GAE:* gallic acid equivalent; *GGT:* gamma-glutamyl transferase; GI_{50}: growth inhibitory activity (extract concentration that resulted in a 50% reduction in the cellular growth relative to the untreated control cells); *GIP:* glucose-dependent insulinotropic polypeptide; *GSH:* glutathione; *HepG2:* human liver carcinoma cell line; *HF/HS:* high-fat/high-sucrose diet; IC_{50}: extract concentration that resulted in a 50% reduction in the initial concentration/counts; *LDL-c:* low-density lipoprotein cholesterol; *MCF-7:* human breast adenocarcinoma cell line; *MDA:* malondialdehyde; *MIC:* minimal inhibitory concentration; *MNPCEs:* micronucleated polychromatic erythrocytes; *MPO:* myeloperoxidase; *NEFA:* non-esterified fatty acid; *NF-κB:* nuclear factor kappa-B; *ORAC:* oxygen radical absorbance capacity; *PC-3:* prostate adenocarcinoma cell line; *PCX:* pyruvate carboxylase; *SNI:* spared nerve injury; *STa:* heat-stable enterotoxin type A; *T84:* human colorectal carcinoma cell line; *TE:* Trolox equivalents; *TEAC:* Trolox equivalent antioxidant capacity; *TG:* triglycerides; *TNBS:* trinitrobenzesulphonic acid; *TNF-α:* tumor necrosis factor-alpha.

damage. Catechin and gallic acid derivatives have been identified in the jatobá-do-cerrado pulp and may explain, at least partially, the antioxidant effect observed (Orsi et al., 2012). Moreover, the jatobá-do-cerrado pulp is a rich source of dietary fiber (see Table 1), which can be metabolized by the intestinal microbiota, producing short-chain fatty acids. These acids, especially butyric acid, can exert antioxidant activity (Orsi et al., 2014).

Recent studies have shown that mangaba is a potent antioxidant *in vivo*. de Lima et al. (2015) reported that oral administration of mangaba pulp (40 mg/kg/day) for 15 days reduced doxorubicin- and 1,2-dimethylhydrazine-induced oxidative stress in the liver of mice. Aqueous extract from mangaba fruit administered intragastrically (100 and 200 mg/kg) improved the antioxidant status (reduced nitrite production and lipid peroxidation) of the renal tissue of mice that received *Tityus serrulatus* venom (de Yamashita et al., 2020). In another study, Santos et al. (2022) reported that the aqueous extract from mangaba fruit (200 mg/kg/day for 10 days) was also able to reduce acetaminophen-induced oxidative damage (decreased lipid peroxidation and increased superoxide dismutase activity) in rats. The characterization of the edible portion of mangaba has revealed the presence of several phenolic compounds (see Table 3), especially chlorogenic acid and rutin, which may explain the results found.

In addition to antioxidant capacity, the fruits of cagaita, jatobá-do-cerrado, gabiroba, lobeira, and mangaba also presented anti-inflammatory activity. Oral administration of a phenolic-rich extract obtained from cagaita pulp (7 and 14 mg GAE/kg/day) for 8 weeks attenuated inflammation in obese mice by reducing TNF-α expression and NF-κB phosphorylation in the liver (Donado-Pestana et al., 2018). Consumption of a diet containing 10 % jatobá-do-cerrado pulp for 23 consecutive days mitigated colonic inflammation (reduced myeloperoxidase and alkaline phosphatase activities) in rats treated with trinitrobenzesulphonic acid (Orsi et al., 2014). Morais et al. (2020) evaluated the anti-inflammatory potential of the ethanolic extract from lobeira pulp + seeds in a carrageenan-induced paw edema model. The authors observed that intraperitoneal treatment of mice with lobeira extract (300 mg/kg) was able to significantly reduce paw sole tissue injury and leukocyte infiltration into the dermis. In a later study, the same group evaluated the anti-inflammatory effect of hexane, ethyl acetate, and hydroethanolic fractions obtained from the ethanolic extract from lobeira pulp + seeds using the same animal model. The authors observed that the ethyl acetate fraction did not show any anti-inflammatory activity, while the hexane (100 and 300 mg/kg) and hydroethanolic (100 mg/kg) fractions significantly inhibited carrageenan-induced paw edema (Morais et al., 2022).

Similarly, Torres-Rêgo et al. (2016) reported that intravenous administration of mangaba aqueous extract (20, 30, or 40 mg/kg) inhibited carrageenan-induced cell migration in the peritoneal cavity and the production of pro-inflammatory cytokines (IL-1β, IL-6, IL-12, and TNF-α). In addition, mice treated intraperitoneally with this extract (40, 50, or 60 mg/kg) showed a reduced formation of xylene-induced ear edema and zymosan-induced leukocyte migration. Tests performed with rutin and chlorogenic acid (major compounds present in the mangaba aqueous extract) reported the same anti-inflammatory effects. Meanwhile, intragastric administration of the mangaba aqueous extract (100 or 200 mg/kg) was able to reduce edema, myeloperoxidase levels, and the production of pro-inflammatory cytokines (IL-1β, IL-6, and TNF-α) in the lung tissue of mice that received *Tityus serrulatus* venom (de Yamashita et al., 2020). In another study, de Reis et al. (2019) found that supplementation with mangaba pulp (15 mL/kg/day) for 14 days suppressed intestinal inflammation by reducing the number of leukocytes in the small and large intestines of rats. The methanolic extract from gabiroba peel proved to be effective in the inhibition of COX-1 and COX-2 *in vitro* (Lescano et al., 2016, Lescano et al., 2018). Studies in animal models have also reported the anti-inflammatory potential of gabiroba peel. Oral administration of hydroethanolic extract from gabiroba peel (100 or 300 mg/kg) significantly inhibited leukocyte migration and protein extravasation into the pleural cavity of carrageenan-treated mice (de Souza et al., 2017). Reduction of carrageenan-induced paw edema and leukocyte migration in the pleural cavity was also observed in mice that received microencapsulated gabiroba pulp (100 or 300 mg/kg) (Viscardi et al., 2017). In addition, cardamonin, a chalcone isolated from the gabiroba fruits, was able to reduce the NF-κB1 expression in prostate cancer cells *in vitro* (Pascoal et al., 2014). As in the antioxidant activity, phenolic compounds were the main bioactive compounds present in the fruits/extracts analyzed for anti-inflammatory activity (see Tables 3 and 4). In addition to sequestering ROS/RNS and chelating transition metals, phenolic compounds are capable of modulating endogenous signaling pathways involved in oxidative damage and inflammation, inhibiting the production and/or action of inflammatory mediators (Arruda et al., 2020).

6.2. Antinociceptive activity

Pain is a symptom associated with several pathological conditions, being the main symptom reported by patients in medical consultations (da Costa Oliveira et al., 2019). In addition, since pathological pain (neuropathic pain, inflammatory pain, and cancer pain) is a chronic pain (pain lasting at least 3 months), it significantly affects the quality of life and well-being of patients (Sun et al., 2018). As can be seen in Table 4, some preparations containing fruit parts of gabiroba and lobeira presented analgesic activity in animal models.

In addition to anti-inflammatory activity, the ethanolic extract from lobeira pulp + seeds applied intraperitoneally exhibited antinociceptive activity in mice by reducing acetic acid-induced abdominal contractions (30, 100, and 300 mg/kg) and formalin-induced licking time (30, 100, and 300 mg/kg), and increasing the latency to response in the hot-plate test (300 mg/kg). Several phenolic compounds derived from caffeic acid (see Table 3) and steroid alkaloids have been identified in this extract (Morais et al., 2020). The hydroethanolic extract from gabiroba peel (100 mg/kg) administered orally for 15 days to rats with spared nerve injury was able to attenuate mechanical hyperalgesia and cold hypersensitivity duration (de Souza et al., 2017). Similarly, the intake of microencapsulated gabiroba pulp (100 and 300 mg/kg) reduced formalin-induced licking time, paw edema and cold hypersensitivity duration, as well as prevented Freund's Complete Adjuvant-induced mechanical and cold hyperalgesia. Gabiroba fruit parts were rich in flavonoids and chalcones (see Table 3) (de Souza et al., 2017; Viscardi et al., 2017). The antinociceptive potential of these fruits can be partly attributed to the synergistic effect between the bioactive substances present in their extracts/formulations, especially phenolic compounds and alkaloids. These compounds can act alone or together, exerting antioxidant and anti-inflammatory effects that suppress tissue injury and stimulation of pain receptors in the brain (Morais et al., 2020; Viscardi et al., 2017).

6.3. Anticarcinogenic and antimutagenic activities

Cancer is a group of multifactorial chronic diseases conditioned by alterations resulting from biological, chemical, radiological, and hereditary impacts that culminate in uncontrolled cell growth. Cancer is the second leading cause of death worldwide, accounting for 1 in 6 deaths annually. Thus, cancer represents a significant global public health problem (Arruda & Pastore, 2019; Zolotovskaia et al., 2019). Recent studies have shown the anticarcinogenic potential of extracts and bioactive compounds isolated from Brazilian Cerrado fruits against different tumor cell lines (Table 4).

de Araújo et al. (2019) have found that the ethanolic extract from mangaba pulp presented significant antiproliferative activity against breast cancer cells (MCF-7 cells) co-cultured with blood cells. The extract activated blood cells, increasing the superoxide release and superoxide dismutase levels, which may contribute to the control of tumor cells proliferation. Pascoal et al. (2014) observed that the ethanolic

extract from gabiroba fruit and chalcone cardamonin (a compound present in the fruits) inhibited the proliferation of prostate cancer cells (PC-3 cells) with GI_{50} values of 14.25 and 11.35 μg/mL, respectively. The authors studied the mechanism of action of cardamonin and found that this chalcone induces apoptosis of tumor cells by reducing the NF-κB1 expression and increasing DNA fragmentation. In another study, Lescano et al. (2016) reported that the methanolic extract from gabiroba peel was able to reduce the viability and proliferation of colorectal cancer cells (T84 cells). Lima e Silva et al. (2018) investigated the cytotoxic potential of dichloromethane extracts from gabiroba peel and pulp against five tumor cell lines. The pulp extract was the most active against all tumor cell lines tested (GI_{50} 15.27–24.65 μg/mL) and presented a high selectivity (selectivity index ≥ 1.13). Tumor cell lines B16-F10 (murine melanoma cell line), PC-3 (prostate adenocarcinoma cell line), and HepG2 (human liver carcinoma cell line) showed the highest susceptibilities to pulp extract (GI_{50} 15.27–16.17 μg/mL). Among the compounds isolated from gabiroba pulp extract, dimethylchalcone presented the highest cytotoxicity on B16-F10 cells. In addition, the authors reported that the extract inhibited the B16-F10 cells' proliferation by caspase-3-induced apoptosis and reduced nitric oxide release.

Mutations in DNA play a key role in the development and progression of cancer (Zolotovskaia et al., 2019). Mangaba pulp has been tested for its mutagenic, antimutagenic, and toxic potential by Swiss mice peripheral blood micronucleus test (de Lima et al., 2015). Treatment with mangaba pulp (10–40 mg/kg/day) for 14 days had an antimutagenic effect, reducing the doxorubicin- and dimethylhydrazine-induced frequency of micronuclei in the bone marrow and gut epithelial cells, apoptosis of gut epithelial cells, DNA damage of bone marrow cells, and oxidative stress in liver cells. Moreover, no toxic/mutagenic effects were observed (≤40 mg/kg/day). According to the authors, the antimutagenic effect can be attributed to bioactive compounds present in mangaba, such as phenolic compounds, which can act as antioxidants or by modulating endogenous signaling pathways involved in antioxidant homeostasis and DNA protection/repair (de Lima et al., 2015).

6.4. Anti-obesity and antidyslipidemic activities

Obesity is a major global public health problem, affecting about 13 % of the world's adult population. It has been linked to an increased risk of heart disease, type 2 diabetes, hypertension, dyslipidemia, cancer, and numerous adverse health effects (Silvester et al., 2019). Therefore, much attention has been focused on the search for natural products with anti-obesity potential. In this context, Donado-Pestana et al. (2015) have studied the effect of a phenolic-rich extract obtained from cagaita pulp on mice treated with a high-fat/high-sucrose diet. The orogastric administration of this phenolic extract (7 or 14 mg GAE/kg/day) for 8 weeks prevented weight gain, adiposity, and dyslipidemia. These effects have been attributed to the ability of the phenolic compounds present in this extract to attenuate hyperglycemia, hypertriglyceridemia, hypercholesterolemia, hepatic triglycerides accumulation, and oxidative stress, and to stimulate fecal excretion of triglycerides. On the other hand, oral administration of this extract (7 or 14 mg GAE/kg/day) for an equal period (8 weeks) did not affect the body weight and adiposity of mice with already established obesity. However, the extract stimulated carbohydrate oxidation and energy expenditure; protected against dyslipidemia (reduced serum cholesterol and triglycerides levels), hyperglycemia, and glucose intolerance; and attenuated both gluconeogenesis and liver inflammation (reduced TNF-α expression and NF-κB phosphorylation) (Donado-Pestana et al., 2018).

6.5. Antidiabetic activity

Diabetes is a multifactorial metabolic disorder characterized by persistent hyperglycemia. Diabetes and its associated complications (*e.g.,* hypertension, dyslipidemia, obesity, cardiovascular disease, chronic kidney disease, and atherosclerosis) are one of the leading causes of morbidity and mortality in the world. It is estimated that, in 2035, about 592 million people will be affected by this chronic disease (Peixoto Araujo et al., 2021). Several phenolic compounds present in Brazilian Cerrado fruits have been reported in the treatment and/or management of diabetes and its associated complications (see Table 4). These bioactive compounds can prevent or control the progression of diabetes by different mechanisms of action.

In vitro studies have shown that phenolic-rich extracts/phenolic compounds isolated from Brazilian Cerrado fruits can attenuate hyperglycemia by reducing intestinal carbohydrate digestion and intestinal glucose absorption through inhibition of key digestive enzymes, particularly α-amylase and α-glucosidase. Phenolic-rich extracts/fractions obtained from the pulp, peel, and seeds of cagaita (Balisteiro et al., 2017; Daza et al., 2017; Justino et al., 2020, Justino et al., 2022) and jatobá-do-cerrado pulp (da Silva et al., 2019) were effective inhibitors of α-amylase and/or α-glucosidase. Phenolic compounds inhibit the activity of carbohydrase enzymes due to their ability to bind to the active site of these enzymes or occupy the substrate binding pocket (Justino et al., 2020, Justino et al., 2022).

Chronic postprandial hyperglycemia induces protein glycosylation that leads to the formation of advanced glycation end-products (AGEs). This glycation process is irreversible and the AGEs formed are involved in the pathology of diabetic complications due to their ability to generate ROS and modify the chemical and functional properties of various biological structures (*e.g.,* proteins, lipids, DNA, and enzyme activity) (Peixoto Araujo et al., 2021). *In vitro* studies conducted by Marques et al. (2018) and Justino et al. (2020) reported that the methanolic extract from mangaba pulp and the aqueous and ethanolic extracts from cagaita pulp inhibited protein glycation. In another study, Justino et al. (2022) observed that the ethanolic extracts from peel and seeds of cagaita and its dichloromethane, ethyl acetate, *n*-butanol, and aqueous fractions were potent inhibitors of protein glycation, but only the ethyl acetate fraction obtained from peel ethanolic extract was able to inhibit the formation of AGEs. The antiglycation potential was attributed to the presence of phenolic compounds that can suppress the formation of AGEs by the capture of precursors (*e.g.,* dicarbonyl intermediates such as methylglyoxal) preventing them from binding and damaging proteins, interaction with glucose in preventing it from binding to proteins, inhibition of Schiff's base and Amadori products, and blockade of AGEs receptors (Justino et al., 2020, 2022; Marques et al., 2018).

In vivo and clinical trials have confirmed the antidiabetic potential of the Brazilian Cerrado fruits reported *in vitro* and revealed other molecular mechanisms underlying its antidiabetic effect. The phenolic-rich extract obtained from cagaita pulp (7 or 14 mg GAE/kg/day for 8 weeks) improved glucose homeostasis in obese mice, as evidenced by increased carbohydrates utilization as a fuel substrate, reduced fasting hyperglycemia, improved glucose tolerance, and decreased hepatic gluconeogenesis (reduced expression of the key gluconeogenic enzyme pyruvate carboxylase and tended to reduce the expression of phosphoenolpyruvate carboxykinase and glucose-6-phosphatase). In addition, this extract was able to improve antioxidant status and mitigate some complications associated with diabetes, such as increased fat accumulation, dyslipidemia, liver inflammation and steatosis, and kidney dysfunction (Donado-Pestana et al., 2015, Donado-Pestana et al., 2018). The hypoglycemic effect of cagaita pulp has also been observed in interventional studies with humans. Balisteiro et al. (2017) reported that the intake of 300 mL of clarified cagaita juice along with a 50 g portion of white bread was able to improve plasma antioxidant status and reduce postprandial glycemia in healthy subjects, while de Araujo et al. (2021) found that the same treatment suppressed the increase in postprandial glycemia and insulinemia in dysglycemic women with metabolic syndrome. The juice also reduced the absolute increase of glucose, glucose incremental percentage, and glucose peak value in both healthy and dysglycemic subjects, showing its potential in reducing glucose absorption (de Araujo et al., 2021; Balisteiro et al., 2017). Furthermore,

the juice decreased the insulin peak value, C-peptide secretion, and glucose-dependent insulinotropic polypeptide levels in the dysglycemic subjects, signaling that it may improve insulin sensitivity and inhibit the activity of glucose transporters in the intestine of these subjects (de Araujo et al., 2021). Similarly, da Silva et al. (2019) found that bread with 20 or 30 % jatobá-do-cerrado pulp flour instead of wheat flour reduced the glycemic response of healthy individuals who consumed a meal containing 42 g of available carbohydrates. The authors associated this effect with the synergism between the phenolic compounds and fibers present in the jatobá-do-cerrado pulp.

6.6. Hepatoprotective activity

The liver performs critical functions in metabolic and detoxification processes, thus being an essential organ for maintaining the homeostasis of the human body. However, xenobiotics (*e.g.,* viruses, bacteria, metabolites, and medications) can be hepatotoxic, inducing liver disorders, inflammation, fibrosis, and cirrhosis (Xia et al., 2019). *In vitro* and *in vivo* studies have reported that formulations containing some Brazilian Cerrado fruits are effective and safe hepatoprotective agents (Table 4).

de Fernandes et al. (2015) evaluated the hepatoprotective effects of hydromethanolic extracts (70 % methanol) from gabiroba pulp and by-products (peel + seeds) on HepG2 cells exposed to CCl_4. Both extracts (800–1000 μg/mL) protected liver cells against CCl_4-induced cytotoxicity, but the by-product extract was more effective than the pulp extract. The extracts were able to prevent morphological changes (general and nuclear) in cells and normalize the levels of liver enzymes (AST and ALT). Donado-Pestana et al. (2018) reported that oral administration of a hydromethanolic extract (80 % methanol) from cagaita pulp (7 or 14 mg GAE/kg/day) for 8 weeks reduced serum ALT activity and attenuated liver inflammation (reduced TNF-α expression and NF-κB phosphorylation in the liver) in obese mice. Mangaba pulp (10, 20, or 40 mg/kg/day), administered orally for 15 days, reduced lipid peroxidation in the liver of mice treated with doxorubicin and dimethylhydrazine (de Lima et al., 2015). The aqueous extract from mangaba fruit, administered intragastrically (100 or 200 mg/kg), reduced serum AST levels in mice poisoned by *Tityus serrulatus* (de Yamashita et al., 2020). In another study, Santos et al. (2022) have shown that rats treated orally with the aqueous extract from mangaba fruit (200 mg/kg/day) for 10 days had the hepatotoxic effects of acetaminophen suppressed, presenting lower serum levels of liver enzymes (AST, ALT, and GGT) and reduced hepatocellular degeneration. The hepatoprotective effects observed in these studies are attributed, at least in part, to the presence of phenolic compounds that can modulate several liver biochemical parameters, including ROS/RNS scavenging, reduction of lipid peroxidation, regulation of the endogenous antioxidant system, DNA repair, and activation of xenobiotic detoxification (Arruda & Pastore, 2019; de Fernandes et al., 2015).

6.7. Gastrointestinal protection

Functional gastrointestinal disorders (*e.g.,* irritable bowel syndrome, functional dyspepsia, functional constipation, functional diarrhea, and functional bloating/distension) are characterized by one or more of the following markers: disturbance in motility, visceral hypersensitivity, altered mucosal and immune function, dysbiosis of gut microbiota, and disturbed central nervous system processing. This set of diseases results in significant global health care costs and impairment to the quality of life of affected individuals (Sperber et al., 2021). Formulations from cagaita, gabiroba, jatobá-do-cerrado, mangaba, and lobeira fruits have shown potential protection to the gastrointestinal tract in cellular and animal models (Table 4).

Lescano et al. (2016) have studied the antidiarrheal potential of the methanolic extract from gabiroba peel. Although it has no antimicrobial effect *in vitro* against *E. coli*, *S. typhimurium*, and *S. aureus*, the extract inhibited the action of heat-stable enterotoxin type A (STa) in intestinal cells (T84 cells) by reducing cGMP accumulation. The antidiarrheal effect was attributed to the phenolic compounds present in the extract, especially gallic acid, which was able to strongly bind to the STa toxin, preventing its interaction with guanylate cyclase.

de Reis et al. (2019) evaluated the effect of mangaba pulp intake on intestinal motility and gut health in Wistar rats. Experiments conducted after the administration of charcoal meal revealed that eating mangaba pulp (15 mL/kg/day) for 14 days was able to stimulate intestinal motility and reduce inflammation in both the small and large intestines. Moreover, treatment with mangaba pulp did not exert any toxic effect on the liver and intestinal tissues. Fibers and phenolic compounds present in mangaba pulp may be related to its laxative and anti-inflammatory activities.

In vivo studies have shown that the jatobá-do-cerrado pulp protects the gastrointestinal system from the toxic action of some chemicals. The consumption of a diet containing 10 % of jatobá-do-cerrado pulp for 23 days protected the colon of trinitrobenzesulphonic acid-treated rats by suppressing oxidative stress and colonic inflammation (Orsi et al., 2014). Similarly, supplementation of a diet with 10 % jatobá-do-cerrado pulp for 14 days protected the stomach and small intestine of rats against injury caused by acetic acid. The results have indicated that jatobá-do-cerrado pulp was able to improve the healing of gastric and duodenal ulcers (Orsi et al., 2012). Gastrointestinal protection was attributed to the antioxidant activity of flavonoids and tannins present in the jatobá-do-cerrado pulp (Orsi et al., 2012, Orsi et al., 2014).

6.8. Antimicrobial activity

Microorganisms, such as bacteria, yeasts, and fungi, cause food spoilage, contributing to annual food losses that can reach up to 40 %. In addition, foodborne illness due to the consumption of food products contaminated by pathogenic microorganisms is a constant public health concern (Gonelimali et al., 2018). Extracts and compounds isolated from different parts of the Brazilian Cerrado fruits discussed here have shown antimicrobial effects against food spoilage and pathogenic microorganisms (Table 4).

The hydroethanolic extract from cagaita pulp was investigated against six bacterial strains. This extract was active only against Gram-positive bacteria (*S. aureus* and *L. monocytogenes*), and its inhibition values were similar to the antibiotics Vancomycin and Ceftriaxone. Furthermore, the encapsulated extract was more active against both bacteria (MIC 0.012–0.024 mg/mL) compared to the lyophilized form (MIC 0.16–4.44 mg/mL) (Daza et al., 2017). Morais et al. (2015) tested the antibacterial activity of the ethanolic extract and its fractions obtained from ripe lobeira fruit against 10 bacterial strains of clinical interest. Both extract and fractions exhibited selective antibacterial activity against Gram-positive bacteria, especially inhibiting *L. monocytogenes* and *B. cereus*, which are foodborne pathogens responsible for gastrointestinal infections with high morbidity. Moreover, the ethanolic extract and/or some fractions inhibited other bacteria, including *S. mutans*, *K. pneumoniae*, *S. aureus*, *E. faecalis*, and *S. pyogenes*. The ethyl acetate extract and its fractions obtained from gabiroba fruit were evaluated against *M. tuberculosis*. Antibacterial activity was noted in the extract and in its respective fractions (MIC 39–>250 μg/mL), especially in the fractions rich in 5,7-dihydroxy-6,8-di-*C*-methylflavanone and 2′,4′-dihydroxy-3′,5′-dimethyl-6′-methoxychalcone, showing that these compounds may be the main contributors to the anti-*M. tuberculosis* effect (Pavan et al., 2009). The antimicrobial activity of these extracts may be linked to the presence of bioactive compounds, especially phenolic compounds. The presence of hydroxyl groups in the structure of these compounds can cause disturbances in the membranes of microbial cells, slowing the growth and/or multiplication of microorganisms (Daza et al., 2017).

6.9. Antidepressant activity

Depression is one of the most frequent and severe psychiatric conditions worldwide, with an estimated prevalence of 1 in 20 individuals and risk of affecting 1 in 6 individuals throughout life. This condition is characterized by sadness, loss of interest or pleasure, feelings of guilt or low self-esteem, disturbed sleep or appetite, tiredness, and lack of concentration, making it one of the leading causes of years lost to disability worldwide. In addition, in its most severe forms, depression can lead to suicide and increase the risk of mortality from other general medical conditions (*e.g.,* cardiovascular disease) (Gold et al., 2020; Lim et al., 2018). Microencapsulated gabiroba pulp (100 mg/kg/day for 10 days) and hydroethanolic extract from gabiroba peel (100 mg/kg/day for 15 days) presented antidepressant effects in animal models by reducing the immobility time of Freund's Complete Adjuvant- and spared nerve injury-induced rats, respectively. This effect was attributed to the presence of flavonoids and chalcones in the analyzed fractions of this fruit (see Table 3) (de Souza et al., 2017; Viscardi et al., 2017).

6.10. Antithrombotic activity

Thrombosis is a condition caused by the accumulation of blood clots that hinders the flow of blood in the arteries and veins, leading to various pathologies, including ischemic heart disease, ischemic stroke, and venous thromboembolism. Moreover, thrombotic conditions are the leading causes of death in the world, accounting for 1 in 4 deaths (Laridan et al., 2019). Lescano et al. (2018) have shown the antithrombotic potential of the methanolic extract from gabiroba peel. This extract inhibited platelet aggregation via COX-1 inhibition by increasing cyclic nucleotide levels (cAMP and cGMP) and reducing calcium mobilization and thromboxane B2 levels. The authors also reported, by simulations of molecular docking, that the quercetin present in this extract inhibited the access of arachidonic acid to the catalytic site of COX-1.

6.11. Antileishmanial activity

Leishmaniasis is a set of tropical diseases caused by more than 20 species of parasitic protozoa belonging to the genus *Leishmania*. Currently, this disease affects about 12 million people in the world, causing approximately 20 to 30 thousand deaths annually (Arruda & Pastore, 2019). Ferreira et al. (2021) reported that the aqueous and ethanolic extracts from jatobá-do-cerrado pulp inhibited the growth of *L. amazonensis* and *L. braziliensis* (IC_{50} values ranging between 160 and 200 μg/mL). Furthermore, it was found that both extracts showed high selectivity against these protozoa due to low cytotoxicity in J774.A1 macrophages and human erythrocytes. Epicatechin and kaempferol-3-*O*-rutinoside were the main bioactive compounds identified in these extracts and, therefore, may respond, at least partially, by the observed antileishmanial activity.

6.12. Treatment of scorpion stings

Scorpion stings pose a serious public health problem in underdeveloped tropical and subtropical countries. Despite often causing only moderate symptoms, such as localized skin rashes, scorpion stings can lead to neurological, cardiovascular, and respiratory complications, and in some cases can be fatal (Rafinejad et al., 2020). de Yamashita et al. (2020) have found that intragastric administration of an aqueous extract from mangaba fruit (100 or 200 mg/kg) was able to reduce pulmonary edema and kidney damage in mice poisoned by *Tityus serrulatus*. The authors attributed these effects, at least in part, to the presence of phenolic compounds present in the extract, which can act synergistically in reducing the inflammatory processes.

7. Conclusion

Native fruits from the Brazilian Cerrado have attracted increasing interest from researchers and consumers around the world due to their sensory, nutritional, and bioactive potential. Cagaita, gabiroba, jatobá-do-cerrado, lobeira, and mangaba present macro- and micronutrients indispensable to the human diet, in addition to several phenolic compounds that exert different biological activities. Phenolic-rich extracts obtained from different parts of these fruits have been used in the treatment/management of various pathological conditions, including cancer, diabetes, obesity, parasitic diseases, inflammation, and pain, among others. These effects have been attributed to the ability that phenolic compounds have in modulating signaling pathways involved in different biochemical processes, particularly inflammation, oxidative damage, autophagy, and apoptosis. Although the literature presents important data regarding these fruits and their phenolic-rich extracts, their effect on human health is still unclear. Unfortunately, the data available in the literature are still scarce and insufficient to confirm the functional claims reported by folk medicine. Therefore, clinical and interventional studies with humans must be carried out to understand the real benefits of consuming these fruits and/or their phenolic-rich extracts on human health and well-being.

8. Current knowledge and future research directions

According to the current available literature, some native fruits from the Brazilian Cerrado, namely cagaita, gabiroba, jatobá-do-cerrado, lobeira, and mangaba, represent good or excellent sources of essential nutrients for the proper functioning of the human body, particularly fibers, and some minerals and vitamins. In addition, these fruits presented low levels of caloric value and sodium content. Therefore, the consumption of these Brazilian Cerrado fruits could be a key tool to mitigate food insecurity, malnutrition, and risk for several diseases, especially in individuals from socially vulnerable families living in the countryside.

Recent studies have shown that edible parts and by-products from the cagaita, gabiroba, jatobá-do-cerrado, lobeira, and mangaba are rich in phenolic compounds which are highly correlated with their biological properties, including antioxidant, anti-inflammatory, antinociceptive, anticarcinogenic, antimutagenic, anti-obesity, antidyslipidemic, antidiabetic, hepatoprotective, gastrointestinal protective, antimicrobial, antidepressant, antithrombotic, and antileishmanial activities. Although there are numerous studies investigating the occurrence of the total phenolic content in these Brazilian Cerrado fruits, there is limited information on the profile and content of specific phenolic compounds found in them. Bearing in mind that both the profile and the content of individual phenolic compounds are essential for the effectiveness of biological activity and the determination of effective concentrations and toxicity levels, more research should be carried out to determine the complete profiles of phenolic compounds as well as their individual contents in different parts of these Brazilian Cerrado fruits.

As mentioned above, phenolic-rich extracts/fractions obtained from the cagaita, gabiroba, jatobá-do-cerrado, lobeira, and mangaba have been studied for their biological activities and positive effects on management and/or treatment of several diseases have been observed. However, most of the studies on bioactivities carried out to date with these Brazilian Cerrado fruits consist of *in vitro* assays and animal models. Among all the literature pointing to some biological activity for these fruits, only 3 studies (2 studies with cagaita juice and 1 study with bread with jatobá-do-cerrado pulp) evaluated the acute antidiabetic effect on humans. There are no scientific reports about clinical studies on humans to assess their actual benefits to human health. Therefore, studies in humans, such as toxicological (particularly with non-edible fruit parts), pre-clinical, and clinical trials must be conducted to confirm these biological effects in humans, evaluate their mechanisms of action, estimate the minimum effective dose, and assure the safety and

well-being of consumers.

Finally, the critical and careful analysis of the data obtained so far for these Brazilian Cerrado fruits in association with the results generated by future research, particularly clinical trials, could be a powerful tool for the food and pharmaceutical industries for the selection of promising fruits/phenolic-rich extracts for the development of functional foods and natural-modern drugs to prevent and treat several diseases, facilitating and maximizing their applicability.

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

Data availability

No data was used for the research described in the article.

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