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REVIEW

Some wild fruits from amazon biodiversity: composition, bioactive compounds, and characteristics

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Abstract

Brazil is one of the countries that share a part of the Amazon region that has been called Legal Amazon. Amazon forest offers the most extraordinary biodiversity of flora and fauna on the planet and, on its surface, can cohabit 50% of the total existing living species. According to some botanists, it would contain about 16-20% of the species that exist today. This region has native fruits with antioxidants and antiproliferative activities already reported by some authors. Consumption of these fruits would be an alternative because they are good sources of nutritional constituents, such as minerals, fibre, vitamins, water, and caloric content. However, the number of scientific studies related to their health benefits is still low. *Eugenia stipitata*, *Myrciaria dubia* H. B. K. (Mcvough), *Endopleura uchi* (Huber) Cuatrecasas*, Eugenia punicifolia* (Kunth) D.C *and Garcinia madruno*. Among the main compounds reported are the most interesting groups: phenolic compounds, unsaturated fatty acids, carotenoids, phytosterols, and tocopherols, flavonoids, vitamin B, vitamin A, and vitamin C, and carotenoids. The main beneficial effect of the Amazon fruits is the antioxidant effect; other functional properties as medicinal, antimicrobial, antimutagenic, antigenotoxic, antigenotoxic, and anti-inflammatory, antinociceptive, antidiabetic, and gastroprotective, are also reported. Therefore, these fruits can be considered a valuable source of functional foods due to their phytochemical compositions and their corresponding antioxidant activities.

1. Introduction

Statistics show that more than 820 million people worldwide suffer from a lack of food that meets the nutritional requirements necessary for healthy living (FAO *et al*. 2019). Among the factors that generate this problem are the inequality of income distribution and the difficulty of accessibility to food, which causes a significant portion of the world population to be in a state of food insecurity (FAO, 2020).

The consumption of fruits is an alternative to enrich the diet because they are sources of nutritional constituents, such as minerals, fibre, vitamins, water, and caloric content (Andrade Jr and Andrade, 2014). However, native fruits from South America still do not have sufficient studies related to their health benefits compared to fruits from Europe and North America (Rufino *et al*. 2010; Gironés-Vilaplana *et al*., 2014). Brazil is the second centre in the rank for tropical fruit worldwide, concentrating just in the Brazilian Amazon approximately 40% of edible fruit-producing species. The majority is obtained through the extraction (EMBRAPA, 2016).

The Amazon rainforest reflects a rich diversity of flora and fauna, serving as a refuge to about 20% of all known species (Ministry of the Environment, 2019) This biome's endemic fruits are consumed in large quantities by most native populations, and access to these products happens quickly in local markets (Matos *et al*., 2019). These fruits are generally recognized as 'exotic fruits' because they have unusual characteristics such as shape, colour, and flavour (Chang *et al*., 2019). The wide availability of different bioactive and therapeutic compounds, in addition to the wide variety of species in the Amazon Biome, has attracted worldwide attention from researchers and food industries to those seeking alternatives for a healthy lifestyle (Lima Yamaguchi *et al*., 2015).

Within this scenario, this review seeks to bring

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information about some fruits from Amazon Forest with high technological and pharmaceutical potential, highlighting aspects of their composition, bioactive compounds, and therapeutic properties, but which are not so well known by the scientific community. For this purpose, the literature data on the aspects already mentioned of Amazonian fruits published between 1993 and 2020 on digital platforms such as ScienceDirect, ResearchGate, SciELO, Scopus, EMBRAPA, and Google Scholar were grouped, with the primary material collected through a search in English, Spanish and Portuguese.

2. Main characteristics of the fruits from the Amazon biome

2.1 Araçá-boi (Eugenia stipitata)

From the *Myrtaceae* family, the araçá-boi (*Eugenia stipitata*) is a fruit of climacteric behaviour, found in the western Amazon, Ecuador, and Guyana. Trees from this fruit develop in deep and fertile soil, the fruiting occurs three times a year, and the harvest can occur 38 days after the flowering process (Neves *et al*., 2015; Avila-Sosa *et al*., 2019). With a globular berry shape measuring about 12 cm in diameter, the fruit can weigh up to 300 g and has a velvety and thin skin, canary yellow colour, ranging from 4 to 10 seeds per unit, and succulent and acid pulp (Baldini *et al*., 2017; Bohry *et al*., 2019).

Many of the fruit species that belong to the *Myrtaceae* family are used as natural medicines by the local population. This healing art is traditionally transmitted from generation to generation, and it is used to treat inflammatory conditions, intestinal disorders, high blood pressure, and diabetes (Reynertson *et al*., 2008; Leite-Legatti *et al*., 2012; Malta *et al*., 2012; Neri-Numa *et al*., 2013).

The araçá-boi tends to show moisture higher than 90% and a lipid content lower than 0.3%, thus characterizing an ideal non-caloric fruit for the production of juices and jams. Carbohydrates stand out as the main component, representing about 50% of dry weight, with fructose as the primary sugar found. The soluble solids content is around 4.5°Bx; the acid flavour is derivated from the low pH of 2.5. The protein content reported in the literature is low, and the percentage of minerals (Neves *et al*., 2015; Negri *et al*., 2016; Avila-Sosa *et al*., 2019; Berni *et al*., 2019).

With its acid flavour, the fresh consumption of this fruit is low. Still, its industrial processing has been explored to enrich the final products due to its beneficial health components (Neves *et al*., 2015). An example of this is that papaya jam production with araçá-boi obtained wide sensory acceptance among tasters (Viana *et al*., 2012). Likewise, supplementation of apple nectar with araça-boi pulp increased the product's antioxidant activity (Baldini *et al*., 2017).

Many bioactive compounds (Table 1) are present in the araça-boi, and among these, carotenoids as all-trans-β -carotene, lutein, and esters such as palmitic acids, can be highlight (Garzón *et al*., 2012; Berni *et al*., 2019). The reported content of phenolic compounds and Vitamin C is high. However, the ripening decreases such compounds' concentration (Neves *et al*., 2015). The highest antioxidant capacity in the fruit occurs in its unripe state, and the tendency to fall as it matured (Garzón *et al*., 2012; Cuellar *et al*., 2013). Besides that, antimutagenic and antigenotoxic activity was found (Neri-Numa *et al*., 2013). *In vivo* studies have determined the anti-inflammatory effects of *E. stipitata* extract, a result related to phenolic compounds in its composition (Soares *et al*., 2019).

2.2 Camu-camu (Myrciaria dubia H. B. K. (Mcvough)*)*

Popularly known as camu-camu, caçari, or araçá-d'água, the *Myrciaria dubia* H. B. K. (McVough) is a small tree that belongs to the *Myrtaceae* family. It is present over practically the entire Amazon region. The trees have an average height, not exceeding 3 m, and are found in the non-domesticated state, mainly on the riverbanks and lakes with dark-colored water (INPA, 2012). The trees produce rounded fruits with an average mass ranging from 2.2 to 13.5 g, flat and shiny exterior, diameter ranging from 1.0 to 3.8 cm, and containing three to four seeds per fruit unit. When in the ripening state, its color varies from dark red to purple, fruiting between November to March (Chagas *et al*., 2012; Langley *et al*., 2015; Neves *et al*., 2017).

In some Peru regions, camu-camu is widely used in traditional medicine to treat respiratory diseases, cataracts, depression, flu, gingivitis, infertility, migraine, osteoporosis, and malaria (Castro *et al*., 2018). Yazawa *et al*., (2011) proposed in their study that the fruit seed extract has potential as a source of betulinic acid, which as a functional food, prevents diseases linked to the immune system, in addition to having antimicrobial and anti-diabetic properties (Myoda *et al*., 2010; Fujita *et al*., 2013).

The fruits are useful minerals (Table 2) because they contain sodium, potassium, calcium, zinc, magnesium, manganese, and copper. They also have small amounts of pectin and starch in their composition. The pulps have different types of fatty acids, mainly stearic, linoleic, and oleic. Highlighted sugars are glucose and fructose, and they also have various kinds of amino acids with an

Table 1. Chemical, nutritional and bioactive composition of Araçá-boi (*Eugenia stipitata*)

Components	Part of the plant	References
Moisture	Pulp and waste	Baldini *et al*. (2017); Barros *et al*. (2017); Berni *et al*. (2019)
Soluble solids (°Bx)	Pulp and waste	Baldini *et al*. (2017); Barros *et al*. (2017); Bohry *et al*. (2019)
pH	Pulp and waste	Baldini *et al*. (2017); Barros *et al*. (2017); Bohry *et al*. (2019)
Total titratable acidity	Pulp and waste	Baldini *et al*. (2017); Barros *et al*. (2017); Bohry *et al*. (2019)
Ashs	Pulp	Baldini *et al*. (2017); Berni *et al*. (2019)
Lipids	Pulp	Baldini *et al*. (2017); Berni *et al*. (2019)
Proteins	Pulp	Baldini *et al*. (2017); Berni *et al*. (2019)
Total fibers	Pulp	Baldini *et al*. (2017);
Soluble fibers	Pulp	Baldini *et al*. (2017); Berni *et al*. (2019)
Insoluble fibers	Pulp	Baldini *et al*. (2017); Berni *et al*. (2019)
Digestible carbohydrates	Pulp	Baldini *et al*. (2017);
Carbohydrates	Pulp	Berni *et al*. (2019)
Color	Pulp, peel	Bohry *et al*. (2019)
Vitamin C	Pulp	Neves *et al*. (2015)
Carotenoids		
all-trans-β-carotene	Pulp	Berni *et al*. (2019)
all-trans-α-carotene	Pulp	Berni *et al*. (2019)
β-cryptoxanthin	Pulp	Berni *et al*. (2019)
cis-β-carotene	Pulp	Berni *et al*. (2019)
Violaxanthin	Pulp	Berni *et al*. (2019)
Lutein	Pulp	Berni *et al*. (2019)
Zeaxanthin	Pulp	Berni *et al*. (2019)
all-trans-γ-carotene	Pulp	Berni *et al*. (2019)
cis-γcarotene	Pulp	Berni *et al*. (2019)
all-trans-lycopene	Pulp	Berni *et al*. (2019)
Retinol activity equivalents	Pulp	Berni *et al*. (2019)
Minerals		
K	Pulp	Leterme *et al*. (2006)
P	Pulp	Leterme *et al*. (2006)
S	Pulp	Leterme *et al*. (2006)
Ca	Pulp	Leterme *et al*. (2006)
Mg	Pulp	Leterme *et al*. (2006)
Cl	Pulp	Leterme *et al*. (2006)
Na	Pulp	Leterme *et al*. (2006)
Co	Pulp	Leterme *et al*. (2006)
Cu	Pulp	Leterme *et al*. (2006)
Fe	Pulp	Leterme *et al*. (2006)
Zn	Pulp	Leterme *et al*. (2006)
Mn	Pulp	Leterme *et al*. (2006)
Cr	Pulp	Leterme *et al*. (2006)
Se	Pulp	Leterme *et al*. (2006)
Ni	Pulp	Leterme *et al*. (2006)
Phenolic compounds		
Vanillic acid-O-hexoside	Waste	Soares *et al*. (2019)
Ellagic acid	Waste	Soares *et al*. (2019)
Coumaric acid	Waste	Soares *et al*. (2019)
Acid-Ohexoside	Waste	Soares *et al*. (2019)
Catechin	Waste	Soares *et al*. (2019)
Epicatechin	Waste	Soares *et al*. (2019)
Gallocatechin-gallate	Waste	Soares *et al*. (2019)
Dihydroquercetin glucoside	Waste	Soares *et al*. (2019)
Naringin hydrate	Waste	Soares *et al*. (2019)
Eriodictyol	Waste	Soares *et al*. (2019)
Tellimagrandin II	Waste	Soares *et al*. (2019)
Pterocaryanin C	Waste	Soares *et al*. (2019)
Casuarictin	Waste	Soares *et al*. (2019)
Potentillin	Waste	Soares *et al*. (2019)

Table 2. Chemical, nutritional and bioactive composition of Camu-camu (*Myrciaria dubia* H. B. K. (Mcvough)).

Components	Part of plant	References
Moisture	Pulp	Alves *et al*. (2002); Justi *et al*. (2000); Zapata and Dufour (1993)
Carbohydrate	Pulp	Alves *et al.* (2002); Justi *et al.* (2000); Zapata and Dufour (1993)
Monosaccharides	Pulp	Alves *et al.* (2002); Justi *et al.* (2000); Zapata and Dufour (1993)
Protein	Pulp	Alves *et al.* (2002); Justi *et al.* (2000); Zapata and Dufour (1993)
Ashs	Pulp	Alves *et al.* (2002); Justi *et al.* (2000); Zapata and Dufour (1993)
Crude fiber	Pulp	Alves *et al.* (2002); Justi *et al.* (2000); Zapata and Dufour (1993)
Lipids	Pulp	Alves *et al.* (2002); Justi *et al.* (2000); Zapata and Dufour (1993)
Total soluble solids (°Bx)	Pulp	Alves *et al.* (2002); Justi *et al.* (2000); Zapata and Dufour (1993)
Total titrable acidity	Pulp	Alves *et al.* (2002); Justi *et al.* (2000); Zapata and Dufour (1993)
pH	Pulp	Alves *et al.* (2002); Justi *et al.* (2000); Zapata and Dufour (1993)
Starch	Pulp	Alves *et al.* (2002); Justi *et al.* (2000); Zapata and Dufour (1993)
Pectin	Pulp	Alves *et al.* (2002); Justi *et al.* (2000); Zapata and Dufour (1993)
Citric acid cycle intermediates	Pulp	Alves *et al.* (2002); Justi *et al.* (2000); Zapata and Dufour (1993)
Polyphenols		
Polyphenols	Pulp, peel	Fracassetti *et al*. (2013); Fujita *et al*. (2013)
Ellagic acid and derivatives	Leaves	Ueda *et al*. (2004)
1-methylmalate	Fruit juice	Akachi *et al*. (2010)
C-glycosidic ellagitannins	Peel, seed	Kaneshima *et al*. (2016)
Betulinic acid	Seed	Yazawa *et al*. (2011)
Essential Aminoacids		
Phenylalanine	Pulp	Zapata and Dufour (1993)
Threonine	Pulp	Zapata and Dufour (1993)
Valine	Pulp	Zapata and Dufour (1993)
Leucine	Pulp	Zapata and Dufour (1993)
Isoleucine	Pulp	Zapata and Dufour (1993)
Lysine	Pulp	Zapata and Dufour (1993)
Histidine	Pulp	Zapata and Dufour (1993)
Methionine	Pulp	Zapata and Dufour (1993)
Essential Fatty Acids		
Stearic	Pulp	Justi *et al.* (2000)
Linoleic	Pulp	Justi *et al.* (2000)
Oleic	Pulp	Justi *et al.* (2000)
γ-linolenic	Pulp	Justi *et al.* (2000)
α-linolenic	Pulp	Justi *et al.* (2000)
Tricosanoic	Pulp	Justi *et al.* (2000)
Eicosadienoic	Pulp	Justi *et al.* (2000)
Vitamins		
Vitamin C	Pulp	Alves *et al.* (2002); Castro *et al.* (2015); Zapata and Dufour (1993); Rodrigues and Marx (2006); Rufino *et al*. (2010); Chirinos *et al*. (2010)
Niacin	Pulp	Zapata and Dufour (1993)
Riboflavin	Pulp	Zapata and Dufour (1993)
Thiamine	Pulp	Zapata and Dufour (1993)
Vitamin A	Pulp	Zanatta and Mercadante (2007); Zapata and Dufour (1993)
Vitamin B12	Pulp	Zapata and Dufour (1993)

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Table 2 (Cont.). Chemical, nutritional and bioactive composition of Camu-camu (*Myrciaria dubia* H. B. K. (Mcvough)).

Components	Part of plant	References
Minerals		
K	Pulp	Justi *et al.* (2000); Zapata and Dufour (1993)
PO_4	Pulp	Justi *et al.* (2000); Zapata and Dufour (1993)
SO_4	Pulp	Justi *et al.* (2000); Zapata and Dufour (1993)
Ca	Pulp	Justi *et al.* (2000); Zapata and Dufour (1993)
Mg	Pulp	Justi *et al.* (2000); Zapata and Dufour (1993)
Cl	Pulp	Justi *et al.* (2000); Zapata and Dufour (1993)
Na	Pulp	Justi *et al.* (2000); Zapata and Dufour (1993)
Co	Pulp	Justi *et al.* (2000); Zapata and Dufour (1993)
Cu	Pulp	Justi *et al.* (2000); Zapata and Dufour (1993)
Fe	Pulp	Justi *et al.* (2000); Zapata and Dufour (1993)
Zn	Pulp	Justi *et al.* (2000); Zapata and Dufour (1993)
Al	Pulp	Justi *et al.* (2000); Zapata and Dufour (1993)
Mn	Pulp	Justi *et al.* (2000); Zapata and Dufour (1993)
B	Pulp	Justi *et al.* (2000); Zapata and Dufour (1993)
Br	Pulp	Justi *et al.* (2000); Zapata and Dufour (1993)
Cr	Pulp	Justi *et al.* (2000); Zapata and Dufour (1993)
Mo	Pulp	Justi *et al.* (2000); Zapata and Dufour (1993)
Se	Pulp	Justi *et al.* (2000); Zapata and Dufour (1993)
Carotenoids		
Neoxanthin	Pulp	Zanatta and Mercadante (2007)
cis-neoxanthin	Pulp	Zanatta and Mercadante (2007)
Violaxanthin(all-trans*+ cis)	Pulp	Zanatta and Mercadante (2007)
Luteoxanthin	Pulp	Zanatta and Mercadante (2007)
Flavoxanthin*+mixture	Pulp	Zanatta and Mercadante (2007)
5,6-epoxy-lutein	Pulp	Zanatta and Mercadante (2007)
5,8-epoxy-zeaxanthin	Pulp	Zanatta and Mercadante (2007)
5,6-epoxy-zeaxanthin	Pulp	Zanatta and Mercadante (2007)
All-trans-lutein	Pulp	Zanatta and Mercadante (2007)
Zeaxanthin	Pulp	Zanatta and Mercadante (2007)
Sintaxanthin	Pulp	Zanatta and Mercadante (2007)
b-Cryptoxanthin(all-trans*+ cis)	Pulp	Zanatta and Mercadante (2007)
5,8-Epoxy-b-carotene	Pulp	Zanatta and Mercadante (2007)
β-carotene	Pulp	Zanatta and Mercadante (2007)

emphasis on valine, serine, glutamate, and leucine. Among the organic acids, there is an expressive presence of critical acid when the fruit is not fully ripe and malic acid when it ripened. Camu-camu has significant amounts of B vitamins, vitamin A and vitamin C content 60 times higher than that found in oranges, which according to RDC n° 269 of 2005 (Brazil, 2005), this quantity are 66 times higher than the recommended daily intake (Justi *et al*., 2000; Alves *et al*., 2002; Rodrigues and Marx, 2006; Akter *et al*., 2011; Hernández *et al*., 2011; Castro, Cobos, Maddox *et al*., 2015; Castro, Maddox, Cobos *et al*., 2015).

The amount of bioactive compounds changes as the fruit ripens. Carotenoids, flavonoids, anthocyanins, and vitamin C are in higher concentrations before harvest (Avila-Sosa *et al*., 2019). All-trans-lutein is the carotenoid in greater abundance (Zanatta, 2007). Among the polyphenol compounds are anthocyanins, total phenolics, flavonols, and flavonoids (Zanatta *et al*., 2005; Reynertoson *et al*., 2008; Chirinos *et al*., 2010; Goncalves *et al*., 2010; Myoda *et al*., 2010; Rufino *et al*. 2010). Camu-camu shows a high antioxidant capacity (Akter *et al*., 2011; Avila-Sosa *et al*., 2019) and antimicrobial and antigenotoxic characteristics (Chirinos *et al*., 2010; Da Silva *et al*., 2012; Fujita *et al*., 2013).

The fruit is not consumed because of the high acidity in its natural form, except for the indigenous people. This happens due to the high content of L-ascorbic acid and phenolic acid, which affect its palatability (Langley *et al*., 2015). Although there is evidence of its beneficial effect on health, fruit juice still has high sensory rejection rates (Vidigal *et al*., 2011). However, these acidic characteristics have been explored for yogurt production, obtaining high acceptability (Aguiar and Do

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Amaral, 2015).

The camu-camu can be considered a food additive since their lyophilized aqueous extract increases the final product's antioxidant activity when added to milk products. This higher antioxidant activity decreased the necessity of preservatives in this type of food (Gaglio *et al*., 2019; Fidelis *et al*., 2020). The camu-camu yogurt containing its seed extract obtained an acceptance rate of 84%, demonstrating that the camu-camu seed extract can be a potential ingredient for addition to dairy products (Fidelis *et al*., 2020). Thus, this type of food is suitable in a series of new approaches to make them naturally healthy, using natural extracts in the production of dairy foods (Zikiou and Zidoune, 2019).

2.3 Uxi (Endopleura uchi (Huber) Cuatrecasas*)*

Popularly known as uchi, uxi, axuá, uchi-pucu, uxi-amarelo, uxi-liso, and uxi-ordinário (Sá *et al*., 2015), *Endopleura uchi* (Huber) Cuatrecasas is a botanical species belonging to the Humiriaceae family and is present throughout the Brazilian Amazon basin. Developing on dry land, the fruit trees of *Endopleura uchi* (Huber) Cuatrecasas can reach 30 m in height, with trunks of rigid reddish wood, commonly used in construction. After the end of the rainy season, flowering begins between June and July. The ripening of the fruits occurs between December to July (Marx *et al*., 2002). The fruits have the shape of an oblong-ellipsoid drupe, diameter varying from 5 to 7 cm, rough yellow-orange skin, weighing about 60 g, and the pulp is the only edible portion (Neves *et al*., 2015; Lima *et al*., 2020).

Tea from the bark of the uxizeiro tree trunk is used by the inhabitants of the Amazon region to treat diabetes, arthritis, rheumatism, cholesterol control, and to treat menstrual disorders (Oliveira *et al*., 2017). Infusion of *E. uchi* peel has antidiabetic activity due to a high content of phenolic compounds, specifically bergenine and its derivatives (De Abreu *et al*., 2008). Bergenin acts as an inhibitor of α-glucosidase (AGIs), an enzyme that acts in the catabolism of carbohydrates to reduce the postprandial peaks of glucose and insulin (Silva and Teixeira, 2015).

Endopleura uchi peel extracts showed a better option for diabetes treatment compared to other plants that have already been studied for this, such as *Cecropia obtusifolia, Malmea depressa, Acosmium panamense,* and *Spergularia rubra* (Vinholes *et al*., 2011). Kumar *et al*. (2012) tested the type 2 antidiabetic activity of bergenin in diabetic rats. The results obtained allowed the authors to conclude that bergenin has significant antidiabetic, hypolipidemic, and antioxidant activity in type 2 diabetic rats.

Regarding antibacterial activity, *Pseudomonas aeruginosa* showed a high sensitivity for the infusion of *E. uchi* peel. However, *Bacillus cereus* and *Micrococcus luteus* showed greater sensitivity to the *E. uchi* hydroethanolic extract (Silva and Teixeira, 2015). Politi *et al*. (2012) reported that *E. uchi* infusion extracts could have an inhibition potential against *S. aureus*. The antibacterial activity of *E. uchi* may be associated with the presence of phenolic compounds. It is also possible that there are other bioactive compounds in the extracts, which interfere with the real antimicrobial potential, such as tannins and organic acids (Silva *et al*., 2009; Taveira *et al*., 2010).

Among other benefits of *E. uchi* is the ability to act in the inhibition of pancreatic lipase (Yun, 2010; Sukhdev and Singh, 2013) and the formation of lipoproteins (Klop *et al*., 2013); thus becoming a potential for preventing obesity and hyperlipidemia (Hyacienth *et al*., 2019). This ability to inhibit pancreatic lipase may be directly related to the content of polyphenols, especially flavonoids, which can have an essential role in preventing obesity and also preventing serum lipoproteins oxidation (Oliveira *et al*., 2017). Phenolic compounds interact with specific amino acids at the lipase catalytic active site, forming stable complexes, inactivating the enzyme (Pereira *et al*., 2011; Souza *et al*., 2011, Shikov *et al*., 2012, Lunagariya *et al*., 2014).

As for the proximal composition (Table 3), the uxi has a moisture content of less than 50% in all fruit portions. The pulp shows high levels of total lipids, emphasizing the presence of linoleic and α-linolenic acids, and its peel similarly has significant levels of palmitic acid and oleic acid (Berto *et al*., 2015). Among the mineral compounds in the whole fruit, magnesium is present in high concentrations, which is an essential constituent of bones and teeth, which offers the population easy access to a resource that brings permanent benefits to the health and quality of life of those who consume (Elige *et al*., 2012; Berto *et al*., 2015). Fractions of sugars are relatively low, with the highest concentration being fructose. Similarly, organic acids are also present in low amounts. The crude protein fraction is low, which differs from the total dietary fiber, which achieves a surprising concentration for fruits, emphasizing pectin (Marx *et al*., 2002).

The content of ascorbic acid present in the fruit is evident. However, it is worth noting that the storage time deteriorates the ascorbic acid. This deteriorating behavior with storage is opposite to what occurs with the total phenolic content (Marx *et al*., 2002; Neves *et al*., 2015), where bergenia is the more abundant compound

Table 3. Chemical, nutritional and bioactive composition of Uxi (*Endopleura uchi* (Huber) Cuatrecasas).

Components	Part of plant	References
Moisture	Pulp, seed and peel	Marx *et al*. (2002); Berto *et al*. (2015)
Raw protein	Pulp, seed and peel	Marx *et al*. (2002); Berto *et al*. (2015)
Lipid fraction	Pulp, seed and peel	Marx *et al*. (2002); Berto *et al*. (2015)
Acid content	Pulp	Marx *et al*. (2002)
Soluble solids (°Brix)	Pulp and peel	Neves *et al*. (2015)
Soluble sugars	Pulp and peel	Neves *et al*. (2015)
Titratable acidity	Pulp and peel	Neves *et al*. (2015)
Carbohydrates		
Available carbohydrates	Pulp, seed and peel	Marx *et al*. (2002); Berto *et al*. (2015)
Glucose	Pulp	Marx *et al*. (2002)
Fructose	Pulp	Marx *et al*. (2002)
Saccharose	Pulp	Marx *et al*. (2002)
Starch	Pulp	Marx *et al*. (2002)
Pectin	Pulp	Marx *et al*. (2002)
Organic acids		
Citric acid	Pulp	Marx *et al*. (2002)
Maleic acid	Pulp	Marx *et al*. (2002)
Fatty acids		
Myristic acid	Pulp, seed and peel	Marx *et al*. (2002); Berto *et al*. (2015)
Palmitic acid	Pulp, seed and peel	Marx *et al*. (2002); Berto *et al*. (2015)
Palmitoleic acid	Pulp, seed and peel	Marx *et al*. (2002); Berto *et al*. (2015)
Stearic acid	Pulp, seed and peel	Marx *et al*. (2002); Berto *et al*. (2015)
Oleic acid	Pulp, seed and peel	Marx *et al*. (2002); Berto *et al*. (2015)
Linoleic acid	Pulp, seed and peel	Marx *et al*. (2002); Berto *et al*. (2015)
Linolenic acid	Pulp, seed and peel	Marx *et al*. (2002); Berto *et al*. (2015)
Eicosanoic acid	Pulp, seed and peel	Marx *et al*. (2002); Berto *et al*. (2015)
Fatty acids related compounds	Extract	Lima *et al*. (2020)
Amino acids		
Glutamic acid	Pulp	Marx *et al*. (2002)
Leucine	Pulp	Marx *et al*. (2002)
Valine	Pulp	Marx *et al*. (2002)
Phenylalanine	Pulp	Marx *et al*. (2002)
Serine	Pulp	Marx *et al*. (2002)
Tyrosin	Pulp	Marx *et al*. (2002)
Alanine	Pulp	Marx *et al*. (2002)
Threonine	Pulp	Marx *et al*. (2002)
Proline	Pulp	Marx *et al*. (2002)
Isoleucine	Pulp	Marx *et al*. (2002)
Lysine	Pulp	Marx *et al*. (2002)
Aspartic acid	Pulp	Marx *et al*. (2002)
Asparagine	Pulp	Marx *et al*. (2002)
Glycine	Pulp	Marx *et al*. (2002)
Glutamine	Pulp	Marx *et al*. (2002)
Arginine	Pulp	Marx *et al*. (2002)
Histidine	Pulp	Marx *et al*. (2002)
Methionine	Pulp	Marx *et al*. (2002)
γ-Aminobutyric acid	Pulp	Marx *et al*. (2002)
α-Aminoadipic acid	Pulp	Marx *et al*. (2002)
Amino acid related compounds	Extract	Lima *et al*. (2020)
Biogenic amines		
Ornithine	Pulp	Marx *et al*. (2002)
Taurine	Pulp	Marx *et al*. (2002)
Ethanolamine	Pulp	Marx *et al*. (2002)
Vitamins		
Ascorbic acid	Pulp and peel	Marx *et al*. (2002); Neves *et al*. (2015)
α-Tocopherol	Pulp	Marx *et al*. (2002)

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Table 3 (Cont.). Chemical, nutritional and bioactive composition of Uxi (*Endopleura uchi* (Huber) Cuatrecasas).

Components	Part of plant	References
Minerals		
Mn	Pulp, seed and peel	Marx *et al*. (2002); Berto *et al*. (2015)
Zn	Pulp, seed and peel	Marx *et al*. (2002); Berto *et al*. (2015)
Cu	Pulp, seed and peel	Marx *et al*. (2002); Berto *et al*. (2015)
Fe	Pulp, seed and peel	Marx *et al*. (2002); Berto *et al*. (2015)
Mg	Pulp, seed and peel	Marx *et al*. (2002); Berto *et al*. (2015)
Na	Pulp, seed and peel	Marx *et al*. (2002); Berto *et al*. (2015)
P	Pulp, seed and peel	Marx *et al*. (2002); Berto *et al*. (2015)
Bioactive compounds		
Phenolic Acid	Extract	Lima *et al*. (2020)
Total Phenolic Compounds	Tree bark extract, pulp and peel	Neves *et al*. (2015); Silva and Teixeira (2015); De Oliveira *et al*. (2017); Lima *et al*. (2020)
Flavonoids	Extract	Lima *et al*. (2020)
Chalcones	Extract	Lima *et al*. (2020)
Coumarins	Extract	Lima *et al*. (2020)
Others phenolic compounds	Extract	Lima *et al*. (2020)
Terpenoids	Extract	Lima *et al*. (2020)
Total flavonoids content	Tree bark extract	De Oliveira *et al*. (2017)
Antioxidant activity		
AChE and BuChE inhibitory activity	Tree bark extract	Silva and Teixeira (2015)
Antibacterial activity	Tree bark extract	Silva and Teixeira (2015)
α-Glucosidase inhibitory activity	Tree bark extract	Silva and Teixeira (2015)

(Nunomura *et al*., 2009; Silva and Teixeira, 2015). The pulp and peel of the uxi showed great antioxidant potential, but similar to what occurs with vitamin C the storage time decreases this potential (Neves *et al*., 2015; Hyacienth *et al*., 2019). The principal carotenoid found in the uxi pulp is trans-β-carotene, which guarantees its potential as a functional food (Lima *et al*., 2020). It can also be considered a vitamin E source, as it has an amount higher than the daily intake recommended according to RDC n° 269 of 2005 (Brasil, 2005).

2.4 Pedra-ume caá (Eugenia punicifolia (Kunth) D.C.*)*

Eugenia punicifolia (Kunth) D.C. belongs to the *Myrtaceae* family and is popularly known as pedra-ume-caá, pedra-ume, murta, or muta. It is a shrub widely distributed in the Amazon region and the savanna biome (Périco *et al*., 2019). Pedra-ume caá (*Eugenia punicifolia*) is a fruit species used as an alternative source of functional food. The fruits are similar to a small cherry with sweet pulp, which presents different colors according to ripening stages (Ramos *et al*., 2019). The flowering season is from June to March, and fruiting can occur all year round (Souza and Lorenzi, 2008).

The species is characterized by a cylindrical stem, with bark in irregular plaques that expose the yellow-colored epidermis with light spots. The leaves are elliptical (approximately 6 cm long and 2 cm wide), opposite, and petiolate. Its numerous flowers are arranged in white panicles. The wood of this plant, when dry, is red and very resistant, being used in posts and rafters (Brito *et al*., 2014).

Eugenia punicifolia is one of the traditional medicinal plants unexplored by pharmacists in Brazil. Traditionally used by the local community, this species was registered by the French naturalist August de Saint-Hilaire on his travels to Brazilian territories from 1816 to 1822 (Brandão *et al*., 2012). Besides that, *Eugenia punicifol*ia has agricultural and industrial importance due to its traditional medicinal applications as multiple biological activities, such as antioxidants (Cunha *et al*., 2016), antimicrobial (Santos *et al*. 2018), anti-inflammatory (Costa *et al*., 2016; Lazarini *et al*., 2016), antinociceptive and gastroprotective (Basting *et al*., 2014), cytotoxic (Sousa *et al*., 2015) and insecticidal activities (Gonzalez *et al*., 2014). The leaves of this medicinal plant are popularly used in aqueous decoctions or infusions as a natural therapeutic agent for the treatment of inflammations, fever, and flu, diabetes, and in alcoholic infusions for the treatment of wounds and infectious diseases (Oliveira *et al*., 2005; Leite *et al*., 2010; Chaves and Barros, 2012; Perico *et al*., 2019). In addition to being a source of phenolic, flavonoid, essential oils (Linalool, β-caryophyllene, and α-terpineol), coumarin, tannin, and galotanin (Basting *et al*., 2014; Galeno *et al*., 2014; Cunha *et al*., 2016; De Albuquerque *et al*., 2019).

Phytochemical studies carried out on the pulp and seed of the *Eugenia punicifolia* fruit demonstrated the occurrence of sucrose, α-D-glucopyranose, β-D-glucopyranose, linoleic acid, gallic acid, shikimic acid, β -glucogallic acid, 3'-rhamnoside myricetin, ellagic acid, quercetin 3-O-rhamnoside and kaempferol 7-O-rhamnoside (Ramos *et al*., 2019). From a pharmacological point of view, studies using crude extracts of this genus have shown its anti-inflammatory, analgesic, antifungal, antipyretic, hypotensive, antidiabetic, and antioxidant activities (Donepudi *et al*., 2012; Basting *et al*., 2014; Tenfen *et al*., 2016). Besides, the exotic flavor, juiciness, high acidity, and unique sensory characteristics of the fruit make it suitable for the production of juices, nectars, jams, and jellies (Lizcano *et al*., 2010; Calvi *et al*., 2017).

2.5 Madroño (Garcinia madruno)

Garcinia madruno is a species native to Central and South America, traditionally known as madroño, charichuelo, cozoiba, naranjita, ocoró, satro, and belongs the Clusiaceae family (Lim, 2012). It is a tropical fruit tree commonly grown in the Amazon region and easily found in its natural habitat, the Eastern Amazon, and in dry forests with sandy soils. Its trees are 6 to 12 m high, with a dense green crown, and the fruiting occurs in summer. This plant produces yellow fruit with one to three seeds, covered by a white pulp. The fruit is used as food and has a characteristic acidic flavor (Chávez Cury *et al*., 2012).

Garcinia madruno is widely used in the healing of skin infections and wounds due to its anti-inflammatory characteristics (Baggett *et al*., 2005). Also, it is a supplement to the diet of the local population due to the presence of proteins, lipids, carbohydrates, and minerals (Ca, Mg, Na, K, P, Fe, Zn, Cu, Mn) (Chávez Cury *et al*., 2012).

One of the reasons that aroused interest in *Garcinia madruno* is due to the presence of bioactive compounds previously identified in its leaves and fruits, such as vitamin A, vitamin C, total phenolic content, antioxidant activity, glyceryl palmitate, polyisoprenylated benzophenones, hydroxycitric acid, and biflavonoids (Osorio *et al*., 2013; Carrillo-Hormaza *et al*., 2016; Ramirez *et al*., 2019). In general, polyisoprenylated benzophenones show broad biological activity with antibacterial, antifungal, anti-inflammatory, and antioxidant properties (Kumar *et al*., 2013).

Garcinia madruno stands out for producing a high content of biflavonoids (6-11%), establishing itself as a species of relevance because most fruits do not reach 8% (Tabares-Guevara *et al*., 2017; Sabogal-Guáqueta *et al*., 2018). Biflavonoids call attention compared to the other chemical groups in Garcinia due to their bioactive potential. Some studies show that these compounds can inhibit the lipid peroxidation of human LDL and stabilize the DPPH radical (Osorio *et al*., 2009; Osorio *et al*., 2013). Studies show that biflavonoids generally have a high level of antioxidant activity and relevant pharmacological activities, such as antimicrobial, antiallergic, anti-inflammatory, hepatoprotective antiviral (Ferreira *et al*., 2012; Carillo-Hormaza *et al*., 2019; Ramirez *et al*., 2019). However, although the functionality of biflavonoids is positively related to their antioxidant capacity, there is no evidence or studies that clarify the structural differences between biflavonoids with antioxidant activity (Carrillo-Hormaza *et al*., 2016).

3. Future perspectives

Given the vast bioavailability of Amazonian fruits, many are still unknown or little explored by the scientific community. However, several authors have been paying attention to this availability and have started investigating bioactive compounds' quantification in these exotic fruits. Information about the composition of exotic fruits from the Amazon is still scarce. Many of their bioactive compounds still need to be fully identified and characterized (phenolic acids, flavonoids, biflavonoids, anthocyanins, among others). Thus, more research must be carried out to determine the complete profile of the bioactive compounds.

Given the presence of essential phytochemicals in Amazonian fruits and their association with biological properties, these fruits' possible applications as functional ingredients of food products should be examined. Another point that needs to be explored more is the medicinal application of leaf extracts, fruit peels, and seeds in pharmacology and cosmetology. Finally, the use and enhancement of by-products (peel and seeds) produced during the processing of these fruits should be investigated once they can be a new source of value-added ingredients. This can also help solve some environmental issues about the sustainable management of these materials.

Conflict of interest

The authors declare no conflicts of interest.

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