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Review article

Chemical composition, bioactive compounds, and perspectives for the industrial formulation of health products from uvaia (*Eugenia pyriformis* Cambess – Myrtaceae): A comprehensive review

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ABSTRACT

Uvaia (*Eugenia pyriformis* Cambess – Myrtaceae family) is an unexplored native fruit from the Brazilian Atlantic Rainforest with a high potential for agro-industrial processing. Nevertheless, scientific information on existing research of uvaia should be explored to provide the trends and perspectives for the industrial application of this fruit. This review summarized the chemical composition, bioactive compounds, and biological activity of uvaia. The novelty enclosed in this review is based on the perspectives for the industrial formulation of health products from uvaia. Uvaia fruits reveal a remarkable aroma, high content of nutritional and bioactive compounds, high antioxidant, antimicrobial, and anti-inflammatory activity. The findings elucidated in this review support the application of uvaia in the industrial development of health products, such as foods, beverages, medicines, and cosmetics, contributing to the worldwide dissemination of this unexplored fruit.

1. Introduction

The Food and Agriculture Organization (FAO) reported that 868 million tons of fresh fruits were produced in 2018 (FAOSTAT, 2020). Brazil has favorable geography and climatic conditions for fruit production, being the third major worldwide producer of common fruits, such as orange, banana, pineapple, papaya, grape, and apple. Furthermore, the Brazilian territory has several biomes, including the Atlantic Rainforest, which is one of the most degraded by human action, with only 12.4% of its original area (Sos Mata Atlantica. 2021). Although the Atlantic Rainforest devastation, this biome shows rich biodiversity, highlighting the abundance of native fruits with worldwide potential for consumption and industrialization. Notwithstanding, the ecological resources of the Atlantic Rainforest include genetic material preservation, while the production of unconventional fruits supports the employment of small and local producers, being an important factor for the sustainable development of the Brazilian Atlantic Rainforest (Sganzerla et al., 2021; Lopes et al., 2018). Therefore, the Brazilian biodiversity presents a range of native fruit trees, and many of them are not completely known even by the scientific community. For instance, some examples of Brazilian native's fruits are Rio Grande cherry (*Eugenia involucrata*), gabiroba (*Campomanesia reitziana*), araç á (*Psidium cattleyanum*), cambuci (*Campomanesia phaea*), abiurana (*Pouteria torta*), and pitanga (*Eugenia uniflora*) (Sganzerla et al., 2021; Tokairin et al., 2018; da Silva et al., 2016a; da Silva et al., 2016b).

Additionally, one of the native fruits naturally grown in the Atlantic Rainforest is the uvaia (*Eugenia pyriformis* Cambess). This species belongs to the Myrtaceae family, which is one of the most important for the Brazilian flora. The Myrtaceae family accounts for 121 genera and 5800 species (Jacomino, da Silva, Freitas, & Morais, 2018). The fruits from uvaia present a rounded (or spherical), flat, and piriform shape, and the texture may be softer or firm, and the coloration varies between yellow and orange tones. Its exotic aroma can be characterized as pleasant and striking, with sweet and acidic notes (da Silva et al., 2019). Uvaia fruits have economic importance mainly between local producers. Also, this fruit has been recognized for its high nutritional value and rich sources

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of bioactive compounds (da Silva et al., 2019; Sganzerla et al., 2019; Silva et al., 2018; da Silva et al., 2016a).

Nowadays, there is a nutritional appeal for a healthy diet, and the intake of bioactive compounds in fresh and processed food products is associated with the inhibition of free radicals. A healthy diet based on bioactive compounds decreases the probability of developing chronic diseases, such as cancer, Alzheimer's disease, cardiovascular and pulmonary disease (Alkaltham et al., 2021; Donado-Pestana et al., 2018; Hacıseferoğulları et al., 2012). Hence, the food and pharmaceutical industry has been focusing on the development of bioactive products based on pulp and byproducts of fruits (Rodrigues et al., 2021; de Avelar et al., 2019). Recently, uvaia fruits and its by-products have been described as a rich source of phenolic compounds and carotenoids, with anti-inflammatory, antimicrobial, and antioxidant activity (Rodrigues et al., 2021).

Scientific information on existing research of uvaia should be explored to provide the trends and perspectives for the industrial application of this fruit. Therefore, this study aimed to conduct a detailed literature review regarding the chemical composition and functional properties of uvaia (*Eugenia pyriformis* Cambess), for the industrial formulation of health products. This review makes it possible to disseminate information for future applications of this fruit, which can act as a strategy for the preservation of the Brazilian biodiversity, contributing to decision-making in the field of food science and technology.

2. Botanical characteristics of uvaia

Uvaia is a fruit considered native from the Brazilian Atlantic Forest, especially in altitudes greater than 800 m. This species has predominance on the Brazilian coast, from the Northeast to the South regions. Other countries in South America, such as Paraguay and Argentina, also demonstrate the presence of this fruit, however, it is not so much expressive when compared to Brazil (Jacomino et al., 2018; Lisbôa, Kinupp, & Barros, 2011). Fig. 1 shows the appearance of uvaia tree, flowers, and fruits.

In Brazil, the fruits of uvaia are popularly known as "uvalha", "ubaia", "uvaia do mato", "uvaieira", "uvalheira", and "azedinha". The production of uvaia fruits for a 10-year old plants, was estimated at 5 kg of fruit per plant per year (Jacomino et al., 2018). This species has a medium-sized tree (5–15 m) with a rounded or elongated crown. The leaves are opposite, glabrous, subcorse, pinkish-red when young and 4–7 cm long. The flowers are white, solitary, hermaphroditic, tetrameric, with many stamens. The fruits are classified as berry type,

Fig. 1. General aspects of uvaia tree, flowers, and fruits, disseminated in the Brazilian territory. Pictures of accessions were obtained from Estância das Frutas (2018).

rounded, with thin and velvety epicarp. The fruits present a pulp with yellow or orange coloration, which can vary in shape from globose to piriform. The trunk is generally upright, and the bark tends to peel into large pieces (Lorenzi, 2002). The seeds are classified as large, and account for 2–4 seeds per fruit, with high germination capacity (Silva et al., 2003). From an ecological perspective, this plant has aroused interest from its cultivation in agroforestry systems, as it can be used due to its hardwood, resistance to diseases and, mainly, for presenting edible fruits with exotic taste. In addition, the fruit is also looked to many bird species, making this plant recommended for heterogeneous reforestation intended for the restoration of degraded areas and permanent preservation (Oliveira et al., 2019).

Otherwise, few studies have been performed with uvaia phenology, and this factor is related to the regions of occurrence and due to the genetic characteristics (Danner et al., 2010). Uvaia plants flourish at different times, and little is known about their diversity. In São Paulo State uvaia blooms from August to September; while in the south of the country is later, extending until February; and in the Pantanal region flourishes until November (Sganzerla et al., 2021). In the phenological stages of uvaia it was possible to observe seven different stages until the beginning of the fruit development (Fig. 1). The stage “A” is the reproductive budding; “B” is the development of flower buds wrapped by a pair of smooth bracts; “C” represents the development of buds, with the appearance of pale-colored petals; “D” represents the balloon, petals about to open and export their anthers and stigma; “E” is flowering with the opening of the flower; “F” represents the fall of the petals; “G” fall of the stigma and stylus (Sganzerla et al., 2021). This knowledge is important because allows crop scheduling in future commercial plantations through genotypes with different harvest periods.

3. Uvaia diversity in Brazil

A great variability between uvaia plants can be observed in Brazil, presenting significant differences in fruit size, number, and size of seeds. This variability can be explained because even showing strong potential, this species is not domesticated or cultivated as a commercial-level plantation, only for small producers in Brazil (Sganzerla et al., 2019). Thereby, the fruits characterization is important for taxonomy, helping to identify genetic variability within populations of the same species as well as the relationships with environmental factors (Silva et al., 2018; Sganzerla et al., 2018; Sganzerla et al., 2019). The characterization of uvaia from different plants have been conducted in terms of the beneficial impact for food, cosmetic and pharmaceutical industries (Jacomino et al., 2018). Through these studies, fruits with distinct properties can be obtained in the field. For instance, samples with extremely low levels of acidity and a high ratio between soluble solids and acidity demonstrate that this fruit can be used for fresh consumption, enabling its acceptance by the consumer market (da Silva et al., 2019; Sganzerla et al., 2019). Otherwise, mostly of the accessions studied by Sganzerla et al. (2019) were classified as extremely acid, and therefore, these fruits should be predominantly used for industrial processing, allowing the development of pulp, jelly, ice cream, among other products.

Sartori et al. (2010) identified six accessions of uvaia cultivated in Rio Claro municipality, Brazil. The accession evaluated were different in terms of size, firmness, and color. To confirm this hypothesis, da Silva et al. (2019), characterized the six accessions concerning physical, chemical, and bioactive compounds characteristics and obtained an expressive difference between the accessions “comum”, “rugosa”, “doce Patos de Minas”, “p ê ra”, “rugosa doce”, and “dura” (Fig. 1). Indeed, the accessions coded as “rugosa doce” presented high levels of bioactive compounds, such as phenolics, carotenoids, and high antioxidant capacity. Corroborating with this statement, Sganzerla et al. (2019) demonstrated that the geographical origin of uvaia fruits presents an acute difference in chemical composition, even been from the same region. Using the chemometric approach, Sganzerla et al. (2019) concluded that genetic improvement of uvaia can be conducted based on natural selection to improve the quality of uvaia pulp and increase the fruit market. The study also reported that some plants presented higher content of total soluble solids, carbohydrates, TSS/TA (ratio between total soluble solids and total acidity), bioactive compounds, and antioxidant capacity. Finally, the postharvest conservation of uvaia accession was studied to provide a perspective for industrial processing. For instance, the accession “dura” maintained the quality suitable for consumption for up to 3 days after harvest. However, the accession “p ê ra” started the senescence process immediately after the harvest, and subsequently, the appearance of an unpleasant odor makes its consumption and commercialization unfeasible. Otherwise, the “dura” accession presented a more resistant cell wall, which hinders mechanical damage, cell respiration, and probably a longer shelf life for fresh consumption (da Silva et al., 2016a).

4. Nutritional composition

Table 1 presents the nutritional composition of uvaia fruits. In general, uvaia fruits are rich in fibers, minerals, soluble sugars, and proteins. This review focuses on their fiber content and minerals, as these compounds are directly associated with several health benefits.

Dietary fiber contents in uvaia ranged from 31.09 to 44.10 g 100 g^{-1} (d.w., dry weight) (Table 1). Dietary fibers comprise a type of carbohydrate, an indigestible cell wall component present in fruits, nuts and seeds, vegetables, wheat bran, and whole-grain foods. These macromolecules play an important dietary and human health role, as they aid in the absorption of dietary fat and cholesterol and prevent constipation due to accelerated food movement and waste transport through the digestive system. Furthermore, a diet rich in fruits containing high fiber contents is recommended, as increased fiber intake has been associated with reduced risk factors for coronary heart disease, hypertension, obesity, chronic diseases like diabetes, cardiovascular diseases, and colon neoplasia (Viguiliouk et al., 2019).

The consumption of 200 g of fresh uvaia provides 15.97–39.03% of the total fiber dietary reference intake (DRI) established for adults (da Silva et al., 2019; Institute of Medicine, 1999–2011). Conventional fruits considered rich fiber sources, such as blueberries and avocados, provide an 11.47% and 2.86% lower fiber intake than uvaia, respectively. Therefore, uvaia fruits are also considered a rich source of dietary fibers (da Silva et al., 2019), although *in vivo* dietary effects should be investigated to propose novel human health perspectives.

Uvaia pulp contains high amounts of essential minerals, including potassium (K), calcium (Ca), and iron (Fe) (Table 1), all essential for vitamin functioning. Iron uvaia contents, for example, are higher than those found in strawberries and apples (Pereira et al., 2014). In addition, as they are essential metals, K, Ca, and Fe deficiencies compromise certain human organs, such as bones and teeth. K is essential for cellular functioning and electrical homeostasis, while Fe is required for hemoglobin blood production and its deficiency causes anemia. In addition, Fe is presented in numerous proteins and plays many roles at the cellular level (Gupta & Gupta, 2014).

The World Health Organization (WHO) recommends a minimum daily intake of 3510 mg K, 1200 mg Ca, and 25 mg Fe for adults (Institute of Medicine, 1999–2011). da Silva et al. (2019) analyzed the contribution of 200 g uvaia intake as a percentage of the DRI of minerals for adults (19–50 years old), and reported that, although K was present in the highest amounts, this mineral contributes with only 3.16–5.32% of the DRI per 200 g of fresh uvaia, while Ca contributes with 3.08–5.64%, and Fe with 2.45–16.01%. However, an appropriate daily mineral intake is observed, individuals are less likely to develop high blood pressure and may lower the risk of cardiovascular diseases, *i.e.,* stroke, heart attack, and coronary heart disease.

Table 1
Nutritional composition, minerals, vitamins, and antioxidant capacity of uvaia (*Eugenia pyriformis* Cambess) fruits.

Parameters	Composition	Unit	Parameters	Composition	Unit
Moisture	88.14 – 94.50	g 100 g^{-1} (f.w.)	Total acidity	0.70 – 1.87	g 100 g^{-1} (f.w.)
Ashes	0.23 – 0.52	g 100 g^{-1} (f.w.)	Soluble solids	3.60 – 10.50	°Brix (f.w.)
Lipids	0.21 – 0.61	g 100 g^{-1} (f.w.)	Vitamin C	9.45 – 122.51	mg 100 g^{-1} (f.w.)
Protein	0.66 – 1.69	g 100 g^{-1} (f.w.)	Vitamin A	3.78	mg 100 g^{-1} (d.w.)
Total dietary fiber	3.09 – 44.10	g 100 g^{-1} (d.w.)	Vitamin B2	0.04	mg 100 g^{-1} (f.w.)
Insoluble dietary fiber	3.09 – 39.05	g 100 g^{-1} (d.w.)	Phosphorus (P)	134 – 235.55	mg 100 g^{-1} (d.w.)
Soluble pectin	0.17	g 100 g^{-1} (f.w.)	Potassium (K)	888.24 – 1559.67	mg 100 g^{-1} (d.w.)
Total pectin	0.95	g 100 g^{-1} (f.w.)	Calcium (Ca)	54.25 – 341.33	mg 100 g^{-1} (d.w.)
Carbohydrates	4.20 – 11.64	g 100 g^{-1} (f.w.)	Magnesium (Mg)	27 – 60.33	mg 100 g^{-1} (d.w.)
Energy	13.57 – 27.00	kcal 100 g^{-1} (f.w.)	Sulfur (S)	49.87 – 75.3	mg 100 g^{-1} (d.w.)
Total sugars	4.41 – 5.61	g 100 g^{-1} (f.w.)	Sodium (Na)	9.97	mg 100 g^{-1} (d.w.)
Reducing sugar	36.54	g 100 g^{-1} (d.w.)	Boron (B)	0.57 – 1.08	mg 100 g^{-1} (d.w.)
Glucose	4.04 – 5.21	g 100 g^{-1} (f.w.)	Copper (Cu)	0.45 – 7.25	mg 100 g^{-1} (d.w.)
Fructose	4.64 – 6.50	g 100 g^{-1} (f.w.)	Iron (Fe)	2.11 – 5.53	mg 100 g^{-1} (d.w.)
Sucrose	1.42 – 9.53	g 100 g^{-1} (f.w.)	Manganese (Mn)	0.76 – 3.05	mg 100 g^{-1} (d.w.)
Citric acid	0.002 – 0.091	g 100 g^{-1} (f.w.)	Nickel (Ni)	0.45	mg 100 g^{-1} (d.w.)
Tartaric acid	0.006 – 0.063	g 100 g^{-1} (f.w.)	Zinc (Zn)	0.71 – 6.04	mg 100 g^{-1} (d.w.)
Malic acid	0.189 – 0.628	g 100 g^{-1} (f.w.)	ABTS	33.62 – 923.5	mmol TE100g^{-1} (f.w.)
Lactic acid	0.116 – 0.1271	g 100 g^{-1} (f.w.)	DPPH	9.94 – 29.71	mmol TE100g^{-1} (d.w.)
Succinic acid	0.088 – 0.834	g 100 g^{-1} (f.w.)	FRAP	227.99 – 933.6	mg TE100g^{-1} (f.w.)
pH	2.96 – 3.74	–	ORAC	4.48 – 17.09	mmol TE100g^{-1} (d.w.)

References: da Silva et al. (2019), da Silva et al. (2016a), Pereira et al. (2012,2014), Rufino et al. (2010), Silva et al. (2014), Silva et al. (2018), Sganzerla et al. (2018,2019).

5. Bioactive compounds

5.1. Vitamin C

Uvaia fruits are a known rich source of Vitamin C, ranging from 9.45 to 122.51 mg 100 g^{-1} (f.w., fresh weight) (Table 1). This vitamin plays an essential role in human health, for example, as an important antioxidant molecule in plant and animal metabolisms, whose lack implies disease, and as a cofactor in many enzymes. These vitamins are not synthesized in the human body, so they must be included by the dietary route, mainly ingested through fruit and vegetable consumption, which comprise significant sources of this antioxidant (Fenech et al., 2019). Asencio et al. (2018) analyzed the edible tissues of nine traditional citrus fruits, recognizing bioactive compound sources and reporting that 'Blanco' grapefruit and 'Fino' lemons exhibit similar bioactive compound levels when compared to uvaia, and that mandarins ('Mandarina' type) contain lower vitamin C contents than uvaia, demonstrating uvaia potential in providing dietary Vitamin C.

A daily ascorbic acid intake of 75 and 90 mg for men and women, respectively, is recommended by the WHO (Institute of Medicine, 1999–2011). An uvaia weighing on average 11.4 g can provide from 72.04% and 86.45% of the ascorbic acid DRI for men and women, respectively, suggesting that this fruit is a natural alternative source of this vitamin (da Silva et al., 2019; Sganzerla et al., 2019).

Table 2
Bioactive compounds (phenolics, flavonoids, and carotenoids) of uvaia (*Eugenia pyriformis* Cambess) fruits.

Parameters	Composition	Unit	Parameters	Composition	Unit
Phenolic acids			*Carotenoids*		
Gallic acid	25.71 – 34.61	mg 100 g^{-1} (f.w.)	9-cis-neoxanthin	22.8	µg 100 g^{-1} (f.w.)[3]
Chlorogenic acid	3.84	mg 100 g^{-1} (f.w.)	all-trans-neochrome	11.7	µg 100 g^{-1} (f.w.)[3]
Caffeic acid	0.52	mg 100 g^{-1} (f.w.)	cis-antheraxanthin	22.1	µg 100 g^{-1} (f.w.)[3]
p-coumaric acid	0.15	mg 100 g^{-1} (f.w.)	9-cis-violaxanthin	19.4	µg 100 g^{-1} (f.w.)[3]
Ferulic acid	0.34	mg 100 g^{-1} (f.w.)	all-trans-lutein	86.0	µg 100 g^{-1} (f.w.)[3]
Dicaffeic acid	2.0	mg 100 g^{-1} (f.w.)[1]	5,6-epoxy-β-cryptoxanthin	24.3	µg 100 g^{-1} (f.w.)[4]
Flavonols			all-trans-zeaxanthin	56.0	µg 100 g^{-1} (f.w.)[4]
Rutin	0.11	mg 100 g^{-1} (f.w.)	5,8-epoxy-β-cryptoxanthin	36.5	µg 100 g^{-1} (f.w.)[4]
Myricetin	2.95	mg 100 g^{-1} (f.w.)	13-cis-β-cryptoxanthin	22.8	µg 100 g^{-1} (f.w.)[4]
Quercetin	14.97	mg 100 g^{-1} (f.w.)	phytoene	5.9	µg 100 g^{-1} (f.w.)[5]
Kaempferol	1.34	mg 100 g^{-1} (f.w.)	all-trans-zeinoxanthin	78.4	µg 100 g^{-1} (f.w.)[4]
Quercetin deoxyhexoside	4.8	mg 100 g^{-1} (f.w.)[1]	all-trans-β-cryptoxanthin	521.1	µg 100 g^{-1} (f.w.)[4]
Hydroxybenzoic acids	0.33	mg 100 g^{-1} (f.w.)	5,8-epoxy-β-carotene	32.9	µg 100 g^{-1} (f.w.)[5]
Hydroxycinnamic acids	0.10	mg 100 g^{-1} (f.w.)	9-cis-β-cryptoxanthin	57.9	µg 100 g^{-1} (f.w.)[4]
Flavonoids	0.26	mg 100 g^{-1} (f.w.)	9-cis-β-cryptoxanthin	68.1	µg 100 g^{-1} (f.w.)[4]
Gallotannins			all-trans-α-carotene	14.2	µg 100 g^{-1} (f.w.)[5]
galloyl hexoside	5.1	mg 100 g^{-1} (f.w.)[1]	all-trans-β-carotene	170.9	µg 100 g^{-1} (f.w.)[5]
galloyl hexoside isomer	1.8	mg 100 g^{-1} (f.w.)[1]	9-cis-β-carotene	56.5	µg 100 g^{-1} (f.w.)[5]
trigalloyl acid lactonized	13.8	mg 100 g^{-1} (f.w.)[1]	lutein	307.49	g g^{-1} (d.w.)
galloyl-bis-HDDP hexoside	19.3	mg 100 g^{-1} (f.w.)[1]	zeaxanthin	40.38	g g^{-1} (d.w.)
Total bioactive compounds			β-carotene 5,6-epoxide	16.39	g g^{-1} (d.w.)
Phenolic compounds	94.40 – 483.25	mg 100 g^{-1} (f.w.)[1]	cryptoxanthin	159.09	g g^{-1} (d.w.)
Flavonoids	1.2 – 38.58	mg 100 g^{-1} (f.w.)[2]	13-cis-β-carotene	38.30	g g^{-1} (d.w.)
Yellow flavonoids	7.3 – 17.5	mg 100 g^{-1} (f.w.)	α-carotene	124.39	g g^{-1} (d.w.)
Anthocyanins	1.13	mg 100 g^{-1} (f.w.)	β-carotene	191	g g^{-1} (d.w.)
Carotenoids	1.3 – 441.26	mg 100 g^{-1} (f.w.)	9-cis-β-carotene	32.27	g g^{-1} (d.w.)

1Gallic acid equivalent.; [2]CE equivalent; [3]all-trans-lutein equivalent; [4]all-trans-β-cryptoxanthin equivalent; [5]all-trans-β-carotene equivalent. References: Stafussa et al. (2018); Haminiuk et al. (2014); Silva et al. (2014); Pereira et al. (2012).

5.2. Phenolic compounds

Phenolic compounds are natural antioxidants comprising a complex class of over 8000 compounds (da Silva, 2021). Phenolic compound consumption has been associated with several human health benefits, *i.e.,* inflammatory system improvement, lower risk of developing cardiovascular diseases, including coronary heart disease, heart attacks, strokes, hypertension, diabetes, obesity, and lower cancer risks (Durazzo et al., 2019).

It has been reported that uvaia contains high total phenolic compound concentrations, ranging from 94.40 to 483.25 mg GAE 100 g^{-1} (f.w.), depending on the studied accessions (Table 2). These values are higher than those reported for other popularly consumed fruits, such as mango (74.32 mg GAE 100 g^{-1}, f.w.), melon (69.98 mg GAE 100 g^{-1}, f.w.), and pineapple (69.76 mg GAE 100 g^{-1}, f.w.) (Stafussa et al., 2018). This demonstrates uvaia potential in enriching human diets with bioactive compounds. Additionally, uvaia also is an excellent source of flavonoids, a class of phenolic compounds, ranging from 1.2 to 38.58 mg CE 100 g^{-1} (f.w.) (Table 1). Farias et al. (2020) reported 6.49 mg CE g^{-1} (d.w.) for uvaia pulps and 101.46 mg CE g^{-1} (d.w.) for uvaia seeds, while Sganzerla et al. (2019) indicated from 0.0005 to 0.0120 g GAE kg^{-1} (f.w.) for uvaia pulp.

Farias et al. (2020) identified phenolic compounds present in uvaia pulp and seed. Sixteen phenolic compounds were identified in the edible uvaia portion, namely comprising phenolic acids, flavonols, flavan-3-ols, and flavones, while nine were identified in seeds, comprising phenolic acids, flavonols, monomeric flavan-3-ols, and flavones. Silva et al. (2014) identified and quantified twelve phenolic compounds in uvaia pulp, highlighting gallic acid and its derivatives as major compounds (Table 2). Gallic acid is an essential phenolic acid displaying powerful antioxidant capacity as a free radical scavenger. This ability has been associated with several biological effects, such as antioxidant, anti-cancer, and anti-inflammatory activities. This is probably due to its chemical structure and chemical group (radical) conformity, such as the number of hydroxyl groups, phenolic ring substitutions, and carboxyl group esterification (Kahkeshani et al., 2019).

Bioactive compound extraction and isolation are important steps for the separation, identification, and quantification of phenolic uvaia compounds. Haminiuk et al. (2014) used methanol, ethanol, distilled water, methanol/water (1:1, v/v), and ethanol/water (1:1, v/v) to assess the use of different solvents in the recovery of phenolic acids and flavonols from uvaia pulp, namely gallic acid, chlorogenic acid, caffeic acid, p-coumaric acid, ferulic acid, rutin, myricetin, quercetin, and kaempferol. The determined phenolic compounds ranged from 255.91 to 588.31 mg kg^{-1} (f.w). Pure methanol was the most efficient solvent, resulting in the highest phenolic acid (gallic acid, caffeic acid, and ferulic acid) and flavonol (rutin, myricetin, and kaempferol) recovery rates.

Additionally, Sganzerla et al. (2019) evaluated the effect of three solutions (aqueous, ethanol, and hydroethanolic) in phenolic compound extraction from uvaia pulp from twelve plants sampled from the Brazilian Southern Atlantic Rainforest. Phenolic contents ranged from 0.27 to 4.3 g GAE kg^{-1} (f.w.), respective for aqueous and hydroethanolic solution. Higher total phenolic compounds and total flavonoid contents, as well as antioxidant capacity, were detected in the same plant, demonstrating that genetic diversity affects secondary metabolite contents.

Some eco-friendly extraction methods have been developed aiming to reduce environmental damage. Rodrigues et al. (2021), for example, used an ultrasound-assisted extraction method alongside membrane separation *via* reverse osmosis to concentrate bioactive compounds obtained from uvaia by-products (peel), reporting a 6.2-fold increase for phenolics (332.22 mg GAE 100 g^{-1}) and a 7.8-fold increase for total flavonoids compared to the initial crude extract, demonstrating that innovative extraction methods can be used to upgrade bioactive compound contents in fruit byproducts.

5.3. Carotenoids

Carotenoids are natural pigments presenting bioactive characteristics, found mainly in the form of a C40-hydrocarbon backbone (Ngamwonglumlert et al., 2020). A total of 850 compounds have been described as occurring naturally up to 2018. Carotenoids used to be categorized into only two leading groups based on their chemical structures, carotenes or pure hydrocarbon carotenoids (*i.e.,* lycopene, α-carotene, and β-carotene), and xanthophylls or oxygenated carotenoids, such as neoxanthin, antheraxanthin, zeaxanthin, lutein, and violaxanthin (Ngamwonglumlert et al., 2020). These carotenoids have been widely studied due to their involvement in beneficial health benefit mechanisms (Pereira et al., 2012). Fruits and vegetables, including uvaia, are known sources of these bioactive compounds (da Silva et al., 2019; Silva et al., 2014; Pereira et al., 2012). Total carotenoids in uvaia fruits have been described as ranging from 1.7 to 441.26 mg 100 g^{-1} (f.w.) (Table 1). Rodrigues et al. (2021) quantified total carotenoids in aqueous uvaia residues (seed and peel) following an ultrasound-assisted extraction method coupled to membrane concentration. At the end of the sequential extraction, total carotenoids were 49.5-fold higher (358.05 μg 100 g^{-1}) in the extracts submitted to the reverse osmosis concentration method compared to samples submitted to ultrasound-assisted extraction alone (7.20 μg 100 g^{-1}). This demonstrates that both carotenoid recovery techniques are viable and clean. Furthermore, uvaia by-products (seed and peel) are a highly promising feedstock for the extraction of bioactive compounds and the formulation of functional foodstuff for the food and pharmaceutical industries.

Few studies have been conducted concerning the identification of individual uvaia carotenoids. Silva et al. (2014) identified eighteen uvaia carotenoids containing high all-trans-β-carotene (170.9 μg 100 g^{-1}, f.w.) and all-trans-lutein (86.0 μg 100 g^{-1}, f.w.), all-trans-β-zeinoxanthin (78.4 μg 100 g^{-1}, f.w.), and 9-cis-β-cryptoxanthin (68.1 μg 100 g^{-1}, f.w.) amounts. Pereira et al. (2012) recognized nine uvaia carotenoids, reporting the predominance of lutein (307.49 g g^{-1}, d.w.), cryptoxanthin (159.09 49 g g^{-1}, d.w.), and α-carotene (124.39 g g^{-1}, d.w.).

Carotenoids such as α-carotene and β-carotene undergo a particular route in becoming provitamin A precursors, which is a fat-soluble vitamin and essential micronutrient (Ngamwonglumlert, et al., 2020; Anand et al., 2020; Pereira et al., 2012). Inadequate vitamin A intake compromises a wide spectrum of biological functions, such as embryonic development, reproduction, cellular growth and differentiation, vision, growth and development and immunological activity, and is a serious public health issue, mainly in low-income countries (Gonçalves, Estevinho, & Rocha, 2016). Guava (*Psidium guajava*, belonging to the Myrtaceae family), a well-liked Brazilian native fruit commercialized worldwide, is a significant source of β-carotene. Anand et al. (2020) reported that β-carotene content in guava could range from 0.13 to 2.54 mg 100 g^{-1}. Uvaia contains even higher levels when compared to this Myrtaceae fruit, and, thus, may be considered a new β-carotene source. In addition, α-carotene and β-carotene have been described as displaying other biological activities, such as anti-cancer and antihypertensive profiles, as well as potent anti-inflammatory potential, decreasing inflammatory gene expression in lipopolysaccharide-stimulated macrophage cells and suppressing redox-based NF-κB (nuclear factor kappa light chain enhancer of activated B cells) activation (Bai et al., 2005).

5.4. Volatile compounds

Volatile compounds are responsible for fruit and vegetable aromas. Their biosynthesis depends on both extrinsic and intrinsic factors that take place during physiological fruit development. Depending volatile compounds biosynthesis, which is positively correlated with fruit maturation stage, it is possible to determine which compounds make up the characteristic aroma detected each ripening stage. In this regard, de

Freitas et al. (2019) identified fifty-nine volatile compounds during three uvaia ripening stages, green (immature), yellow (turning), and orange (ripe), indicating that immature fruits presented specific aromas, such as green aromatic herbs (β-bourbonene, 3–hexenol, and 2-transhexenyl acetate) and fruity (delta - elemene, hexyl acetate, α - cubebene, aloaromadendrene, ethyl butyrate, ethyl acetate, ethyl hexanoate, (Z)– 3-hexenyl butyrate and hexyl hexanoate) notes. During the more advanced ripening stages (turning and ripe), fruity (octyl butyrate, 1–octanol, and isoamylacetate), and floral (β-ocimene and nonanal) notes were described, associated with compounds correlated with pleasant and desirable odors that can indicate quality loss and senescence initiation, such as isoamyl alcohol, pentanal, ethanol and neryl acetone (fermented - alcoholic). Ripe fruits contained more compounds than immature fruits, and thus, are more suitable for consumption and use in the pharmaceutical and food industries. Geographical fruit origin may also influence the volatile compound composition. da Silva et al. (2019) characterized the volatile compounds of six uvaia accessions (‘comum’, ‘doce de Patos de Minas’, ‘rugosa’, ‘rugosa doce’, ‘p ê ra’ and ‘dura’) from the Brazilian Southeast and detected seventy-seven volatile compounds. Each accession presented specific compounds, indicating that different accessions can be used to extract a particular compound. Nevertheless, similarities between accessions were observed, due to the presence of α-pinene and D-limonene (monoterpenes), (-)-γ-elemene (sequisterpene), ethyl butyrate, ethyl hexanoate, hexyl acetate, hexyl propionate, octyl acetate, propanoic acid, and octyl hexanoate (esters), ((Z)– 3-hexen-1-ol and 1-octanol (aliphatic alcohols), octanal (aldehyde), alcohols, (E)– 2-hexenal (aliphatic alcohol and aldehyde). Finally, terpenes are also recognized as major volatile compounds in uvaia, resulting in a complex aroma (da Silva et al., 2019).

5.5. *Essential oils*

Essential oils are composed of hydrophobic compounds, comprising complex mixtures that can be obtained from wood (bark), roots, leaves, flowers, and seeds. These compounds can be extracted by the most common hydrodistillation methods, as well as by steam and steam/water distillations. Other techniques include solvent extraction, aqueous infusion, cold or hot pressing, and extraction employing supercritical fluid technology (Doost et al., 2020).

Studies describing the determination of the chemical composition of essential oils obtained from whole uvaia fruits, as well as leaves and flowers, have been published in recent decades (Stefanello et al., 2009; Agredo, 2017; Durazzini et al., 2019). Essential uvaia oils mostly comprise terpenes (*i.e.,* monoterpenes and sequisterpenes), corroborating with previously identified volatile compounds. Stefanello et al. (2009) analyzed the composition of essential oils obtained by the hydrodistillation of uvaia leaves, flowers, and fresh fruits, reporting a total of sixty-five compounds. The major compounds in leaf oil were β-pinene (13.9%), limonene (12.5%), 1,8-cineol (7.0%), spatulenol (5.1%) and caryophyllene oxide (9.7%). In fruits, caryophyllene oxide (16.2%) and limonene (12.4%) were the most noteworthy. Regarding flower oils, major components were E-caryophyllene (22.8%) and germacrene D (15.3%). Apel et al. (2004) obtained essential uvaia oil through the hydrodistillation of fresh leaves, reporting the predominance of sesquiterpenes, comprising α-cadinol (14.0%), T-cadinol (11.9%), bicyclogermacrene (10.2%), δ-cadinene (10.2%), T-cadinol (11.9%) and β-caryophylene (7.2%).

Eco-friendly technologies, such as supercritical fluids, are a promising alternative to obtain plant extracts, providing satisfactory yields and solvent-free extracts. For example, one study performed the extraction of bioactive compounds such as α and β-amyrin from uvaia leaves using supercritical CO_2 and solvent extraction assisted by ultrasound under different pressure (100–200 bar), temperature (40–60 °C) and CO_2 density (280.72–840.67 kg m^{-3}) conditions, resulting in different yields (0.08–1.69%) compared to a conventional extraction method (Klein et al., 2018). High yields were obtained employing supercritical CO_2 at 60 °C and 200 bar. When employing ultrasound-assisted solvent extraction, the best yield was of 1.79% and extraction yield, extract mass, amyrin mass, and leaf mass by the amount of amyrin were high than levels obtained by conventional maceration. Results concerning essential oils obtained from uvaia fruits, portions, and by-products are promising, demonstrating the possibility of using this material for short and long-scale industrial applications, with manufacturing costs ranging from 622.9 to 1102.6 US$ kg^{-1} uvaia extract (Klein et al., 2021).

6. Biological activity and health benefits

6.1. *Antioxidant capacity*

Fruits belonging to the Myrtaceae family, including uvaia, display high antioxidant activity and several beneficial effects. Uvaia has been reported as presenting a strong *in vitro* antioxidant activity as revealed by the DPPH (2,2-diphenyl-1-picrylhydrazyl), ORAC (Oxygen Radical Absorbance Capacity), ABTS (2,2-azino-bis(3-ethylbenzothiazoline-6-sulphonic acid), and FRAP (Ferric Reducing Antioxidant Power) assays. This denotes its potential as a health-promoting agent and increased interest regarding its use in the food industry as an antioxidant additive and natural dye has emerged (Sganzerla et al., 2019; Pereira et al., 2012) (Table 3). This antioxidant potential is associated to several biological effects, attributed mainly to bioactive molecules such as phenolic compounds, carotenoids, and volatile compounds (Donado-Pestana et al., 2018; Rufino et al., 2010). Phytochemicals are abundant in plant-based foods, and these bioactive compounds play an important role in the prevention of degenerative diseases. For example, the consumption of native Brazilian fruits decreases the probability of developing type 2 diabetes, due to oxidative stress and inflammation attenuation (Farias et al., 2020; Donado-Pestana et al., 2018).

Uvaia antioxidant activity determined by the DPPH assay has been reported as ranging from 923 to 7387.8 mg TEAC 100 g^{-1} (f.w.), with an EC_{50} from 170 to 3247 g^{-1} (f.w.). In the ABTS free radical scavenging, antioxidant capacity ranged from 33 to 923.5 mmol TEAC 100 g^{-1} (f.w.), while values the FRAP assay indicated values from 227 to 933 mg TEAC 100 g^{-1} (f.w.). Finally, ORAC levels ranged from 4.48 to 17.09 mmol TEAC 100 g^{-1} (d.w.) (Table 1), demonstrating that bioactive uvaia compounds present strong antioxidant activity.

Based on the high *in vitro* antioxidant capacity reported for uvaia, Ramirez et al. (2012) evaluated the effects of uvaia fruit extracts on the *in vivo* antioxidant capacity of rat plasma employing the TAR (Total Antioxidant Reactivity) and TRAP (Total Reactive Antioxidant Potential) assays. TRAP activity was reduced in a concentration-dependent manner in supplemented rats following paw edema, while TAR activity was higher in rats treated with the investigated uvaia extracts, possibly due to the significant contribution of hydrophilic antioxidants to TAR (Ramirez et al., 2012). Additionally, to demonstrate the capacity of uvaia juice as an enhanced antioxidant factor, Lopes et al. (2018) analyzed the effects of uvaia juice consumption in thirty-two female rats fed either i) a standard diet (C group) or ii) a high-fat diet (HF group), by analyzing protein carbonyls and antioxidant enzyme level in the rat livers. The results indicate that uvaia juice significantly decreased rat oxidative stress metabolism by improving antioxidant efficiency and ameliorating oxidative damage to proteins (Table 3). Oxidative stress occurs when the production of the reactive oxygen species is higher than the antioxidative defense system’s capability to reduce these chemical compounds (Fallah, Sarmast, & Jafari, 2020). A recent meta-analysis demonstrated that the dietary intake of anthocyanins, a subgroup of phenolic compounds, displays the ability to decrease the activity of endogenous enzymes involved in the antioxidative defense system against oxidative stress, such as malondialdehyde, oxidized low-density lipoprotein, and isoprostane, when comparing healthy and unhealthy subjects (Fallah, Sarmast, & Jafari, 2020). Therefore, uvaia have been recognized for their high nutritional value, as rich sources of bioactive

Table 3
Biological properties and health benefits of uvaia.

Source	Product	Model of assay	Health benefits	Reference
Fruit	*Juice*	*In vivo* (Evaluation of juice intake in the fight against oxidative stress in Fischer rats).	Hepatic accumulation of carbonyl proteins and prevented the decrease of the antioxidant activity.	Lopes et al. (2018).
Fruit	*Pulp*	*In vivo* (Evaluation of uvaia fruit extract against the paw edema in male Wistar rats).	Chemotaxis migration inhibited paw edema in a dose-dependent manner (1.0 and 0.5 g kg^{-1} b.w. with 51% and 43% inhibition).	Ramirez et al. (2012).
Leaf	Essential oil	*In vitro* (Evaluation of essential oil against bacteriostatic activity and bactericidal activity).	Bactericidal activity against *Listeria innocua* and *Escherichia coli*. The extract showed a bactericidal activity against *L. innocua* and a bacteriostatic behavior against *S. aureus* and *Candida albicans.*	Agredo, (2017).
Leaf and stem	*Extract*	*In vitro* (Evaluation of leaf and stem against bactericidal activity).	Leaf and stem showed effectiveness against *E. faecalis* and *S. aureus.*	de Souza et al. (2014).
Leaf	extract	*In vitro* (Evaluation of leaf against worm mobility).	Leaf of uvaia extract exhibited high worm mobility against *S. venezuelensis.*	Bastos et al. (2017).
Leaf and seed	extract	*In vitro* (Evaluation of leaf and seed against antimicrobial activity).	Uvaia extracts inhibited the growth of bacteria's and yeasts, except for *M. bovis* and *M. tuberculosis.*	Chavasco et al. (2014).
Leaf	extract	*In vitro* (Evaluation of leaf promastigotes of Leishmania amazonensis).	Leaf of uvaia extract showed Antileishmanial Activity.	Kauffmann et al. (2016).
Leaf	Essential oils and extract	*In vitro* (Evaluation of the essential oil and extracts against acaricidal and larvicidal potential on southern cattle tick at different phases of the reproductive cycle).	Essential oils of *E. pyriformis* showed a larvicidal action for *Rhipicephalus (Boophilus) microplus* southern cattle tick larvae at LC99.9 of 24.6 mg/mL. Also, it showed a 72.25% reduction in tick larvae reproductive efficiency.	Medeiros et al. (2019).

compounds, and exhibiting high antioxidant capacity, all positive factors for worldwide consumption and processing.

6.2. Antimicrobial activity

Several *in vitro* studies have demonstrated antimicrobial uvaia effects against many microorganisms, such as bacteria, fungi, viruses, and protozoa (Medeiros et al., 2019; Bastos et al., 2017; Kauffmann et al., 2016; Chavasco et al., 2014) (Table 3). Chavasco et al. (2014) analyzed the antimicrobial activity of hydroethanolic extracts obtained from uvaia leaves and seeds against Gram-negative and Gram-positive bacteria, yeast, *Mycobacterium bovis,* and *Mycobacterium tuberculosis H37.* The extracts inhibited bacteria Gram positive, Gram negative and yeast, but did not inhibit *M. bovis* and *M. tuberculosis.* Kauffmann et al. (2016) evaluated essential oils obtained from fresh uvaia leaves against *Leishmania amazonensis*, a protozoan parasite that causes chronic cutaneous leishmaniasis disease. This neglected tropical disease causes skin lesions and is responsible for infecting millions of people worldwide. Also, cutaneous leishmaniasis can cause visceral disease in some cases (Martinez, & Petersen, 2014). The analyzed essential uvaia oils were reported as effective against *Leishmania amazonensis*, with an IC_{50} value of 19.73 μg mL^{-1}. The main effect was correlated with the presence of terpenes, resulting in mitochondrial membrane potential changes, isoprenoid cell biosynthesis inhibition and plasma membrane alterations.

Stieven et al. (2009) also evaluated the antimicrobial activity of essential oils obtained from uvaia peel, peel/pulp, and seeds, performing the antimicrobial disk diffusion test against *Escherichia coli, Staphylococcus aureus, Pseudomonas aeruginosa,* and *Enterococcus faecalis* and emphasizing the bacteriostatic action of the investigated oils against the *E. faecalis* strain. On the other hand, de Assis et al. (2011) assessed the fumigating activity of oils obtained from uvaia leaves against *Tyrophagus putrescentiae* and *Suidasia pontifica* mites, reporting the death of 80% of *T. putrescentiae* and 60% of *S. pontifica* populations in at 50 μL L^{-1} air. Furthermore, LC_{50} values were reported as 3.71 μL L^{-1} for *T. putrescentiae* and 11.09 μL L^{-1} for *S. pontifica*. The authors suggest that the observed acaricidal activity is probably associated to the presence of certain specific compounds, such as eugenol, ρ-cimen-7-ol, and karyophylene oxide (de Assis et al., 2011).

Bastos et al. (2017) analyzed uvaia leaf extracts in the treatment of *Strongyloides venezuelensis* and *Strongyloides ratti*. The authors reported higher worm mobility against *S. venezuelensis.* Strongyloidiasis is a neglected disease, with an estimated frequency of about 100–370 million cases worldwide, caused by the nematode *Strongyloides stercoralis* (Eslahi et al., 2021). The risk of infection is higher in developing countries, in regions displaying hot and humid climates and in people who work with soil (Eslahi et al., 2021). *Strongyloides venezuelensis* and *Strongyloides ratti* are both rodent parasites and crucial in the development of models for this disease. Currently, only synthetic drugs have been employed in strongyloidiasis treatment. Due to the high occurrence of this disease and the low therapeutic efficacy of the synthetic medications presently available, a demand for new therapeutic alternatives is noted (Bastos et al., 2017). In this regard, natural treatment with uvaia leaf extracts comprises a promising approach.

In another study, de Souza et al. (2014) evaluated the *in vitro* antimicrobial activity and potential synergistic interactions of *E. pyriformis* with Vancomycin and Fluconazole assessing the Minimum Inhibitory Concentration (MIC), defined as the lowest concentration that visibly inhibits microorganism growth, against selected pathogenic bacteria and fungi. The crude extracts and hexane, chloroform, ethyl acetate, hydroalcoholic, acetonic *E. pyriformis* stem and leaf fractions were tested *in vitro* against *Enterococcus faecalis, S. aureus, Escherichia coli, Klebsiella pneumoniae, P. aeruginosa, Candida albicans, Candida krusei,* and *Candida parapsilosis strains.* Concerning *E. faecalis* and *S. aureus*, the ethyl acetate and hydroalcoholic leaf fractions displayed pronounced inhibitory activity (MIC = 62.5 μg mL^{-1}). Similar results were obtained for the stem and leaf acetonic extracts against *E. faecalis* and *S. aureus* (MIC = 62.5 μg mL^{-1}). Concerning the leveduriform fungi ethyl acetate fraction and leaf acetonic extract, MIC values ranged from 7.81 to 62.5 μg mL^{-1}. These results were categorized as positive in the scale established by the authors. The synergistic activity observed for *Enterococcus faecalis*, *Candida albicans*, *Candida krusei* and *Candida parapsilosis* strains exhibited fractional inhibitory concentration indices below 0.5. Agredo et al. (2017) analyzed the bactericidal activity of essential uvaia oil extracts against *Listeria innocua* and *Escherichia coli*, corroborating the results reported by de Souza et al. (2014), demonstrating the same bactericidal activity behavior, biological activity against *L. innocua* and bacteriostatic behavior against *S. aureus* and *Candida albicans.* These findings indicate that uvaia may be categorized as a medicinal plant able to inhibit *in vitro* bacteria and fungi growth, attributed to the presence of different bioactive compounds that affect microorganism growth and metabolism (Özcan et al., 2015; de Souza et al., 2014).

6.3. Anti-inflammatory activity

Inflammation is a curative tissue process in response to injuries involving cell damage. Anti-inflammatory plant extract activities have been constantly evaluated to provide new alternatives in this regard and comprise a powerful choice to ameliorate this type of cell impairment. In this regard, Ramirez et al. (2012) analyzed the effects of an ethanolic uvaia extract on *in vivo* anti-inflammatory activity administered orally for 21 days in male Wistar rats prior to a sub-plantar carrageenan injection. The findings indicate decreased chemotaxis migration, inhibiting paw edema in a dose-dependent manner (1 and 0.5 g kg^{-1} body weight with 51% and 43% inhibition). *E. pyriformis* extract administration initiated edema inhibition during the first hour and during all inflammation phases, demonstrating that uvaia may be considered a dietary supplement capable of ameliorating inflammation processes. Currently, uvaia potential as an anti-inflammatory agent is associated with its pharmacological properties, attributed to high gallic acid concentrations. In general, gallic acid can minimize inflammatory cascade responses, which begin with nuclear factor kappa B (NF-κB) and mitogen-activated protein kinase (MAPK), causing a massive release of inflammatory cytokines, chemokines, and adhesion molecules, which contribute to pathological changes in organs or tissues, and results in intractable chronic inflammation (Bai et al., 2021; Chen et al., 2020). Furthermore, both chronic and acute inflammation have been reported as stimulating the release of inflammatory mediators like interleukin-1β (IL-1β), tumor necrosis factor-α (TNF-α), nitric oxide (NO) and prostaglandin E2 (PGE2) (Bai et al., 2021). The overproduction and accumulation of these free radicals or factors result in several degenerative diseases, including atherosclerosis, cancer, aging, cardiovascular, and inflammatory diseases (Chen et al., 2020).

7. Perspectives concerning for industrial formulation of healthy products

In recent decades, the food and beverage industries have developed an interest in creating processed food products for commercial applications using native Brazilian fruits. In this context, the craft beer market has expanded in recent years, and research uses brewing adjuncts to impart their aromas and flavors to differentiated products has increased. Therefore, the use of uvaia as a natural brewing adjunct represents a promising alternative for the beverage industry in the development of innovative products with a different taste, highly nutritious, and containing high levels of bioactive compound contents.

Tomaz et al. (2019) formulated a mixed orange and uvaia nectar using orange nectar as a control. The formulations were composed of i) a control (60% orange juice without uvaia pulp); ii) 40% orange juice + 20% uvaia pulp, and iii) 30% orange juice + 30% uvaia pulp. The results indicate that the mixed orange and uvaia at all ratios present good physicochemical stability, while the mixed nectar formulation comprising 30% orange juice + 30% uvaia pulp contained higher ascorbic acid (22 mg 100 mL^{-1}) and phenolic compound (405 mg 100 mL^{-1}) concentrations. Phenolic compound amounts increased with increasing uvaia pulp content in the nectar formulation. These findings suggest technological uvaia potential, which can contribute to the development of a product with significant nutritional and bioactive properties.

Bianchini et al. (2020) carried out chemical and bioactive compound analyses of lactose-free yogurt incorporating pasteurized uvaia pulp. The products maintained the original uvaia coloration (yellow), with a considerable increase in bioactive compounds, demonstrating future marketing potential. This innovative approach indicates a promising alternative to the increasing demands of lactose-intolerant individuals seeking foods containing bioactive properties and unique sensory characteristics.

Giarola et al. (2015) developed an iron-fortified uvaia sherbet containing low sucrose concentrations. Sherbet formulations included iron functionalization and sucrose substitution by micronized sucralose. The determined iron concentration of 11.5–15.0 mg was within the optimum range, and the sherbets were characterized concerning chemical composition (pH, solid soluble contents, carbohydrates, caloric value), overrun, consistency index, and flow index. According to sensorial acceptability parameters, around 80% sucrose substitution by sucralose is required for the iron fortification to reach the maximum established by current legislation, aiming for a product with good acceptance and high nutritional value. These results may aid the dairy industry to diversify market options, by appreciating native fruits in food formulations.

Increasing demands for sustainable, healthier, and natural confectionery products are noted, especially concerning the substitution of synthetic products due to health implications. In this context, de Avelar et al. (2019) evaluated the potential of uvaia byproducts as low-coloring in hard-panning sugar confections, comparing synthetic caramel and a natural fruit/plant-based uvaia concentrate. When comparing sweets containing uvaia to sweets containg the fruit-based concentrate and artificial colorant, the uvaia sweets demonstrated lower water activity and luminosity, higher hardness and a* (redness/greenness), and b* (yellowness/blueness) parameters. The consumers displayed a higher intention to consume the darker and more intense color products obtained by the addition of the uvaia byproduct. However, the uvaia sweets displayed the lowest crispness compared to the fruit-based candies (6.61) for and the artificial colorant (6.77–7.16), in a hedonic structured scale ranging from 1 (disliked) to 9 (liked). The use of the aforementioned uvaia byproduct as a natural coloring in panning confections allows for increased healthy and nutritional components in final products, due to high amounts of vitamins, minerals, fiber, and antioxidant compounds.

From an industrial perspective, Ramos et al. (2017) tested the effects of drying technology on uvaia byproducts regarding phenolic compound contents compared to conventional oven drying. Total phenolic contents ranged from 30.5 and 38.5 mg g^{-1}, considered high (Ramos et al., 2017). The authors concluded that 40 °C and a prior centrifugation step comprised the best conditions to preserve byproduct characteristics. The dried uvaia byproduct, thus, comprised a stable, low-moisture ingredient, which may be interesting for applications in bakery and confectionery product formulations.

According to the aforementioned studies, uvaia fruits, seeds, and leaves can be applied in the development of chemical formulations displaying gastroprotective, analgesic, and anti-inflammatory properties (Klein et al., 2021). In the food science and technology field, uvaia fruits are usually consumed in the form of juices, jellies, liquors, compotes, ice cream, and sweets (Jacomino et al., 2018). Due to their antioxidant and anti-inflammatory activities, as well as ultraviolet protection of phenolic plant compounds, uvaia also can be applied in cosmetics (creams and soaps) and sunscreen (da Silva et al., 2019). Finally, this fruit should be disseminated in the field production, making it available to the population and the food industry, as it presents a high agro-industrial potential for the development of exotic and unique health products, which can be commercialized worldwide.

8. Conclusion

Uvaia fruits present high nutritional value and economic importance for local producers, although they are still unexplored by the industry. Due to their high phytochemical content, uvaia fruits present antioxidant, antimicrobial, and anti-inflammatory activity, which are the main parameters investigated in the future formulation of healthy products. Therefore, innovative technologies and processes should be applied in the development of nutraceutical supplements, chemicals, cosmetics, and food products containing this fruit, contributing directly to the sustainable development of the Brazilian Atlantic Rainforest. Novel studies in this regard are required to obtain bioactive compounds, vitamins, minerals, and dietetic fiber. Furthermore, the elucidation of bioactive compound synergistic and antioxidant uvaia mechanisms should be better explored to understand their bioavailability and human health effects. Additionally, a lack of studies concerning bioactive uvaia compound preservation techniques are also noted. Therefore, encapsulation, nanoemulsion, nanodispersion, and film-formulation assessments should be encouraged to increase this unexplored uvaia potential regarding technological applications. In conclusion, this study discussed uvaia research trends and perspectives, contributing to the development of innovative and healthy formulations, as well as stimulating the sustainable industrial development of novel products for worldwide consumption.

CRediT authorship contribution statement

Aline Priscilla Gomes da Silva: Conceptualization, Writing – original draft, Writing – review & editing, Funding acquisition. **William Gustavo Sganzerla:** Conceptualization, Writing – original draft. **Angelo Pedro Jacomino**: Resources, Project administration, Funding acquisition. **Edson Pablo da Silva:** Writing – original draft, Writing – review & editing. **Jianbo Xiao:** Project administration, Funding acquisition, Writing – review & editing. **Jesus Simal-Gandara:** Project administration, Funding acquisition, Writing – review & editing.

Declaration of competing interest

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.

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CRediT authorship contribution statement

All authors equally contribute to Conceptualization, Methodology, Formal Analysis, Investigation, Writing, and Visualization, under Supervision of the corresponding authors Aline Priscilla Gomes da Silva and Jesus Simal-Gandara.

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