DOI: https://doi.org/10.1590/1678-992X-2019-0259

ISSN 1678-992X

Scientia Agricola

Food Science and Technology

Yerba mate: cultivation systems, processing and chemical composition. A review

Camila Pereira Croge[1]*, Francine Lorena Cuquel[1], Paula Toshimi Matumoto Pintro[2]

[1]Universidade Federal do Paraná – Depto. de Fitotecnia e Fitossanitarismo, R. dos Funcionários, 1540 – 81531-990 – Curitiba, PR – Brasil.

[2]Universidade Estadual de Maringá – Depto. de Agronomia, Av. Colombo, 5790 – Zona 7 – 87020-900 – Maringá, PR – Brasil.

*Corresponding author <camilacroge@epagri.sc.gov.br>

Edited by: Luís Guilherme de Lima Ferreira Guido

Received October 30, 2019
Accepted April 05, 2020

ABSTRACT: The unique chemical composition of yerba mate and its functionalities suggest that it needs to be explored for its innovation potential. New uses may boost consumption, surpassing the traditional consumption barrier, and making yerba mate accessible on a global level. Thus, to highlight the importance of yerba mate as a potential source of agro-economic resources, we present a review on its botanical, ecological, agronomic, and industrial aspects, along with information on the biochemical composition of this species and its biological activity.

Keywords: *Ilex paraguariensis*, natural product, agro-economic resources

Introduction

In recent years, more studies have been conducted on yerba mate (*Ilex paraguariensis*), focusing mainly on its health effects. Yerba mate has several pharmacological activities, including antioxidant, anti-inflammatory, antimutagenic, anti-obesity, and cardioprotective functions (Gómez-Juaristi et al., 2018). These benefits are related to a unique chemical composition including alkaloids, polyphenols, terpenes, and essential oils, among others (Mateos et al., 2018; Riachi et al., 2018).

Ilex paraguariensis is abundant in the understory of *Araucaria* forests and has a considerable economic value and a significant importance in agricultural production systems, generating income and playing a strategic role in the preservation of native forest areas in ecosystems with a multiple-use perspective of natural resources (Inventário Florístico Florestal de Santa Catarina, 2013).

However, with some exceptions, scientific evidence shows that implementation of yerba mate had a late onset, while studies on *Camelia sinensis* and *Coffea* sp. are numerous. Compared to mate, these species have a similar economic and biological potential and are widely consumed worldwide due to their stimulating effects on the nervous system (Heck and Mejia, 2007; Baeza et al., 2017). The consumption of infusions prepared from the leaves of yerba mate dates back to the XIX century, while studies on this species have only be performed in the last three decades (Heck and Mejia, 2007).

Our current knowledge on yerba mate is rather fragmented, requiring further studies. The species has potential to be used not only as a drink, but also as raw material for the cosmetics, nutraceutical, and pharmaceutical industries (Heck and Mejia, 2007; Bracesco et al., 2011; Berté et al., 2014; Souza et al., 2015; Cardoso Junior and Morand, 2016). Thus, changes are necessary in agronomic research to obtain a high-quality raw material through breeding programs, variety selection, as well as improved production strategies in efficient systems that ensure the best chemical composition, thereby, optimizing its biological activities (Cardoso Junior and Morand, 2016).

To emphasize the importance of this species as potential source of agro-economic resources and highlight its versatile chemical composition and the possibility of multiple uses, we conducted a literature review on its botanical, ecological, agronomic, and industrial aspects. In addition, we present information on its biochemical composition and biological activity.

Classification and botanical aspects

Yerba mate was first described in 1822 by the French naturalist Auguste de Saint-Hilaire, who published in "*Mémoires du Muséum d'Histoire Naturelle*" in France. His observations described a perennial tree with many branches and leaves, relatively developed size, and an outline that resembled that of cypresses. The leaves are dark green in the ventral aspect and odorless when fresh; however, with an herbaceous and bitter flavor. When prepared for consumption, the faint aroma reminds that of Swiss tea (Berté et al., 2014). Its complete botanical classification is shown in Figure 1.

Yerba mate is a perennial tree of the family Aquifoliaceae, which can reach 8 to 15 m high. Its leaves are perennial, alternating, coriaceous, obovate to elliptic, with slightly shallow margins, an obtuse apex, and a wedge-shaped base. The petioles are up to 15 mm long. In its original habitat, flowering occurs from Oct to Dec. Inflorescences are pistils in fascicles, with monoic flowers that can appear grouped in the axilla, petals, and rounded ones. Fruits are drupes, ranging from red to black, oval to globose, with 4.5 to 6.5 mm diameter and four to five seeds (Figure 2) (Bracesco et al., 2011; Cabral et al., 2018).

Ecological aspects and geographical distribution

The family Aquifoliaceae, in its present constituency, is represented solely by the genus *Ilex*,

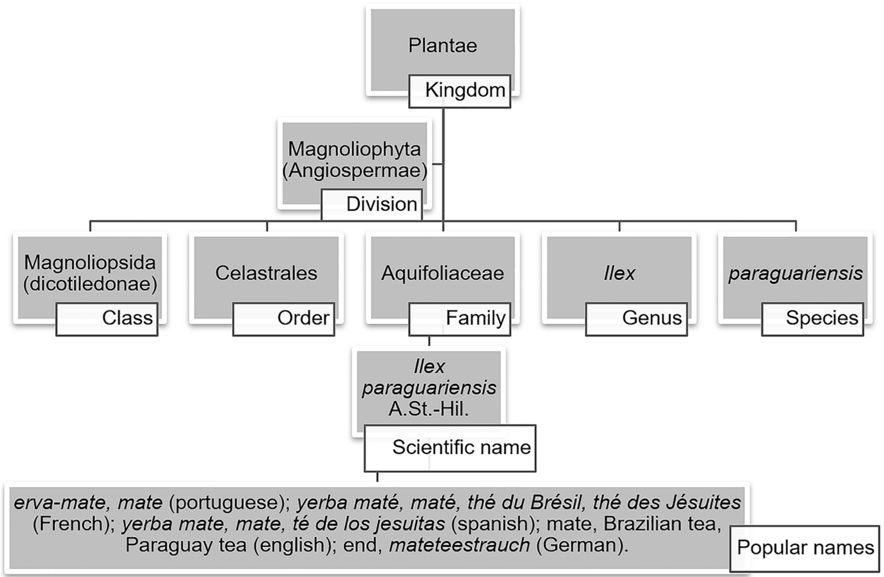

Figure 1 – Botanical classification of yerba mate (Bracesco et al., 2011; Cabral et al., 2018).

Figure 2 – Yerba mate: tree, leaves, branches and flowers – A) tree; B) flowering; C) leaves and branches. (Source: A and C = Author; B = Herbário Dr. Roberto Miguel Klein (FURB), 2018).

with more than 600 species. *Ilex* has a predominantly tropical distribution, extending to temperate regions of the northern and southern hemispheres, with East Asia and South America as the global centers of diversity (Yi et al., 2017; Cabral et al., 2018).

Yerba mate is the most important commercial species of the genus and occurs in its native state in the subtropical and temperate regions of South America, including Argentina, Brazil, and Paraguay, between latitudes 21°00′00″ S, 30°00′00″ S and longitudes 48°30′00″ W, 56°10′00″ W (Figure 3), preferably at altitudes between 500 and 1,500 m (Heck and Mejia, 2007; Chaimsohn et al., 2014). About 80 % of the species are native to Brazil and mainly distributed in the states of Paraná, Santa Catarina, and Rio Grande do Sul (CEPA, 2015).

The species are endemic and distributed in the wild exclusively in the forested regions of South America, composed of Mixed Ombrophilous Forest, in the Atlantic Forest biome, always in associations, and clearly evolved with *Araucaria angustifolia* (Heck and Mejia, 2007). To develop, *Ilex* requires average annual temperatures between 17 and 21 °C and regular rainfall, with high air and soil humidity. *Ilex* occurs in the sub-forest layer in acidic soils of low natural fertility, high aluminum content, low available phosphorus levels, and high organic matter concentration. It tolerates shade at any age and is considered an ombrophilous species with slow or moderate growth, typical of mature forests, where it can reach density of hundreds individuals per hectare (Caron et al., 2014b; Chaimsohn et al., 2014).

Agronomic aspects - cropping systems

The world production of yerba mate in 2016 amounted to 937,310 tons, mainly from Brazil, Argentina, and Paraguay (FAO, 2017). In *Araucaria* forests, the species is abundant, with a considerable economic value and a significant importance in agricultural production systems, becoming a stabilizing factor of income and having, many times, a strategic preservation function of native forests in their ecosystems with perspective of multiple use of natural resources (Marques et al., 2014; Pires et al., 2016).

Figure 3 – Natural distribution area of yerba mate. Adapted from Voigt et al., 2016.

In general, herbs occur is diverse habitats, based on their adaptability to different light conditions and management strategies, enabling different designs of production systems. In this sense, we highlight the extractive systems, consorted with native forests, agroforestry, and monoculture (full sun) (Marques et al., 2014; Vogt et al., 2016).

The extractive activity of a natural forest (Araucaria Forest or Mixed Ombrophilous Forest) is considered the traditional system of cultivation, mainly in terms of native herbs. Yerba mate produced in this system is extracted sustainably from the most significant native forest areas of southern Brazil. In this system, management or cultural treatments are not common and crops are harvested periodically (Marques et al., 2014; Vogt et al., 2016).

A system in consortium with native forest, also called "mixed cultivation" or "*caívas*", is traditionally the exploration of forest remnants where yerba mate grows naturally or in cultivations managed in association with other plant species, usually native species, and in some cases even associated with cattle livestock. This system also has economic, social, and environmental importance, since it contributes to the preservation of forest remnants and generates income to the farmer (Chaimsohn et al., 2014).

Most of these *caívas* are forest fragments of different sizes in rural properties of southern Paraná and northern Santa Catarina States in Brazil. These fragments in the region contribute to the landscape formation, composing a mosaic of cultivated areas interspersed by forests (Hanisch et al., 2010).

The agroforestry system is the yerba mate cultivation associated with logging and/or agricultural activities. These systems are composed of plant species in the arboreal and/or herbaceous-shrub layer and managed in a way that favors the production of yerba mate in the understory. The species planted have different cycles, sizes, and functions, resulting in an increased biodiversity, which promotes physical-chemical, hydrological, and microbiological improvements of the soil, besides generating income (Barbosa et al., 2017).

Monocultures allow cultivation of more plants in an area, generating higher yields, and enabling mechanized harvesting. However, trees are exposed to full sun, which can lead to alterations in their metabolic processes and damages in leaf quality. These species have evolved as Ombrophilous species and are subjected to physiological stresses when cultivated in open places, making them more susceptible to pest attacks and diseases (Marques et al., 2014).

Maintenance of native herbs in traditional systems (extractive and intercropped with native forests) can represent an important stimulus for environmental conservation to ensure maintenance of the forest and its significant economic value, providing monetary value to forest remnants. In addition, such systems generally have fewer phytosanitary problems, favoring plant production without the use of agrochemicals (Marques et al., 2012; Chaimsohn et al., 2014). Characteristics of the consortium system are common, such as shading of plants, presence of other forest species, and sometimes conservation of the original material of mate (Marques et al., 2014).

In addition to the significant volume of yerba mate produced in traditional and agroforestry systems, the product obtained from these systems has a higher value, since the shading provided by other tree species results in a product with a better flavor, more accepted in the Brazilian and Uruguayan markets (major yerba mate consumers in the world) (Marques et al., 2012). Industrial demands for this type of weed have increased markedly in recent years (Caron et al., 2014a; Caron et al., 2014b).

Composition of yerba mate varies considerably depending on factors, such as seasonality, temperature, water and nutrient availability, cultivation system, and adopted management practice, with effects on its physiological effects. Thus, studies that elucidate the relationship between its composition and its constituent factors are necessary to determine the association between health benefits, mate consumption, and maintenance of sustainable supply chains with forest preservation (Berté et al., 2014; Pires et al., 2016; Cardoso Junior and Morand, 2016; Kahmann et al., 2017; Riachi et al., 2018).

Processing and uses

The first explorers of yerba mate were the native inhabitants of northeastern Argentina, southern Brazil, Paraguay, and Uruguay, who consumed mate due to its stimulating and medicinal properties. Several tribes, such as the Guaranis, the Amerindians (Incas and Quechuas), and the Caingangues, consumed its leaves, infused, or chewed. Infusion of leaves became a popular drink and, nowadays, the product obtained from dry leaves, also called mate or maté, is used in several types of infusions, such as the *chimarrão*, *tereré*, and mate tea (roasted leaves) (Holowatt et al., 2016; Lima et al., 2016).

Yerba mate exploration is based on the use of selected leaves and branches, which are subjected to thermal bleaching (*sapeco*) for enzyme inactivation, followed by drying, grinding, and separation. These last two steps allow obtaining a product with standard particle size, followed by milling and aging for up to 24 months, depending on the desired product (Figure 4). Intensity, grinding type, and the aging period result in products with differentiated standards (Meinhart et al., 2010).

The agro-industrial processing of yerba mate has not been significantly altered since the beginning of its economic exploration, with disadvantages related to its high energy requirement, difficulties in controlling its variables and, consequently, in the standardization of the final product. Another negative aspect concerns the oxidative environment of the bleaching and drying process, which potentially contributes to the degradation of the biochemical compounds of the leaves. Thus,

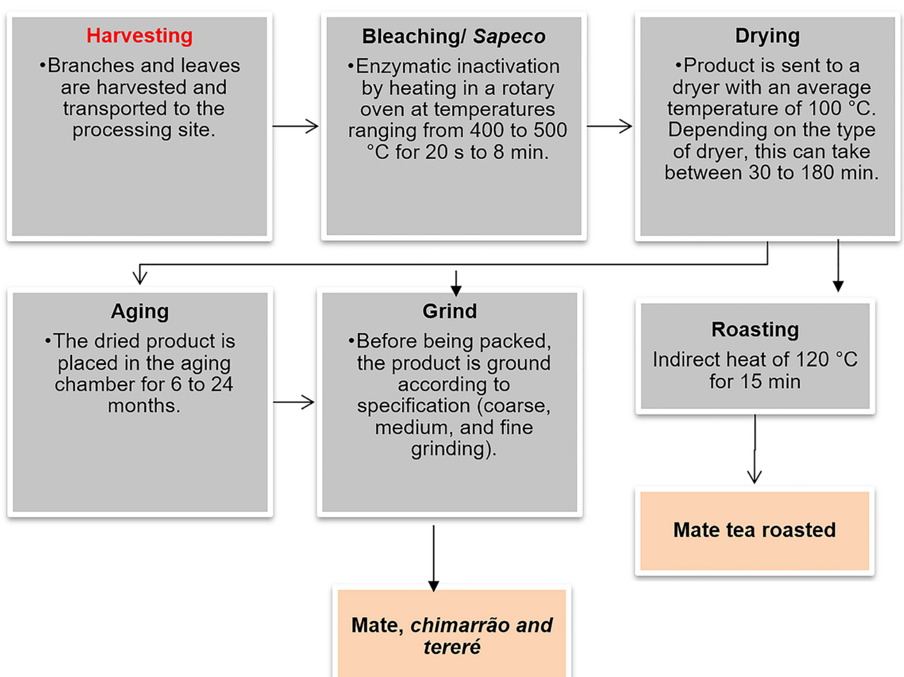

Figure 4 – Traditional processing of yerba mate (Berté et al., 2014; Silveira et al., 2017; Riachi et al., 2018).

the development of new technological processes for preserving its compounds is a strategy that must be considered (Meinhart et al., 2010; Cardoso Junior and Morand, 2016).

Mate is consumed as leaf infusion, with variations in the manufacturing and preparation of the beverage. The leaves are infused in hot water and sipped through a tube and gourd. *Tereré* is a cold drink, while mate tea is obtained from the roasted leaves and consumed hot or cold (Bracesco et al., 2011; Cardoso Junior and Morand, 2016).

Roasted mate can also be subjected to the extraction of soluble solids with hot water, followed by drying in a spray-dryer, resulting in soluble roasted mate. Soluble solid extraction from the crushed green yerba mate yields the soluble green mate; both products are intended primarily for export and present as market innovation (Berté et al., 2014).

The *per capita* consumption of yerba mate in Uruguay, Argentina, and Brazil is estimated at 8 to 10 kg yr^{-1}, 5 to 6 kg yr^{-1}, and 1.2 to 5 kg yr^{-1}, respectively (Berté et al., 2014; Cardoso Junior and Morand, 2016). In Brazil, the state of Rio Grande do Sul is the largest consumer of herb for *chimarrão* (70,000 t yr^{-1}), while Rio de Janeiro is the largest consumer of roasted mate tea (1,500 t yr^{-1}). In Brazil, the entire yield is exported, mainly to Uruguay and Chile, followed by the United States, Europe, and Asia, which receive the product as whole or ground dried leaves or extracts for the pharmaceutical industry (Anesine et al., 2012; Lima et al., 2016).

In the last decade, along with the traditional use, yerba mate has been grown for raw material in the production of beers, soft drinks, cosmetics, sweets, and functional cheeses as well as other non-traditional uses (Table 1). In the case of functional cheeses, a recent study showed that the addition of yerba mate, besides increasing the biological activities due to the interaction between herb polyphenols and milk proteins, increases the sensorial characteristics, with good acceptance by consumers (Marcelo et al., 2014; Saraiva et al., 2019).

Leaves are also used to produce energy drinks as an alternative to coffee, widely appreciated in Europe and the United States because of their high levels of antioxidants and nutritional benefits (Bercher et al., 2011; Bergottini et al., 2017). However, studies on new uses, such as food preservatives, food supplements, dyes, or hygiene and cosmetics products, need to be conducted to allow consumption to exceed the traditional barrier and become increasingly accessible in Latin America, which is also interesting for innovations in the agro-industrial sector (Table 1) (Cardoso Junior and Morand, 2016).

As a secondary use, yerba mate wood produces a blade of excellent quality (Table 1). However, the species is considered inadequate to produce energy, pulp, and paper. Its residue, after processing, has been used by horticultural workers as organic fertilizer and in animal feed, providing forage with 13 % crude protein. In addition, the species is highly recommended because of its ornamental value and biological properties, mainly for afforestation, gardening, and the ecological restoration of degraded ecosystems (Embrapa, 2019).

Rodríguez-Arzuaga and Piagentini (2017) optimized yerba mate concentrations in an aqueous dipping solution to maximize the antioxidant capacity and minimize the browning occurrence without affecting the sensory quality of freshly cut apples. Our results suggest that chemical treatment with yerba mate applied to apples cut freshly was successful in delaying enzymatic browning development, providing compounds with antioxidant capacity with potential benefit for human health (Table 1).

Table 1 – Yerba mate uses.

Plant components	Application	Uses
Leaves and branches	Traditional uses (beverages)	- *Chimarrão*, *tereré*, mate tea (roasted leaves), blend of yerba mate with herbs and flavored tea
	Non-traditional uses (beverages)	- Freeze dried extract, tea (green leaves), tea capsule (roasted and green leaves), mate latte, energy drinks, beers, soft drinks, liqueurs
	Functional foods	- Sweets, jam, breaded, functional cheeses
	Cosmetics	- Shampoo, soap, anti-aging cream, moisturizing cream
	Natural antioxidant (additive)	- Aqueous dipping solution to minimizing browning development of freshly fruits - Biodegradable edible films to be used as packaging for fruits
	Textile industry	- Dyeing silk, wool, linen and cotton fabrics
Fruits	Cosmetics	- Oil essential - Anti-aging cream, moisturizing cream
	Vegetable extracts of the unripe fruits	- Molluscicides
Seeds	Ornamental value and biological properties (seedlings)	- Afforestation - Gardening - The ecological restoration of degraded ecosystems
Wood	Wood industry	- Blade of excellent quality
Residue (after processing)	Agriculture	- Organic fertilizer
	Livestock	- Animal feed

Biodegradable and edible starch-glycerol based films containing different concentrations of a natural antioxidant as yerba mate extract were evaluated to obtain promising biodegradable edible films to be used as packaging. The study demonstrated that yerba mate extract acted as a plasticizer when incorporated as an antioxidant into starch-glycerol based films. Besides, the use of the extract improved biodegradability of the films in compost and preserved their stability (Medina Jaramillo et al., 2016).

Yerba mate was used for dyeing silk, wool, linen, and cotton fabrics. Dyed silk fabrics presented the highest color strength (Yoo and Jeon, 2012). Giacomini et al. (2016) investigated the best dyeing conditions, such as pH, temperature, and dyestuff concentration of silk fabric using roasted yerba mate. The authors concluded that silk fabrics can be dyed easily with yerba mate, providing a yellowish brown color, and the best silk dyeing result was achieved at 90 °C, pH 3.0 and 20 g L^{-1} dye concentration. Bulut and Akar (2012) used some oil-free yerba mate wastes to dye cotton and wool yarn previously cationized without metal salts. Fabrics were dyed successfully with high color strength.

Another study evaluated the effectiveness of extracts of unripe yerba mate fruits for chemical control of piped apple snail (*Pomacea canaliculata*) and non-target species, such as South American catfish (*Rhamdia quelen*), under laboratory conditions. The extracts were particularly attractive considering the source of compounds and their effectiveness as molluscicides (Brito et al., 2018).

Chemical aspects, bioactive compounds and their functionalities

Much attention has been dedicated to yerba mate due to its potential health benefits (Figure 5). These benefits seem to be related to the phytochemical variability, determining the unique chemical composition. Studies have detected different chemical groups, such as polyphenols, saponins, alkaloids, and essential oils (Tables 2, 3 and 4). The leaves also contain vitamins (A, C, B1, and B2), magnesium, calcium, iron, zinc, sodium, and potassium (Heck and Mejia, 2007; Berte et al., 2014).

Compounds, such as polyphenols, saponins, alkaloids, and essential oils from the secondary metabolism of plants and, because of their chemical diversity, these compounds have a variety of functions in plants. Numerous substances act as defense against herbivores and pathogens, while others play a role in mechanical support, as a pollinator or in fruit disperser attraction, protection against ultraviolet radiation, or growth reduction of adjacent competing plants (Taiz et al., 2017; Neugart et al., 2018).

In humans, these compounds have multiple functions. *In vitro* studies show that yerba mate extract helped to prevent cancer and had a high anti-inflammatory potential (Souza et al., 2015). *In vivo* studies show that infusion could inhibit oxidation of LDL (low density lipoprotein), also contributing to treatments of obesity, diabetes, and arteriosclerosis (Godoy et al., 2013; Habtemariam, 2019; Luís et al., 2019). Recent research has shown numerous therapeutic qualities of yerba mate, including hepatoprotective, neuroprotective, resistance against oxidative stress, anti-obesity, cardioprotection, and antioxidant effects (Figure 5) (Baeza et al., 2017; Cahuê et al., 2019; Cittadini et al., 2019b; Panza et al., 2018; Valenca et al., 2019).

Yerba mate samples from different processing steps were analyzed for the chlorogenic acids content and the highest content was found in green leaves and stems (Butiuk et al., 2016). Structurally, chlorogenic acids are a family of non-flavonoid phenolic compounds, comprising caffeic and quinic acid esters and their mono and dicaffeoylquinic isomers. Chlorogenic acid (5-CQA) isomers include 3-O-caffeoyl-quinicacid (3-CQA), 4-O-caffeoyl-quinic (4-CQA), 3,4-dicaffeoylquinic acid, 3,5-dicaffeoylquinic acid and 4,5-dicaffeoylquinic acid (Table 3). Potentially beneficial properties to humans, such as antioxidant, hypoglycaemic, antiviral and hepatoprotective activities have also been attributed to chlorogenic acids in *in vitro*, *in vivo* and epidemiological studies (Butiuk et al., 2016; Meinhart et al., 2018; Riachi et al., 2018).

In addition, caffeine, theophylline and theobromine alkaloids are important active components of yerba mate, derived from xanthine and known as methylxanthines (Table 4). They all have the stimulating effect on the central nervous system in common, with caffeine as the most potent representative. Methylxanthines also affect the cardiovascular system, with theophylline generating the strongest effect. Thus, caffeine, theophylline, and theobromine concentrations in yerba mate beverages is generally of great interest (Holowaty et al., 2016; Friedrich et al., 2017; Konieczynski et al., 2017).

The biochemical composition of yerba mate varies according to the locality, cultivation system or processing method. Yerba mate contents can vary widely (Table 2), and environmental conditions to which the plants are submitted (seasonality, temperature, water and nutrient availability, radiation) determine their biosynthesis (Dutra et al., 2010; Pires et al., 2016).

Thus, cultivation and management systems greatly affect the levels of these substances (Dutra et al., 2010; Berté et al., 2014); thereby, affecting quality of the final product and its effect on human health. However, studies that interrelate these factors are still scarce (Heck and Mejia, 2007; Neugart et al., 2018; Riachi et al., 2018).

Final Remarks

Consumption statistics show that the production chain of yerba mate is based on the use of traditional drinks, such as the *chimarrão* and the *tereré*. However, the innovation potential of yerba mate still needs to

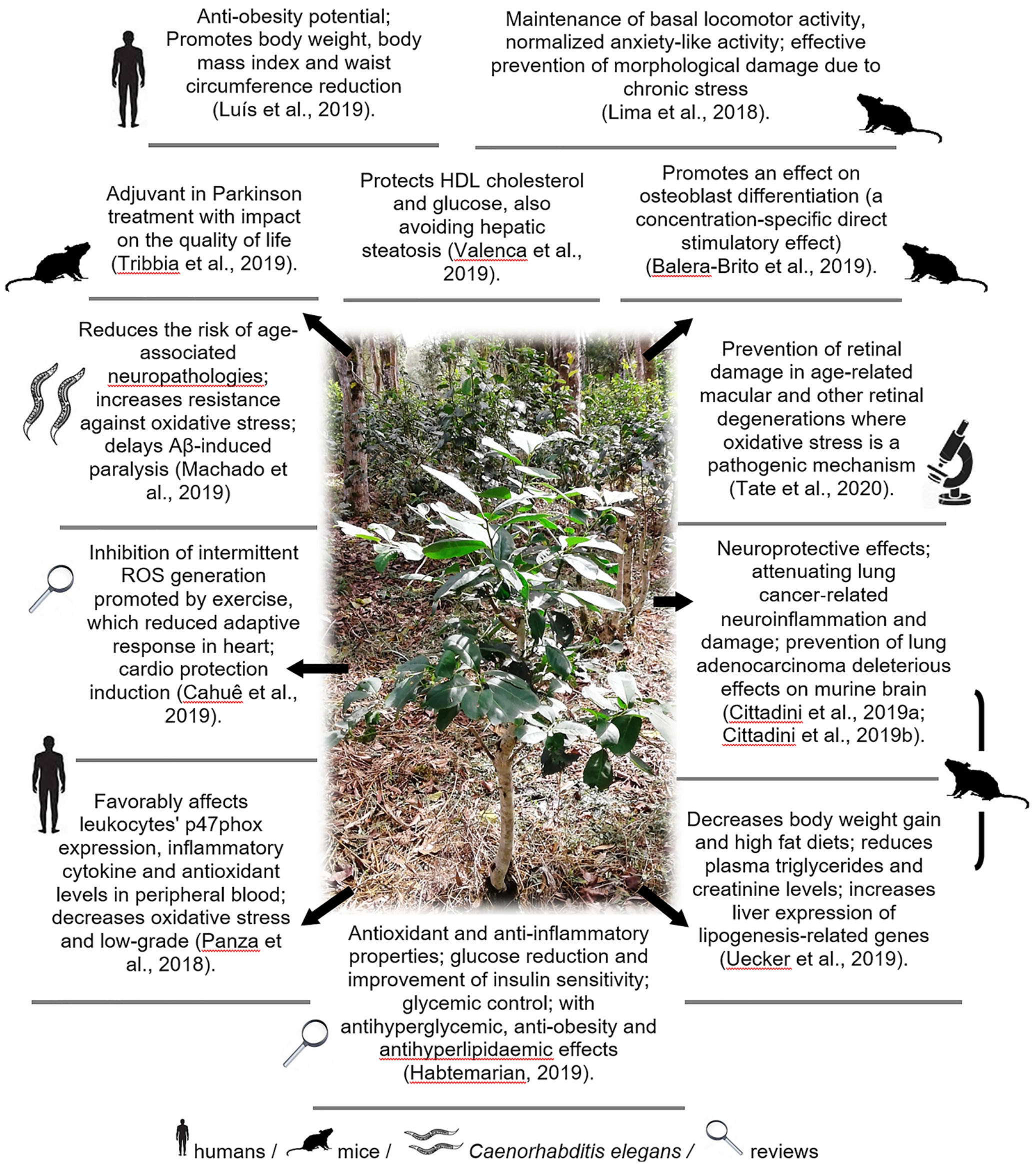

Figure 5 – Some potential health benefits associated with yerba-mate consumption (in vitro and vivo tests).

Table 2 – Phenolic compounds found in yerba mate (2015 – 2018).

Chemical composition	Sample	Content	Unity	References
Total phenolic compounds	Leaves, green branches, extracts	9.45 to 8047.00	mg 100 g^{-1}	Souza et al., 2015; Mateos et al., 2018; Holowaty et al., 2016
	Infusions of *tereré* or *chimarrão*	143. 98 to 1194.90	mg 100 mL^{-1}	Gebara et al., 2017; Baeza et al., 2017
	Fruits	59.25 to 62.25	mg 100 g^{-1}	Fernandes et al., 2016;
	Instant mate	343.17	μmol 100 g^{-1}	Oliveira et al., 2017
Total flavonoids	Leaves, green branches, extracts	3.06 to 757.00	mg 100 g^{-1}	Souza et al., 2015; Mateos et al., 2018
Anthocyanins	Fruits	17.52 to 43.79	mg 100 g^{-1}	Fernandes et al., 2016
Rutin	Leaves, green branches, extracts	1.86 to 6.10	mg g^{-1}	Silveira et al., 2017; Baeza et al., 2017; Mateos et al., 2018
	Infusions of *tereré* or *chimarrão*	1.93	mg 100 mL^{-1}	Silveira et al., 2017
	Fruits	10.96 to 11.72	mg 100 g^{-1}	Fernandes et al., 2016
	Instant mate	3.60	μmol 100 g^{-1}	Oliveira et al., 2017

Table 3 – Phenolic acid content found in yerba mate (2015 – 2018).

Chemical composition	Sample	Content	Unity	References
Caffeic acid	Leaves, green branches, extracts	4.92 to 12.20	mg 100 g^{-1}	Souza et al., 201 5
	Infusions of *tereré* or *chimarrão*	0.04 to 0.10	mg 100 mL^{-1}	Silveira et al., 2017; Riachi et al., 2018
	Leaves	11.47	mg 100 g^{-1}	Souza et al., 2015; Lima et al., 2016;
	Fruits	15.72 to 21.49	mg 100 g^{-1}	Fernandes et al., 2016
	Roasted mate	3.90	mg 100 g^{-1}	Lima et al., 2016
3 – CQA	Leaves, green branches, extracts	14.00	mg 100 mL^{-1}	Meinhart et al., 2018
	Infusions of *tereré* or *chimarrão*	3801.90 to 27628.33	mg 100 g^{-1}	Lima et al., 2016; Meinhart et al., 2017
	Roasted mate	539.10	mg 100 g^{-1}	Lima et al., 2016
	Instant mate	65.28	μmol 100 g^{-1}	Oliveira et al., 2017
4 – CQA	Leaves, green branches, extracts	1179.50 to 6805.91	mg 100 g^{-1}	Lima et al., 2016; Meinhart et al., 2017
	Infusions of *tereré* or *chimarrão*	5090.00	μg 100 mL^{-1}	Meinhart et al., 2018
	Roasted mate	788.50	mg 100 g^{-1}	Lima et al., 2016
	Instant mate	68.68	μmol 100 g^{-1}	Oliveira et al., 2017
5 – CQA or chlorogenic acid	Leaves, green branches, extracts	43.10 to 1207.04	mg 100 g^{-1}	Lima et al., 2016; Meinhart et al., 2017; Souza et al., 2015; Mateos et al., 2018
	Infusions of *tereré* or *chimarrão*	3.66 to 50.00	mg 100 mL^{-1}	Meinhart et al., 2018; Silveira et al., 2017; Butiuk et al., 2016; Riachi et al., 2018
	Fruits	13.58 to 15.85	mg 100 g^{-1}	Fernandes et al., 2016
	Roasted mate	929.50	mg 100 g^{-1}	Lima et al., 2016
	Instant mate	80.42	μmol 100 g^{-1}	Oliveira et al., 2017
3,4-Dicaffeoylquinic acid	Leaves, green branches, extracts	10.30 to 582.00	mg 100 g^{-1}	Souza et al., 2015; Lima et al., 2016; Baeza et al., 2017; Meinhart et al., 2017
	Infusions of *tereré* or *chimarrão*	0.70 to 6.43	mg 100 mL^{-1}	Silveira et al., 2017; Meinhart et al., 2018
	Roasted mate	0.41	mg 100 mL^{-1}	Silveira et al., 2017
	Roasted mate	101.60	mg 100 g^{-1}	Lima et al., 2016
3,5-Dicaffeoylquinic acid	Leaves, green branches, extracts	29.51 to 7265.00	mg 100 g^{-1}	Souza et al., 2015; Lima et al., 2016; Baeza et al., 2017; Meinhart et al., 2017
	Infusions of *tereré* or *chimarrão*	7.60 to 29.51	mg 100 mL^{-1}	Silveira et al., 2017; Meinhart et al., 2018
	Roasted mate	0.45	mg 100 mL^{-1}	Silveira et al., 2017
	Roasted mate	191.50	mg 100 g^{-1}	Lima et al., 2016
4,5-Dicaffeoylquinic acid	Leaves, green branches, extracts	21.20 to 3913.00	mg 100 g^{-1}	Souza et al., 2015; Lima et al., 2016; Baeza et al., 2017; Meinhart et al., 2017
	Infusions of *tereré* or *chimarrão*	1.80 to 7.49	mg 100 mL^{-1}	Silveira et al., 2017; Meinhart et al., 2018
	Roasted mate	0.86	mg 100 mL^{-1}	Silveira et al., 2017
	Roasted mate	346.90	mg 100 g^{-1}	Lima et al., 2016

Table 4 – Methylxanthine contents found in yerba mate (2015 – 2018).

Chemical composition	Sample	Content	Unity	References
Caffeine	Leaves, green branches, extracts	7.10 to 32.23	mg g^{-1}	Holowaty et al., 2016; Friedrich et al., 2017; Konieczynski et al., 2017
	Infusions of *tereré* or *chimarrão*	6.30 to 68.30	mg 100 mL^{-1}	Gebara et al., 2017
	Fruits	8.04 to 8.11	mg 100 g^{-1}	Fernandes et al., 2016
Theobromine	Leaves, green branches, extracts	1.12 to 4.38	mg g^{-1}	Friedrich et al., 2017; Konieczynski et al., 2017; Mateos et al., 2018
	Fruits	2.56 to 4.06	mg 100 g^{-1}	Fernandes et al., 2016
Theophylline	Infusions of *tereré* or *chimarrão*	1.58	mg g^{-1}	Konieczynski et al., 2017

be explored, considering its chemical composition and functionalities. The implementation of new uses, such as food preservatives, food supplements, dyes, hygiene and cosmetic products, leads to the increase of yerba mate consumption worldwide. In addition, studies that explain the effects of crop systems on chemical composition and product quality need to be developed.

Authors' Contributions

Conceptualization: Croge, C.P.; Cuquel, F.L.; Pintro, P.T.M. **Data acquisition:** Croge, C.P. **Data analysis:** Croge, C.P.; Cuquel, F.L.; Pintro, P.T.M. **Design of methodology:** Croge, C.P.; Cuquel, F.L. **Writing and editing:** Croge, C.P.; Cuquel, F.L.; Pintro, P.T.M.

References

Anesine, C.; Turner, S.; Cogoi, L.; Filip, R. 2012. Study of the participation of caffeine and polyphenols on the overall antioxidant activity of mate (*Ilex paraguariensis*). Food Science and Technology 45: 299-304.

Baeza, G.; Sarriá, B.; Bravo, L.; Mateos, R. 2017. Polyphenol content, in vitro bioaccessibility and antioxidant capacity of widely consumed beverages. Journal of the Science of Food and Agriculture 98: 1397-1406.

Balera-Brito, V.G.; Chaves-Neto, A.H.; Barros, T.L.; Oliveira, S.H.P. 2019. Soluble yerba mate (*Ilex paraguariensis*) extract enhances in vitro osteoblastic differentiation of bone marrow-derived mesenchymal stromal cells. Journal of Ethnopharmacology 244: 112131.

Barbosa, J.S.; Silva, K.R.; Carducci, C.E.; Santos, K.L.; Kohn, L.S.; Fucks, J.S. 2017. Physical-hydric Attributes of a humic inceptisol in agroforestry on the Santa Catarina plateau. Floresta e Ambiente 24: e20160251 (in Portuguese, with abstract in English).

Bergottini, V.M.; Hervé, V.; Sosa, D.A.; Otegui, M.B.; Zapata, P.D.; Junier, P. 2017. Exploring the diversity of the root-associated microbiome of *Ilex paraguariensis* St. Hil. (Yerba Mate). Applied Soil Ecology 109: 23-31.

Berté, K.A.S.; Rodriguez-Amaya, D.B.; Hoffmann-Ribani, R.; Maccari-Junior, A. 2014. p. 145-153. Antioxidant activity of maté tea and effects of processing. In: Preedy, V., ed. Processing and impact on antioxidants in beverages. Elsevier, London, England.

Bracesco, N.; Sanchez, A.G.; Contreras, V.; Menini, T.; Gugliucci, A. 2011. Recent advances on *Ilex paraguarensis* research: mini review. Journal of Ethnopharmacology 136: 378-384.

Brito, F.C.; Gosmann, G.; Oliveira, G.T. 2018. Extracts of the unripe fruit of *Ilex paraguariensis* as a potential chemical control against the golden apple snail *Pomacea canaliculata* (Gastropoda, Ampullariidae). Natural Product Research 33: 2379-2382.

Bulut, M.O.; Akar, E. 2012. Ecological dyeing with some plant pulps on woolen yarn and cationized cotton fabric. Journal of Cleaner Production 32: 1-9.

Butiuk, A.P.; Martos, M.A.; Adachi, O.; Hours, R.A. 2016. Study of the chlorogenic acid content in yerba mate (*Ilex paraguariensis* St. Hil.): effect of plant fraction, processing step and harvesting season. Journal of Applied Research on Medicinal and Aromatic Plants 3: 27-33.

Cabral, A.; Cardoso, P.H.; Menini-Neto, L.; Santos-Silva, F. 2018. Aquifoliaceae in Serra Negra, Minas Gerais, Brazil. Rodriguésia 69: 805-814 (in Portuguese, with abstract in English).

Cahuê, F.; Nascimento, J.H.M.; Barcellos, L.; Salerno, V.P. 2019. *Ilex paraguariensis,* exercise and cardioprotection: a retrospective analysis. Journal of Functional Foods 53: 105-108.

Cardoso Junior, L.; Morand, C. 2016. Interest of mate (*Ilex paraguariensis* A. St.-Hil.) as a new natural functional food to preserve human cardiovascular health: a review. Journal of Functional Foods 21: 440-454.

Caron, B.O.; Santos, D.R.; Schmidt, D.; Basso, C.J.; Behling, A.; Eloy, E.; Bamberg, R. 2014a. Biomass and accumulation of nutrients in *Ilex paraguariensis* A. St. Hil. Ciência Florestal 24: 267-276 (in Portuguese, with abstract in English).

Caron, B.O.; Schmidt, D.; Manfron, P.A.; Behling, A.; Eloy, E.; Busanello, C. 2014b. Efficiency of the use of solar radiation for plants *Ilex paraguariensis* A. St. Hil. cultivated under shadow and full sun. Ciência Florestal 24: 257-265 (in Portuguese, with abstract in English).

Centro de Socioeconomia e Planejamento Agrícola [CEPA]. 2015. Santa Catarina Agriculture Numbers = Números da Agricultura Catarinense. CEPA/EPAGRI, Florianópolis, SC, Brazil (in Portuguese).

Chaimsohn, F.P.; Machado, N.C.; Gomes, E.P.; Vogt, G.A.; Neppel, G.; Souza, A.M.; Marques, A.C. 2014. Yerba mate's traditional and agroforestry systems and impacts on territorial development: the center-south of Paraná and northern Santa Catarina = Sistemas tradicionais e agroflorestais da erva-mate e impactos no desenvolvimento territorial: o centro-sul do Paraná e o norte de Santa Catarina. p. 47-54. In: Dallabrida, V.R., ed. Territorial development: Brazilian public policies, international experiences and geographical indication as a reference = Desenvolvimento territorial: políticas públicas brasileiras, experiências internacionais e indicação geográfica como referência. LiberArs, São Paulo, SP, Brazil (in Portuguese).

Cittadini, M.C.; Albrecht, C.; Miranda, A.R.; Mazzuduli, G.M.; Soria, E.A.; Repossi, G. 2019a. Neuroprotective Effect of *Ilex paraguariensis* intake on brain myelin of lung adenocarcinoma-bearing male Balb/c mice. Nutrition and Cancer 71: 629-633.

Cittadini, M.C.; Repossi, G.; Albrecht, C.; Di Paola Naranjo, R.; Miranda, A.R.; Pascual-Teresa, S.; Soria, E.A. 2019b. Effects of bioavailable phenolic compounds from *Ilex paraguariensis* on the brain of mice with lung adenocarcinoma. Phytotherapy Research 33: 1142-1149.

Dutra, F.L.G.; Hoffmann-Ribani, R.; Ribani, M. 2010. Determination of phenolic compounds by isocratic high performance liquid chromatografic method during storage of yerba-mate. Química Nova 33: 119-123 (in Portuguese, with abstract in English).

Food and Agriculture Organization [FAO]. 2017. Faostat: statistics database. FAO, Rome, Italy.

Fernandes, C.E.F.; Kuhn, F.; Scapinello, J.; Lazarotto, M.; Bohn, A.; Boligon, A.A.; Athayde, M.L.; Zanatta, M.S.; Zanatta, L.; Magro, J.D.; Oliveira, J.V. 2016. Phytochemical profile, antioxidant and hypolipemiant potential of *Ilex paraguariensis* fruit extracts. Industrial Crops and Products 81: 139-146.

Friedrich, J.C.; Gonela, A.; Vidigal, M.C.G.; Vidigal-Filho, P.S.; Sturion, J.A.; Cardozo-Junior, E.L. 2017. Genetic and phytochemical analysis to evaluate the diversity and relationships of mate (*Ilex paraguariensis* A.ST.-HIL.): elite genetic resources in a germplasm collection. Chemistry and Biodiversity 14: e1600177.

Gebara, K.S.; Gasparotto-Junior, A.; Santiago, P.G.; Cardoso, C.A.L.; Souza, L.M.; Morand, C.; Costa, T.A.; Cardozo-Junior, E.L. 2017. Daily intake of chlorogenic acids from consumption of maté (*Ilex paraguariensis* A.St.-Hil.) traditional beverages. Journal of Agricultural and Food Chemistry 65: 10093-10100.

Giacomini, F.; Menegazzo, M.A.B.; Santos, J.C.O.; Arroyo, P.A.; Barros, M.A.S.D. 2016. Ecofriendly dyeing of silk with extract of yerba mate (*Ilex paraguariensis*). Textile Research Journal 87: 829-837.

Godoy, R.C.B.; Deliza, R.; Gheno, L.B.; Licodiedoff, S.; Catia, N.T.; Frizon, C.N.T.; Hoffmann-Ribani, R. 2013. Consumer perceptions, attitudes and acceptance of new and traditional mate tea products. Food Research International 53: 801-807.

Gómez-Juaristi, M.; Martínez-López, S.; Sarria, B.; Bravo, L.; Mateos, R. 2018. Absorption and metabolism of yerba mate phenolic compounds in humans. Food Chemistry 240: 1028-1038.

Habtemariam, S. 2019. The chemical and pharmacological basis of yerba maté (*Ilex paraguariensis A.St.-Hil.*) as potential therapy for type 2 diabetes and metabolic syndrome. p. 943-983. In: Habtemariam, S., ed. Medicinal foods as potential therapies for type-2 diabetes and associated diseases. Academic Press, New York, NY, USA.

Hanisch, A.L.; Vogt, G.A.; Marques, A.C.; Bona, L.C.; Bosse, D.D. 2010. Structure and floristic composition of five *caiva* area in north plateau of Santa Catarina State, Brazil. Pesquisa Florestal Brasileira 30: 303-310 (in Portuguese, with abstract in English).

Heck, C.I.; Mejía, E.G. 2010. Yerba Mate Tea (*Ilex paraguariensis*): a comprehensive review on chemistry, health implications, and technological considerations. Journal of Food Science 72: 138-151.

Holowaty, S.A.; Trela, V.; Thea, A.E.; Scipioni, G.P.; Schmalko, M.E. 2016. Yerba maté (*Ilex paraguariensis* st. Hil.): chemical and physical changes under different aging conditions. Journal of Food Process Engineering 39: 19-30.

Kahmann, A.; Anzanello, M.J.; Marcelo, M.C.A.; Pozebon, D. 2017. Near infrared spectroscopy and element concentration analysis for assessing yerba mate (*Ilex paraguariensis*) samples according to the country of origin. Computers and Electronics in Agriculture 140: 348-360.

Konieczynski, P.; Viapiana, A.; Wesolowski, M. 2017. Comparison of infusions from black and green teas (*Camellia sinensis* L. Kuntze) and erva-mate (*Ilex paraguariensis* A. St.-Hil.) based on the content of essential elements, secondary metabolites, and antioxidant activity. Food Analytical Methods 10: 3063-3070.

Lima, J.P.; Farah, A.; King, B.; Paulis, T.; Martin, P.R. 2016. Distribution of major chlorogenic acids and related compounds in Brazilian green and toasted *Ilex paraguariensis* (maté) leaves. Journal of Agricultural and Food Chemistry 64: 2361-2370.

Lima, M.E.; Ceolin-Colpo, A.Z.; Maya-López, M.; Rangel-López, E.; Becerril-Chávez, H.; Galván-Arzate, S.; Túnez, I.; Folmer, V.; Santamaría, A. 2018. Comparing the effects of chlorogenic acid and *Ilex paraguariensis* extracts on different markers of brain alterations in rats subjected to chronic restraint stress. Neurotoxicity Research 35: 373-386.

Luís, A.F.S.; Domingues, F.C.; Pereira Amaral, L.M.J. 2019. The anti-obesity potential of *Ilex paraguariensis*: results from a meta-analysis. Brazilian Journal of Pharmaceutical Sciences 55: e17615.

Machado, M.L.; Arantes, L.P.; Silveira, T.L.; Zamberlan, D.C.; Cordeiro, L.M.; Obetine, F.B.B.; Silva, A.F.; Cruz, I.B.M.; Soares, F.A.A.; Oliveira, R.P. 2019. *Ilex paraguariensis* extract provides increased resistance against oxidative stress and protection against Amyloid beta-induced toxicity compared to caffeine in *Caenorhabditis elegans.* Nutritional Neuroscience 1-13.

Marcelo, M.C.A.; Martins, C.A.; Pozebon, D.; Dressler, V.L.; Ferrão, M.F. 2014. Classification of yerba mate (*Ilex paraguariensis*) according to the country of origin based on element concentrations. Microchemical Journal 117: 164-171.

Marques, A.C.; Denardin, V.F.; Reis, M.S.; Wisniewski, C. 2014. The landscapes of mate in north plateau of Santa Catarina State, Brazil = As paisagens do mate no planalto norte do estado de Santa Catarina, Brasil. p. 33-46. In: Dallabrida, V.R., ed. Territorial development: Brazilian public policies, international experiences and geographical indication as a reference = Desenvolvimento territorial: políticas públicas brasileiras, experiências internacionais e indicação geográfica como referência. LiberArs, São Paulo, SP, Brazil (in Portuguese).

Marques, A.C.; Mattos, A.G.; Bona, L.C.; Reis, M.S. 2012. National forests and research development: yerba mate management (*Ilex paraguariensis* A.St.-Hil.) in flona in Tres Barras/Santa Catarina. Biodiversidade Brasileira 2: 4-17 (in Portuguese, with abstract in English).

Mateos, R.; Baeza, G.; Sarriá, B.; Bravo, L. 2018. Improved LC-MS^n characterization of hydroxycinnamic acid derivatives and flavonols in different commercial mate (*Ilex paraguariensis*) brands. Quantification of polyphenols, methylxanthines, and antioxidant activity. Food Chemistry 241: 232-241.

Medina Jaramillo, C.; Gutiérrez, T.J.; Goyanes, S.; Bernal, C.; Famá, L. 2016. Biodegradability and plasticizing effect of yerba mate extract on cassava starch edible films. Carbohydrate Polymers 151: 150-159.

Meinhart, A.D.; Bizzotto, C.S.; Ballus, C.A.; Rybka, A.C.P.; Sobrinho, M.R.; Cerro-Quintana, R.S.; Teixeira-Filho, J.; Godoy, H.T. 2010. Methylxanthines and phenolics content extracted during the consumption of mate (*Ilex paraguariensis* St. Hil) beverages. Journal of Agricultural and Food Chemistry 58: 2188-2193.

Meinhart, A.D.; Caldeirão, L.; Damin, F.M.; Filho, J.T.; Godoy, H.T. 2018. Analysis of chlorogenic acids isomers and caffeic acid in 89 herbal infusions (tea). Journal of Food Composition and Analysis 73: 76-82.

Meinhart, A.D.; Damin, F.M.; Caldeirão, L.; Silveira, T.F.F.; Teixeira-Filho, J.; Godoy, H.T. 2017. Chlorogenic acid isomer contents in 100 plants commercialized in Brazil. Food Research International 99: 522-530.

Neugart, S.; Baldermann, S.; Hanschen, F.S.; Klopsch, R.; Wiesner-Reinhold, M.; Schreiner, M. 2018. The intrinsic quality of brassicaceous vegetables: how secondary plant metabolites are affected by genetic, environmental, and agronomic factors. Scientia Horticulturae 233: 460-478.

Oliveira, D.M.; Sampaio, G.R.; Pinto, C.B.; Catharino, R.R.; Bastos, D.H.M. 2017. Bioavailability of chlorogenic acids in rats after acute ingestion of maté tea (*Ilex paraguariensis*) or 5⁻caffeoylquinic acid. European Journal of Nutrition 56: 2541-2556.

Panza, V.P.; Brunetta, H.S.; Oliveira, M.V.; Nunes, E.A.; Silva, E.L. 2018. Effect of mate tea (*Ilex paraguariensis*) on the expression of the leukocyte NADPH oxidase subunit p47phox and on circulating inflammatory cytokines in healthy men: a pilot study. International Journal of Food Sciences and Nutrition 70: 212-221.

Pires, D.A.C.K.; Pedrassani, D.; Dallabrida, V.R.; Benedetti, E.L. 2016. The yerba mate in the north of Santa Catarina state: the bioactive compounds in maté in the region as variable in determining the specifics required for recognition as a geographical indication. Desenvolvimento Regional em Debate 6: 207-227 (in Portuguese, with abstract in English).

Riachi, L.G.; Simas, D.L.R.; Coelho, G.C.; Marcellini, P.S.; Silva, A.J.R.S.; Maria, C.A.B. 2018. Effect of light intensity and processing conditions on bioactive compounds in maté extracted from yerba mate (*Ilex paraguariensis* A. St.-Hil.). Food Chemistry 266: 317-322.

Rodríguez-Arzuaga, M.; Piagentini, A.M. 2017. New antioxidant treatment with yerba mate (*Ilex paraguariensis*) infusion for fresh-cut apples: modeling, optimization, and acceptability. Food Science and Technology International 24: 223-231.

Silveira, T.F.F.; Meinhart, A.D.; Souza, T.C.L.; Cunha, E.C.E.; Moraes, M.R.; Godoy, H.T. 2017. Chlorogenic acids and flavonoid extraction during the preparation of yerba mate based beverages. Food Research International 102: 348-354.

Souza, A.H.P.; Correa, R.C.G.; Barros, L.; Calhelha, R.C.; Santos-Buelga, C.; Peralta, R.M.; Bracht, A.; Matsushita, M.; Ferreira, I.C.F.R. 2015. Phytochemicals and bioactive properties of *Ilex paraguariensis*: an in-vitro comparative study between the whole plant, leaves and stems. Food Research International 78: 286-294.

Taiz, L.; Zeiger, E.; Moller, I.M.; Murphy, A. 2017. Plant Physiology and Development. Oxford University Press, Oxford, UK.

Tate, P.S.; Marazita, M.C.; Marquioni-Ramella, M.D.; Suburo, A.M. 2020. *Ilex paraguariensis* extracts and its polyphenols prevent oxidative damage and senescence of human retinal pigment epithelium cells. Journal of Functional Foods 67: 103833.

Tribbia, L.; Gomez, G.; Cura, A.; Rivero, R.; Bernardi, A.; Ferrario, J.; Baldi-Coronel, B.; Gershanik, O.; Gatto, E.; Taravini, I. 2019. Study of yerba mate (*Ilex paraguariensis*) as a neuroprotective agent of dopaminergic neurons in an animal model of parkinson's disease. Neurology 92: P5.8-008.

Uecker, J.N.; Schneider, J.P.; Cerqueira, J.H.; Rincón, J.A.A.; Campos, F.T.; Schneider, A.; Barros, C.C.; Andreazza, R.; Jaskulski, I.B.; Pieniz, S. 2019. *Ilex paraguariensis* extract prevents body weight gain in rats fed a high-fat diet. Food Science and Technology 39: 620-626.

Valenca, S.S.; Valenca, H.M.; Lanzetti, M. 2019. Yerba Mate (*Ilex paraguariensis*) and dimethyl fumarate can improve metabolic syndrome condition induced by high fat diet in mice. FASEB Journal 33: 820.2.

Vogt, G.A.; Neppel, G.; Souza, A.M.A. 2016. The mate activity in north plateau, Santa Catarina state: the geographical indication as an alternative to valorization of yerba mate. Desenvolvimento Regional em Debate 6: 64-87 (in Portuguese, with abstract in English).

Yi, F.; Sun, L.; Hao, D.; Peng, Y.; Han, F.; Xiao, P. 2017. Complex phylogenetic placement of *Ilex* species (Aquifoliaceae): a case study of molecular phylogeny. Pakistan Journal of Botany 49: 215-225.

Yoo, H.J.; Jeon, S.T. 2012. Dyeing properties of yerba mate tea on the fabrics. Journal of the Korean Society of Clothing and Textiles 36: 412-421.