Yerba Mate

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Contributor: Agata Kryczyk-Poprawa

Ilex paraguariensis (yerba mate) is a plant species of the holly genus Ilex native to South America from the family Aquifoliaceae and is used for the production of yerba mate infusion. The leaves of the plant are steeped in hot water to make a beverage known as mate.

Keywords: Ilex paraguariensis ; yerba mate ; antioxidants ; bioelements ; production process

1. Introduction

Ilex paraguariensis A. St.-Hil. (ang. Paraguay holly, yerba mate) is a plant species of the holly genus Ilex native to South America from the family Aquifoliaceae and is used for the production of yerba mate tea (*Mate folium*). Mate was first consumed by the indigenous Guaraní people, and the practice of Mate consumption then spread to the Tupí people, who lived in the department of Amambay and the Alto Paraná territory of Paraguay. The plant was also primarily found in the southern regions of Brazil, Argentina, and Uruguay. In the mid-17th century, the Jesuits managed to domesticate the plant and establish plantations. It is also a medicinal plant known since pre-Columbian times and was used by the Indians to reduce the feeling of hunger, fatigue, and stress; as a diuretic; and as a physical and mental stimulant [1][2][3][4].

Mate products also have the property of detoxification and possess precognitive, hypocholesterolemic, anticancer, and slimming activities. The presence of a large number of chemical compounds and elements in yerba mate indicates the potential antioxidant properties of the raw material.

The leaves of the plant are steeped in hot water to make a beverage known as Mate. Both the plant leaves and the beverage contain purine alkaloids, such as caffeine, and a variety of polyphenols, such as the flavonoids quercetin and rutin, saponins, vitamins, and bioelements. These substances are responsible for the bioactivity of Mate [5][6][7][8][9][10][11][12][13].

I. paraguariensis infusions show protective activity against the oxidation of low-density lipoprotein by free radicals. It also reduces the number of products formed in the process of lipid peroxidation and increases the level of antioxidants in human blood serum. [14] In vivo studies have demonstrated that the aqueous extract of yerba mate shows a potent anti-obesity effect by modulating the expression of several obesity-related genes. Positive effects of Mate inhibiting the proliferation of colon (HT-29), esophageal, and bladder cancer cells have also been found [1][14][15]. Moreover, *I. paraguariensis* infusions have anti-inflammatory effects, as they inhibit the production of nitric oxide, prostaglandin 2, interleukin-6, and interleukin-1ß [16]. Mate is, however, most often consumed for its stimulating properties. yerba mate extract, when consumed in quantities not exceeding 2.5 L/day, has proven health-promoting effects. A study conducted in Uruguay showed an association between the consumption of more than 2.5 L/day of hot aqueous yerba mate extract and an increased risk of esophageal cancer [17].

The name “yerba mate” originated in Spain. The word “yerba” means a drink made from the herb, while the word “mate” means drinking from a calabash mate gourd. The raw material is pre-dried directly over the hearth at temperatures ranging from 250 °C to 550°C for several seconds or several minutes. The leaves are then dried until they reach a moisture content of 3–6%, which usually takes 8 to 24 h. The dried leaves are then subjected to an aging process that can last up to several months. The aging process produces the distinctive flavor of the *I. paraguariensis* leaves. In the next stage, the obtained dried product is grounded and packed. The conditions of all the abovementioned steps have a significant impact on the taste, aroma, quality, and contents of biologically active substances in the final product [1][4].

Yerba mate can be brewed in several ways that vary from country to country or region to region. The leaves of *I. paraguariensis* are brewed differently in Argentina and Brazil, and Paraguay and Uruguay also follow different methods to brew the leaves. The simplest method of preparing an infusion involves placing a bombilla in a container, adding dried leaves of *I. paraguariensis* to fill one-half to three-quarters of the container, and pouring hot, but not boiling, water. Ideally, the water temperature should be around 85–95 °C [18]. Infusions prepared from pure dried holly leaves are usually greenish or greenish-brown in color and have a bitter taste. This taste is very specific to the infusion and is both liked and disliked by consumers. Presently, to improve or mask the bitter taste, several producers add various kinds of fruits, flowers, or herbs to the brewed infusion. Sometimes, such additives not only change the taste of the brew but also enhance its properties; for example, the addition of grounded guarana (*Paullinia cupana*) leaves increases the stimulating properties of yerba mate as the caffeine content of the brew increases.

2. Selected Elements Determined in Yerba Mate by Atomic Absorption Spectrometry

Presently, there is an increasing awareness among people with regard to the impact of food and its components on human health. Studies on the content of bioactive compounds in foods can be used in the rational planning of daily diets. Bioelements have many functions in the human body, and therefore, it is necessary to provide them through food. On the basis of the obtained results for the contents of bioelements in dried yerba mate and considering the Recommended Dietary Allowance (RDA) of the examined bioelements, dried samples with the highest and lowest contents of particular elements were selected for further analyses. **Table 1** shows the results of the determination of the selected metal ions in the prepared yerba mate infusions. Next, researchers assessed the amount of the determined elements extracted from the dried fruit into the infusion and the extent to which these elements covered the RDA for humans, and the results are presented in **Table 2**. Knowledge of the elemental composition of a given product allows the assessment of the products that can prevent deficiencies in macro- and microelements.

Table 1. Mg(II), Zn(II), and Mn(II) contents of yerba mate infusions.

Element	Sample	Content (mg/L)	% of Content in Infusions Compared to the Content in Dried Material
Mg	YM-B1	144.75 ± 6.8	29.9%
	YM-P2	44.45 ± 13.7	14.0%
Zn	YM-P1	3.14 ± 0.0	27.8%
	YM-B1	1.00 ± 0.0	24.9%
Mn	YM-A1	3.67 ± 0.1	18.9%
	YM-P2	1.70 ± 0.0	50.2%

Table 2. Coverage of the daily recommended requirement when drinking 1 L of yerba mate infusion per day prepared using the described method.

Element	Sample	% RDA at Intake of Approximately 1 L per Day	
		Men	Women
Mg	YM-B1	34.5%	45.2%
	YM-P2	10.6%	13.9%
Zn	YM-P1	28.6%	39.3%
	YM-B1	9.1%	12.5%
Mn	YM-A1	159.8%	204.1%
	YM-P2	80.0%	94.5%

Several studies have investigated the elemental content of holly leaves. The contents of Mg, Ca, K, P, Cu, Zn, Mn, Fe, Na, Al, Cd, and Pb were found to vary significantly in available sources [19][20][21][22]. In the present study, the concentrations of Mg in the infusion from samples YM-B1 and YM-P2 were 144.8 mg/L and 44.5 mg/L, respectively. The RDAs for Mg are 420 mg and 320 mg for adult men and women, respectively [23]. Mg deficiency is becoming more common among people, and hence, Mg supplementation is recommended. Early symptoms that accompany Mg deficits include loss of appetite, chronic fatigue, and vomiting. By contrast, severe hypomagnesemia manifests as increased neuromuscular excitability in the form of muscle tremors, wrist cramps, and muscle spasms. Disturbances in heart rhythm, such as atrial and ventricular tachycardia, also occur. Mg deficiency very often accompanies deficiencies of other minerals, such as Ca or K [24].

The concentrations of Zn in the infusion from samples YM-P1 and YM-B1 were 3.14 mg/L and 1.00 mg/L, respectively. The RDAs for Zn are 11 mg and 8 mg for adult men and women, respectively [25]. Long-term intake of Zn ions from food in amounts lower than the recommended intake can lead to many diseases. In children and adolescents, these disorders include poor growth and delayed development. Cellular response mechanisms in patients with Zn deficiency are not as enhanced as those of patients with normal blood Zn levels. Numerous skin lesions appear, which become worse with increasing deficiency of Zn. Wound healing becomes more difficult. The condition of the hair and nails deteriorates, leading to increased brittleness and a tendency for hair loss. In more severe cases, the lingual papillae may disappear [26].

The concentrations of Mn in infusions from samples YM-A1 and YM-P2 were 3.67 mg/L and 1.70 mg/L, respectively. Drinking 1 L per day of infusions prepared using the method described in this research can cover 34.5% of daily Mg requirements for men and 45.2% of those for women; 28.6% of Zn requirements for men and 39.3% of those for women; and 159.8% of Mn requirements for men and 204.1% of those for women. This implies that the amount of Mn in 1 L of the infusion exceeds the daily requirement of the human body for this element. The RDAs for Mn are 2.3 mg and 1.8 mg for adult men and women, respectively [27]. Because of the significant presence of Mn in the diet, Mn deficiencies are very rarely found. Long-term supply of Mn ions to the human body in amounts higher than the recommended amount causes symptoms similar to those of Parkinson’s disease. Although epidemiological studies are lacking, intravenous injection of Mn has been shown to decrease heart rate and blood pressure and increase P-R and QRS intervals in electrocardiography [28].

3. Organic Compounds in the Analyzed Yerba Mate Materials

Compounds found in plant materials with a protective effect against diseases caused by free radicals are ranked in the following order according to their antioxidant activity: phenolic acids > flavonoids > ascorbic acid > tocopherols > purines. In the analyzed material, the following organic compounds with significant antioxidant activity were detected: phenolic acids, flavonoids, and caffeine.

According to the macroscopic analysis of the samples, the most powdered one was YM-B1, and it had the highest content of organic compounds. Similar content was noted in yerba mate samples from Brazil (YM-B2 and YM-B4). An important point to note is that these samples contained mainly leaf blades and differed from the Argentina and Uruguay samples because stems formed a major part of this sample. Compared with the leaf blade, stems contain more cellulose than organic compounds. The lowest content of organic compounds was found in the roasted material (YM-B3, roasted), which was related to the degradation of these compounds by thermal processing (**Table 3**). Industrial processing could affect the polyphenol content and their composition, as well as the antioxidant activity of Yerba Mate extracts [29].

Table 3. Content of organic compounds in yerba mate samples analyzed in the present research.

	Neochlorogenic Acid	Chlorogenic Acid	Cryptochlorogenic Acid	Caffeic Acid	4-Feruloylquinic Acid	isochlorogenic Acid	Rutoside	Astragalin	Caffeine
					[mg/g dry mass] ± SD				
YM-B1	**39.03 ± 0.64 [a]**	**19.00 ± 0.29 [a]**	**17.84 ± 0.29 [a]**	**0.60 ± 0.02 [a]**	**2.92 ± 0.10 [a]**	**28.82 ± 0.47 [a]**	**8.77 ± 0.26 [a]**	**1.61 ± 1.10**	**1.17 ± 0.00 [a]**
YM-B2	**24.46 ± 0.18**	**12.37 ± 0.06**	**12.18 ± 0.19**	**0.44 ± 0.01**	**2.20 ± 0.02**	**22.20 ± 0.20**	**6.53 ± 0.09**	**1.61 ± 0.01**	**0.74 ± 0.02**
YM-B4	**25.95 ± 0.20 [c]**	**12.12 ± 0.30**	**13.59 ± 0.30**	**0.39 ± 0.02**	**1.75 ± 0.08**	**24.32 ± 0.20**	**8.19 ± 0.23**	**1.40 ± 0.03**	**0.86 ± 0.02 [b]**
YM-A1	**15.61 ± 0.28**	**7.04 ± 0.24**	**6.91 ± 0.36**	**0.21 ± 0.01**	**1.19 ± 0.08**	**11.26 ± 0.32**	**4.98 ± 0.21**	**0.93 ± 0.03**	**0.42 ± 0.01**
YM-A2	**20.06 ± 0.05**	**10.22 ± 0.24**	**11.60 ± 0.33**	**0.34 ± 0.03**	**1.40 ± 0.05**	**14.83 ± 0.19**	**6.18 ± 0.14**	**0.94 ± 0.01**	**0.59 ± 0.01**
YM-A3	**23.81 ± 0.28**	**12.13 ± 0.28**	**12.07 ± 0.42**	**0.26 ± 0.01**	**1.52 ± 0.12**	**21.06 ± 0.56**	**6.51 ± 0.49**	**1.00 ± 0.03**	**0.70 ± 0.01**
YM-P1	**16.86 ± 0.07**	**10.52 ± 0.36**	**11.36 ± 0.48**	**0.38 ± 0.02**	**1.91 ± 0.15**	**15.90 ± 0.12**	**5.51 ± 0.16**	**0.98 ± 0.28**	**0.46 ± 0.02**

	Neochlorogenic Acid	Chlorogenic Acid	Cryptochlorogenic Acid	Caffeic Acid	4-Feruloylquinic Acid	isochlorogenic Acid	Rutoside	Astragalin	Caffeine
YM-P2	5.39 ± 0.09 [a]	3.21 ± 0.06 [a]	3.48 ± 0.10 [a]	0.07 ± 0.00 [a]	0.57 ± 0.00 [a]	4.78 ± 0.13 [a]	1.73 ± 0.03 [a]	0.38 ± 0.01	0.18 ± 0.00 [ab]
YM-B3 *	1.24 ± 0.03	1.57 ± 0.050	1.32 ± 0.01	0.05 ± 0.00	0.56 ± 0.02	0.45 ± 0.02	0.27 ± 0.01	0.14 ± 0.00	0.29 ± 0.01

Each analysis was performed in triplicate (Kruskal–Wallis test with Dunn's post hoc test; values followed by a different letter (a, b, c) within the same row are significantly different ($p < 0.05$) * roasted yerba mate (not statistically analyzed because roasting degrades organic compounds).

Among the organic compounds, the highest levels were detected for neochlorogenic acid, chlorogenic acid, and cryptochlorogenic acid, with the highest differences in the amount observed for the last compound. The level of the quantitatively dominant neochlorogenic acid ranged from 1.24 mg/g d.w. to 39.03 mg/g d.w. The highest content of phenolic compounds was determined in the three samples from Brazil, except for one sample that underwent thermal processing by roasting (YM-B3). In the roasted product, similar concentrations of all organic compounds were detected.

Among flavonoids, rutoside and astragalin were detected. The amount of astragalin ranged from 0.14 to 1.61 mg/g d.w., whereas that of rutoside ranged from 0.27 to 8.77 mg/g d.w. (YM-B1).

The highest levels of phenolic compounds were detected in the leaf extract. The total phenolic content (TPC) obtained from *I. paraguariensis* was 51 mg/g d.w. The content of 46 different polyphenols was also quantitatively determined, among which hydroxycinnamic acid derivatives were the predominant group. The dominant compounds were 3-caffeoylquinic acid (chlorogenic acid; 26.8–28.8%), 5-caffeoylquinic acid (neochlorogenic acid; 21.1–22.4%), 4-caffeoylquinic acid (cryptochlorogenic acid; 1.6–14.2%), 3,5-dicaoylquinic acid (9.5–11.3%), and rutin (7.1–7.8%) [6].

The alkaloids found in the leaves of *I. paraguariensis* are purine derivatives, known as purine alkaloids, for example, caffeine. In the present study, the content of caffeine in the prepared infusions ranged from 0.18 to 1.17 mg/g d.w. Similar to the results for phenolic compounds, the highest caffeine content was determined in yerba mate preparations from Brazil, except for the roasted product.

The caffeine content commonly found in dried yerba mate is 1–2%, and that of theobromine is 0.3–0.9% of dry matter. Compared with caffeine and theobromine, theophylline is present in a very small amount in the leaves of yerba mate, and its content in one cup of infusion of this product (about 150 mL) is approximately 78 mg, which is very similar to the caffeine content in coffee (approximately 85 mg). However, it should be noted that in traditional yerba mate brewing, the volume of the beverage consumed sometimes reaches even 500 mL, and this amount of the beverage contains approximately 260 mg or more of caffeine [30].

Previous studies have shown that the mean intake of polyphenols in the diet was 1756.5 ± 695.8 mg/d (median = 1662.5 mg/d) for individuals from an urban population of Krakow, Poland. The highest intake was of isomers of chlorogenic acid, which largely originated from coffee [31]. The average intake of total phenolic compounds by the Brazilian population was 460.15 mg/day, which was mainly derived from beverages (48.9%), especially coffee and legumes (19.5%) [32]. Carnauba et al. reported that nonalcoholic beverages and fruits were the major sources of polyphenols in the Brazilian population, while coffee and orange juice were the main contributors to polyphenol intake [33]. Tea and coffee are the caffeinated beverages commonly consumed worldwide. Yerba mate is another caffeinated drink that is becoming increasingly popular [6]. Coffee, tea, and yerba mate beverages, because of their widespread consumption, can therefore be an important source of compounds with antioxidant properties in the daily diet [34].

The comparison of the content of polyphenols in Yerba Mate is difficult because of the different methods used to separate them from the tested raw material. The authors not only used water infusions prepared at different temperatures and times to simulate and reflect the process carried out by consumers, but they also carried out the extraction process continuously for 4 h in a Soxhlet apparatus, both with water and organic solvents, such as ethanol or ethyl ether, at 76 °C, 40 °C, and 97 °C or triplicate extracted with 2 N hydrochloric acid in aqueous methanol (50:50, *v/v*) for 1 h by constant shaking at room temperature [35][36][37].

The analysis of non-hallucinogenic indole derivatives confirmed the presence of trace amounts of L-tryptophan and 5-hyroxy-L-tryptophan in the extracts of YM-B1 and YM-B2 (Brazil). 5-Hydroxytryptophan is a compound produced in the human body from the amino acid L-tryptophan. It is a precursor of the neurotransmitter serotonin and the hormone melatonin. L-Tryptophan and 5-hydroxy-L-tryptophan have a sleep-depriving effect and support the treatment of depression. They are also precursors of serotonin and melatonin—endogenous compounds responsible for regulating the circadian cycle of the human body. Serotonin also has antioxidant and anticancer properties.

4. Antioxidant Activity

The antioxidant activity of infusions is shown in **Table 4**. The antioxidant activity was highest for the infusion prepared from the yerba mate samples from Brazil and Paraguay (YM-B1 and YM-P2) using the DPPH test. For FRAP antioxidant activity, the test sample from Brazil (YM-B4) was the highest. Thermal treatment (roasting) deprives yerba mate of organic compounds with antioxidant activity and affects the antioxidant properties of infusions prepared from these products. In the DPPH and FRAP tests used, the antioxidant activity of the infusion obtained from a sample from Brazil (YM-B3) was the lowest. Bastos et al. demonstrated that ethanolic and aqueous extracts from green yerba mate and roasted yerba mate showed excellent DPPH scavenging activity (>89%), but continuous extraction was performed for 4 h in a Soxhlet apparatus with ethanol or deionized water (100 mL) at 76 °C, 40 °C, and 97 °C, respectively. The ethanolic extracts from yerba mate, both roasted and green, with phenolic compound contents (3.80 and 2.83 mg/mL) presented high antioxidant activity, even at very low phenolic concentrations [37].

Table 4. Comparison of the total phenolic compounds and antioxidant activity of analyze yerba mate samples.

	DPPH° *	FRAP **	TPC ***	TFC ***
YM-B1	**61.29 ± 1.44 ^{e}**	**69.39 ± 2.84 ^{c}**	**86.23 ± 2.84 ^{c}**	**475.56 ± 11.74 ^{d}**
YM-B2	**52.34 ± 1.98 ^{cd}**	**42.04 ± 1.86 ^{b}**	**70.16 ± 2.61 ^{c}**	**338.35 ± 33.84 ^{bc}**
YM-B3	**20.20 ± 0.77 ^{a}**	**1.94 ± 0.49 ^{a}**	**22.05 ± 0.52 ^{a}**	**36.65 ± 2.82 ^{a}**
YM-B4	**46.23 ± 1.38 ^{bc}**	**117.88 ± 14.45 ^{e}**	**62.92 ± 2.03 ^{bc}**	**360.91 ± 14.92 ^{bc}**
YM-A1	**53.03 ± 0.81 ^{d}**	**62.75 ± 1.77 ^{c}**	**82.23 ± 3.05 ^{c}**	**582.71 ± 24.43 ^{e}**
YM-A2	**43.46 ± 1.27 ^{b}**	**52.22 ± 3.87 ^{bc}**	**57.74 ± 3.88 ^{b}**	**340.23 ± 21.35 ^{bc}**
YM-A3	**50.95 ± 3.01 ^{cd}**	**56.87 ± 1.67 ^{bc}**	**66.03 ± 3.81 ^{bc}**	**329.89 ± 28.19 ^{b}**
YM-P1	**41.86 ± 2.49 ^{b}**	**41.77 ± 3.98 ^{b}**	**56.35 ± 2.01 ^{b}**	**332.71 ± 25.84 ^{b}**
YM-P2	**59.55 ± 1.61 ^{e}**	**62.15 ± 3.83 ^{c}**	**85.06 ± 5.97 ^{c}**	**404.13 ± 14.19 ^{c}**

* % of a reduced radical DPPH°, ** µM Fe^{2+} per 1 mL of Yerba Mate infusion, *** mg per 1 mL of Yerba Mate infusion. Each analysis was performed in triplicate (Tukey test: values followed by a different letter (a, b, c, d, e) within the same row are significantly different (p < 0.05).

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