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INFLUENCE OF NATIVE AND CULTIVATED YERBA MATE ON THE MINERAL COMPOSITION AFTER PROCESSING

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KEYWORDS

Ilex paraguariensis, post-harvest, nutritional quality, types of production.

ABSTRACT

Yerba-mate (*Ilex paraguariensis*) is a native species native from subtropical and temperate regions of South America. Its production process may influence its physicochemical composition and the final quality. In this way, this study aims to evaluate the major macro- and micro minerals present in the yerba mate, both native and cultivated, after the processing. This experiment was conducted in an industry, where samples of dried yerba mate were collected. In total, samples were collected from 31 production areas, with 25 areas of cultivated yerba mate and 6 areas of native yerba mate. The determination of Ca, K, Mg, Na, S, Cu, Fe, Mn, and Zn was released by using inductively coupled plasma optical emission spectroscopy. The highest levels of macronutrients (Ca, K, Mg and S) and micronutrients (Cu, Fe and Mn) were detected, due to the management of the yerba mate plantations, which mostly receive organic or chemical fertilization, as well as the age of the branches and leaves, reflecting on the composition. In contrast, native yerba mate depends on the natural fertilization of the soil and the characteristics of the environment in which it is found.

INTRODUCTION

The yerba mate (*Ilex paraguariensis*) is a native species from subtropical and temperate regions of South America. It is widely used in the preparation of *chimarrão*, a typical beverage in Mercosul countries. In this context, the yerba mate cultivation plays an important socioeconomic role, as it is mainly produced on small rural properties (Goulart et al., 2022; Villarinho, 2023).

The leaves of Yerba Mate can be used to prepare *chimarrão* and *tereré* beverages. Besides, the use of processed yerba mate is gaining more prominence in the pharmaceutical and food industry due to its content of essential amino acids, vitamins E, C, and the B complex. It has also some minerals such as potassium, magnesium, and manganese (Galante et al., 2023).

According to the IBGE Agricultural Census (2017), 619.003 tons of yerba mate were produced in an area of approximately 84 thousand hectares, resulting in an average production of 7.369 kg ha^{-1}, in which the states in the South of Brazil stand out for the highest production. However, it is important to emphasize that the average production is quite variable, as it is directly related to the climate and crop management, which influence the composition and the final quality of the product (Pereira et al., 2021).

The production of yerba mate occurs in two ways: one through plant extraction and the other through cultivation, or silviculture. In the extractivist system, branches and leaves of native yerba mate are harvested from the Mixed Ombrophilous Forest (MOF), while in the crops system, yerba mate is grown inside the MOF or in open fields, i. e., under full-sun plantation. Yerba mate produced in consortia with the MOF, as it is protected against the sunlight, has a better quality with a milder taste. Additionally, it is more economically for the

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industry compared to yerba mate growth under full sunlight (Vestena & Santos, 2022).

The leaves of plants growth in shade result in a larger leaf area but with lower bulk weight and chloroplasts when compared to leaves located in sun-exposed areas. These exposed leaves achieve high photosynthetic rates, producing thicker leaves due to the formation of large palisade cells (Almeida et al., 2023; Aguiar et al., 2024). Therefore, in response to the growing demand and the degradation of native yerba mate plantation, there has been an increase in areas under full-sun yerba mate, although it is a product of lower commercial value.

Currently, the yerba mate sector needs to convert full-sun plantations into shaded ones, or at least, establish some degree of shading for yerba mate plants by reducing the ambient light levels (Cortese et al., 2021). On the other hand, native yerba mate can be an important stimulus for the conservation of the MOF, due to its occurrence in the forest understory and its significant economic value. This economic value that provides monetary benefits to the forest, contributing to forest conservation through the traditional management of these native yerba mate plantations. It is important to highlight that, in addition to its monetary value, native yerba mate plantation has significant cultural and social value for local populations (Chechi & Schultz, 2019). Thus, the present study aimed to determine the principal macro and micronutrient contents in yerba mate, after processing, considering the types of native and cultivated production from different areas, in order to assess whether the production system influences the quality of the final product.

MATERIAL AND METHODS

The coarse-ground yerba mate (*cancheada*) samples used in this experiment were collected from yerba mate industry located in Ilópolis – RS, in July 2023, totaling 31 samples of coarse-ground yerba mate, of which 25 were cultivated and 6 were native.

The production and processing of yerba mate followed the flowchart shown in Figure 1. The semi-mechanized harvest was carried out during the winter, before the beginning of new sprouting, by cutting thin branches and leaves. Subsequently, the branches were reduced in size using a branch chopper. After harvesting, exposure of the yerba mate to heat and light was avoided to reduce the possibility of wilting and enzymatic browning, which could negatively affect the final (Nunes et al., 2024).

The *Sapeco* operation (thermal bleaching) was carried out in order to avoid the browning of the yerba leaves after drying. With the heat, the leaves lost approximately 20% of its water content and acquired green-golden coloration characteristics of high-quality yerba mate. The branches remained in direct contact with the flame generated by the burning firewood and remained there for about one minute. Drying was carried out using a rotary dehydrator, where the material was exposed to heated air for approximately five minutes. In the outlet, the air flows in a cyclone system to cool the yerba mate as observed by Nunes et al. (2024), reaching in this way to the coarse-ground yerba mate (Figure 2a). The milling operation decreased the particle size until a fine powder was obtained. Sieving was then performed to separate the particles by size, followed by the packaging.

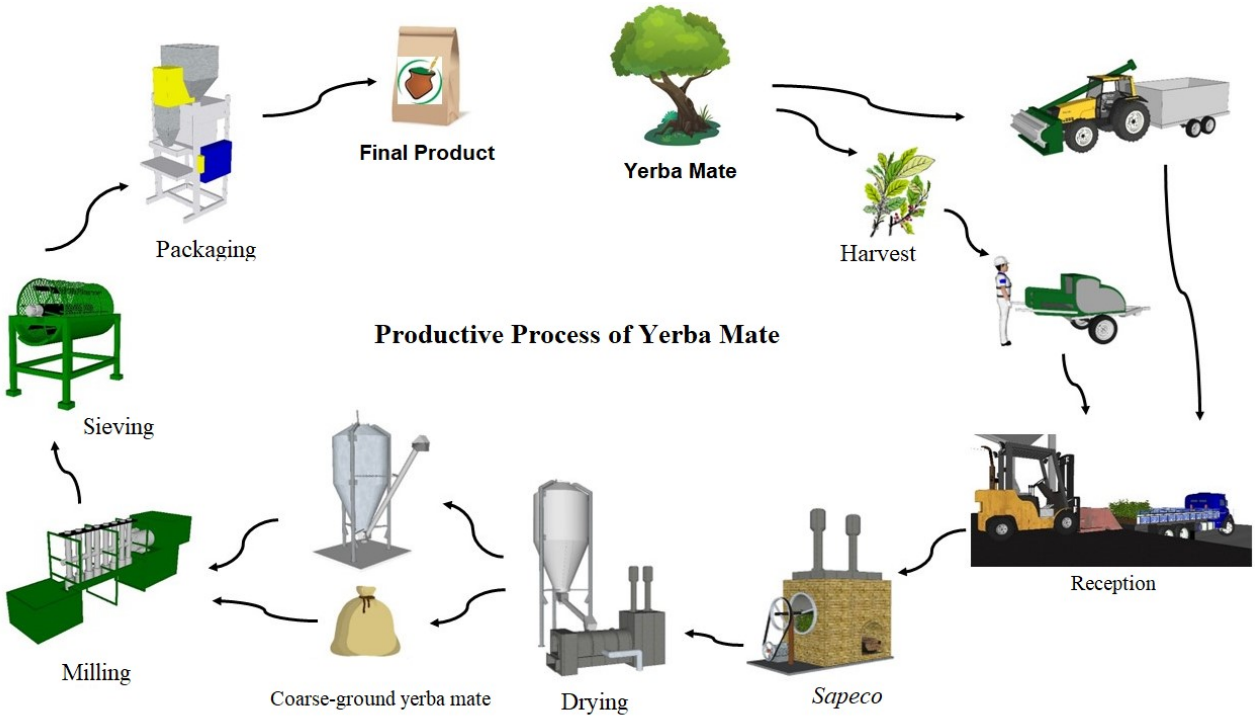


FIGURE 1. Productive process of yerba mate.

The analyzed producing farms have distinct cultivation characteristics, but they share a common feature: cultivation areas ranging from 1,0 to 20 ha, with an average plant spacing of 1.5 x 2.0 m. Sample collection was conducted randomly, following the yerba mate processing in an operational industry. All samples were collected in triplicate and stored in laminated structure packaging (biaxially oriented metallized polypropylene/low-density polyethylene) (Figure 2b), each with a capacity of 0,5 kg each, using vacuum sealing to preserve the characteristics of the yerba mate.

For the determination of elemental composition of the dry matter, the samples were ground (Figure 2c) using *Willey-type* mill (with 5 blades, 1725 rpm, 20-mesh sieve, ground for 3 minutes), at the Post-Harvest Laboratory (LAPOS) at the Federal University of Santa Maria – Cachoeira do Sul Campus (UFSM-CS).



FIGURE 2. Native and cultivated yerba mate samples: (a) coarse-ground yerba mate, (b) sample collection, (c) samples after grinding.

Subsequently, the samples were sent to the Industrial and Environmental Chemical Analysis Laboratory at UFSM for further analysis.

To determine the elemental composition, the samples of yerba mate underwent decomposition. 150 mg of each sample was weighed and placed in Teflon vials (100 mL internal volume) containing 6mL of concentrated, pre-distilled HNO_3.

The vials were properly sealed and processed in a microwave oven (Ethos^{TM} Easy model, Milestone, Denmark), equipped with a rotor capable of holding 44 vials. The heating program consisted of: i) heating up to 200 ºC for 25 min; ii) maintaining 200°C for 15 min; iii) cooling down to 50 ºC. After decomposition, the digested samples were transferred to polypropylene tubes and diluted to a final volume of 25 mL with ultrapure water.

The determination of Ca, K, Mg, Na, S, Cu, Fe, Mn, and Zn was carried out using Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES, Optima 4300 DV model, PerkinElmer, USA).

The obtained results were evaluated: (i) statistically using SISVAR software version 5.8, and with means compared by Tukey's test at a 5% probability level, (ii) through histogram Generation and analysis using Microsoft Excel Office; and (iii) by multivariate analysis using RStudio software, obtaining Pearson's correlation in order to emphasize strong and weak associations under each cultivation and management condition of yerba mate.

RESULTS AND DISCUSSION

The results indicate that the type of yerba mate influences the composition of the main macro- and microminerals in the product, as shown in Table 1. It is observed that cultivated yerba mate presents higher levels of macrominerals such as Ca, K, Mg, and S. On the other hand, Na showed no significant difference between native and cultivated yerba mate.

TABLE 1. Determination of Macro- and Microminerals in Yerba Mate from Native and Cultivated Production Systems.

Yerba Mate	Ca ($\mu g\ g^{-1}$)	K ($\mu g\ g^{-1}$)	Mg ($\mu g\ g^{-1}$)	Na ($\mu g\ g^{-1}$)	S ($\mu g\ g^{-1}$)	Cu ($\mu g\ g^{-1}$)	Fe ($\mu g\ g^{-1}$)	Mn ($\mu g\ g^{-1}$)	Zn ($\mu g\ g^{-1}$)
Native	5.949b	57.27b	3.918b	41.85a	934b	7,73b	7.912b	896b	63.03a
Cultivated	7.243a	74.95a	4.682a	47.77a	1,057a	8.79a	9.004a	1,288a	70.81a
C.V. (%)	11.32*	40.56*	18.10*	36.41^{NS}	11.13*	14.06*	13.08*	53.06*	28.52^{NS}

Means followed by the same letter do not differ from each other at a 5% probability level according to Tukey's test. ^{NS}Not Significant, *Significant, CV: Coefficient of Variation.

According to Gawron-Gzella et al. (2021), the primary macronutrients found in yerba mate leaves produced in Argentina are K, Ca, Mg, and P in amounts of 11,350, 7,690, 6,990, and 1,370 µg g^{-1}, respectively. Among the trace elements, manganese and iron were the most abundant (680 and 120 µg g^{-1}). These findings reveal a difference from the results obtained in the present study, showing that the samples analyzed in Argentina had higher K and Mg contents. However, the samples from this study showed elevated Fe levels, both in native and cultivated yerba mate, with values of 7.912 and 9.004 µg g^{-1}, respectively.

Calcium levels were higher than those found by Bastos et al. (2014) in a study on young yerba mate leaves, where they ranged between 1,500 and 2,700 µg g^{-1}. In contrast, the present research found Ca levels of 5,949 µg g^{-1} in native yerba mate and 7,243 µg g^{-1} in cultivated yerba mate. This difference is possibly due to the harvest period of branches and leaves. During the main harvest season (winter), the leaves are no longer young, unlike the secondary harvest season, which occurs shortly after new shoots emerge (summer).

When analyzing the main microminerals (Table 1), Cu, Fe, and Mn were found in higher amounts in cultivated yerba mate, except for Zn, which did not show a significant difference between yerba mate types. Although Cu is known to have low mobility, as it is present in chloroplasts or bound to enzymes, high levels were found in soluble extracts from yerba mate infusions (Marschner, 2012). This high level of Cu soluble in hot water contributes approximately 10% of the Recommended Daily Intake (RDI), the highest contribution compared to other elements, as accentuated by Bastos et al. (2014).

The mineral element content obtained from young yerba mate leaf infusions, in relation to the recommended daily intake, varies from 0.5% to 11.5%, with the nutrient content ranking in descending order as follows: Cu > Mn > K > P > Mg > Fe > Zn > Ca > Na, where the morphotypes and progenies did not lead to differences in these nutrients (Bastos et al., 2014). However, the present research observed distinctions between yerba mate types, with the highest contents found in the cultivated type, which is predominantly fertilized with chemical and/or organic inputs, influencing its final composition.

According to Prado et al. (2022), native yerba mate is possibly one of the most sustainable forms of exploitation in Brazil's native forest areas. Nevertheless, due to the modernization of Brazilian agriculture, yerba mate is increasingly being removed from its natural environment and cultivated as a monoculture using pesticides and synthetic fertilizers, altering its composition.

In agreement with this, Nunes et al. (2024) emphasized that yerba mate produced under different morphological characteristics and cultivation systems exhibits distinct chemical and sensory attributes. This demonstrates that product quality depends on the characteristics of the raw material.

Understanding the cultivation and management factors of yerba mate allows for the establishment of methods to determine product quality criteria. This leads to the segregation of raw materials for different purposes, contributing to the value chain. This distinction is evident within each type of yerba mate (Figure 3), where the samples showed significant variation in the analysis of potassium, manganese, sodium, and zinc. This variability within the same yerba mate type is attributed to cultivation and management practices, mainly fertilization, pruning, and exposure to sunlight, as younger branches exposed to sunlight produce a distinct product.

In this context, Westphalen et al. (2020) analyzed different yerba mate cultivation conditions over five years to verify their direct impact on leaf phytochemical properties. They concluded that protein content in leaves increased by 8% in plants without fertilization under 30% shading compared to those exposed to 45% and 60% light intensity. Conventional water-soluble mineral fertilizer increased leaf protein content by 5.65% under 30% shading. Shading and fertilization did not alter the phenolic compound levels in the leaves. At 45% shading, there was a 12.5% increase in methylxanthine levels in the leaves. The conventional water-soluble mineral fertilizer increased the total methylxanthine content by 6.29% when yerba mate was grown under 45% light intensity. This study concluded that different cultivation conditions result in phytochemically heterogeneous products, which significantly impact yerba mate quality.

Meanwhile, leaves in shaded areas develop a larger surface area but have a lower specific weight than those exposed to sunlight, as observed by Aguiar et al. (2024). The effects of yerba mate cultivation methods are also noticeable in *chimarrão*, as noted by Bastos et al. (2018). Their study found that *chimarrão*, composed of 70% leaves and 30% stems, made from yerba mate harvested during the main season generally had higher nutrient levels, whereas leaves sampled during the secondary harvest had higher water-soluble nutrient levels.

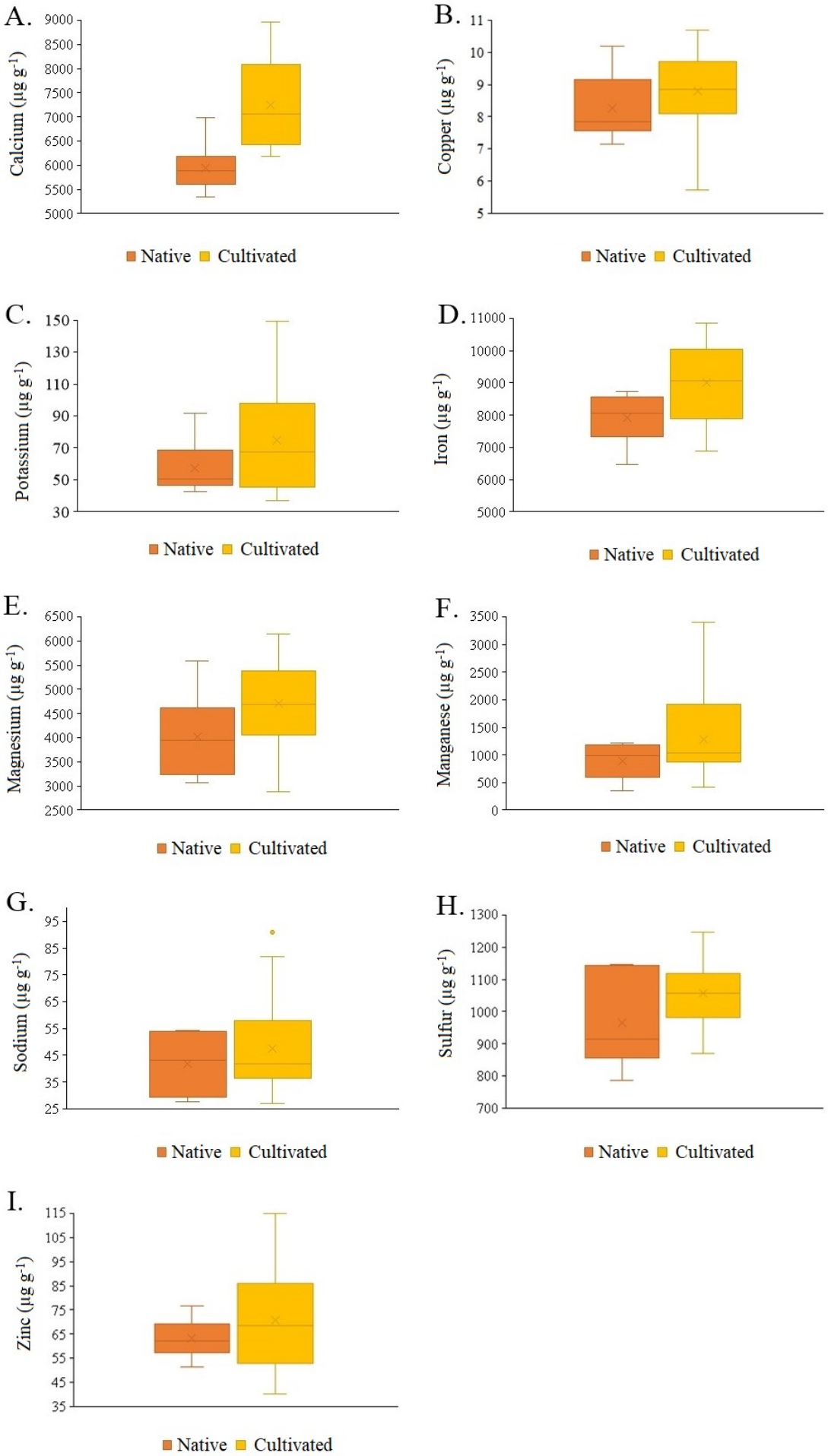


FIGURE 3. Histograms of macro- and micro minerals evaluated in native and cultivated yerba mate: (a) calcium, (b) copper, (c) potassium, (d) iron, (e) magnesium, (f) manganese, (g) sodium, (h) sulfur, (i) zinc.

When comparing native (Figure 4a) and cultivated (Figure 4b) yerba mate using the Pearson's Correlation Network, negative relationships, represented in red, were mainly observed in the native type, particularly between sodium and manganese, magnesium, potassium, iron, and calcium. In contrast, the cultivated yerba mate showed a weaker negative correlation between Na-Mn, as well as between Zn-Mn.

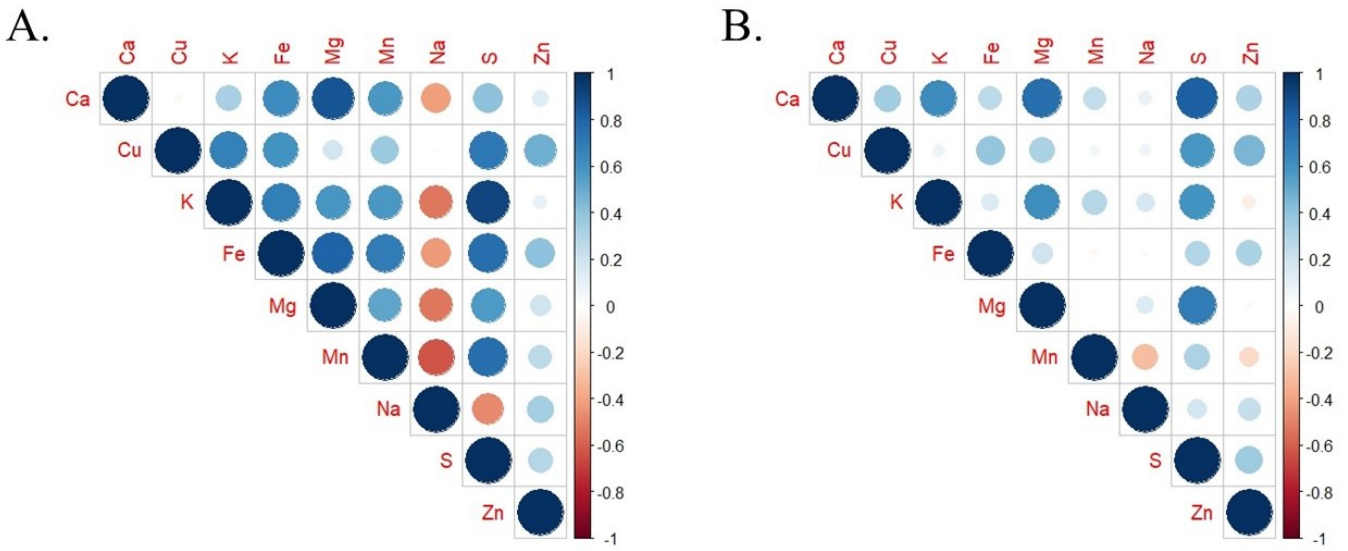


FIGURE 4. Pearson correlation network for macro- and micro minerals in yerba mate samples: (a) native yerba mate, (b) cultivated yerba mate.

Despite the negative correlation between most macro- and micro minerals and sodium in native yerba mate, these minerals had lower levels than in cultivated yerba mate, though Na showed no significant difference (Table 1). This pattern likely results from cultivation and management practices, as cultivated yerba mate receives frequent fertilization and pruning, which enhance plant nutrition and increase the mineral content in processed yerba mate.

Commercial yerba mate samples sold in South America showed significant variation in Zn content: 79.4 µg g^{-1} in Argentina, 44.2 µg g^{-1} in Brazil, 57.1 µg g^{-1} in Uruguay, and 77.3 µg g^{-1} in Paraguay (Pozebon et al., 2015). Zn levels in yerba mate leaves can also vary significantly within the same country. For example, studies in southern Brazil (Rio Grande do Sul, Santa Catarina, and Paraná) reported Zn concentration ranging from 14 to 179 µg g^{-1} (Motta et al., 2020. Similar pattern was observed in commercial products, where Zn levels ranged from 54.5 to 67.6 µg g^{-1} (Ulbrich et al., 2022). The present study found a Zn content average of 69.29 µg g^{-1}.

According to Neves & Fior (2020), yerba mate plants grown without Zn exhibited a decrease in growth, and the younger leaves displayed a characteristic "fading" between the veins. As the deficiency intensified, the leaves became leathery, wrinkled, and the veins shortened. Therefore, Zn deficiency compromises important physiological events and, consequently, the plant's growth and development due to the reduction in chlorophyll content (Oliveira et al., 2009; Marschner, 2012).

As Gabira et al. (2023) point out, with the modernization of Brazilian agriculture, yerba mate tends to be removed from its natural environment and grown in monoculture, with the use of pesticides and synthetic fertilizers. This new cultivation system is capable of increasing productivity by up to 160% in just four years after planting, in super-dense conditions, consisting of more than 25 thousand plants per hectare. Another distinguishing factor is that the cultivation system uses a larger amount of nitrogen, resulting in an 86% increase in total leaf productivity and a large number of young branches and leaves, which impacts biomass growth and opens new markets for the crop.

When analyzing the overall interactions between minerals (Figure 5), regardless of the type of yerba mate, positive correlations stand out, especially between Mn-Ca and S-C. This result is similar to that found in cultivated yerba mate, due to its higher incidence in the experiment.

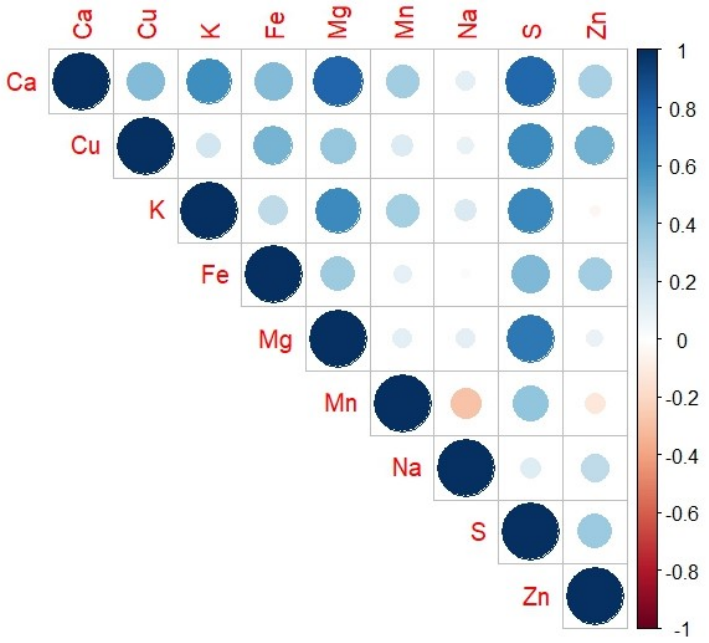


FIGURE 5. General Pearson correlation network between the macro and micronutrients evaluated in the yerba mate samples.

Studies by Długaszek & Kaszczuk (2020) on infusions of hibiscus, horsetail, nettle, and yerba mate, also revealed a positive correlation between Ca-Mg. As observed by Li et al. (2022) in an experiment with green tea that the use of organic fertilization promoted an increase in Ca and Mg in the tea, establishing a positive relationship.

According to Pandolfo et al. (2003), native yerba mate plantations are typically established in acidic soils with high levels of exchangeable aluminum and low available phosphorus. Established yerba mate plantations are located on soils that have usually been limed and cultivated with annual crops, presenting better fertility conditions. For crops like yerba mate, in which a large amount of green biomass is removed from the field, replenishing nutrients in the soil is essential for maintaining its fertility and improving the plant's productive potential. These researchers observed that the highest levels of Ca and Mg are found in the absence of potassium fertilization and organic fertilizer. This can be attributed to the competitive inhibition of K with Ca and Mg, meaning that an increase in the concentration of K in the soil may decrease the absorption of these two elements by the plant.

CONCLUSIONS

- The type of yerba mate affected the composition of macro- and microminerals.
- Cultivated yerba mate showed higher levels of Ca, K, Mg, S, Cu, Fe, and Mn due to cultivation and management factors, including greater use of chemical fertilization and periodic harvesting.
- Although valued by consumers, native yerba mate did not exhibit a high mineral content.

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