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Yerba Mate: The Natural Boost Your Body Craves

Malwina Draim
Southern Hospital in Warsaw
Witolda Pileckiego 99, 02-781 Warsaw, Poland
malwina.draim@gmail.com
ORCID: https://orcid.org/0009-0003-1935-0449

Aneta Rostkowska
Prof. W. Orłowski Independent Public Clinical Hospital
Czerniakowska 231, 00-416 Warsaw, Poland
aarostkowska@gmail.com
ORCID: https://orcid.org/0009-0007-1142-2507

Sebastian Kupisiak
Czerniakowski Hospital
Stępińska 19/25, 00-739 Warsaw, Poland
sebastiankupisiak@gmail.com
ORCID: https://orcid.org/0009-0007-9631-2314

Natalia Pasierb
Military Institute of Medicine - National Research Institute
Szaserów 128, 04-141 Warsaw, Poland
nnpasierb@gmail.com
ORCID: https://orcid.org/0009-0002-9701-1162

Barbara Rękas
Military Institute of Medicine - National Research Institute
Szaserów 128, 04-141 Warsaw, Poland
basiarekas1@gmail.com
ORCID: https://orcid.org/0009-0004-4474-7226

Michalina Kosowska
Military Institute of Medicine - National Research Institute
Szaserów 128, 04-141 Warsaw, Poland
rmkosowska@wp.pl
ORCID: https://orcid.org/0009-0001-8966-342X

Wiktoria Dzierzgowska
Military Institute of Medicine - National Research Institute
Szaserów 128, 04-141 Warsaw, Poland
karla.dzierzgowska@icloud.com
ORCID: https://orcid.org/0009-0007-4459-2094

Julia Latocha
Jerzy Popiełuszko Memorial Bielański Hospital
Cegłowska 80, 01-809 Warsaw, Poland
julia.latocha@gmail.com
ORCID: https://orcid.org/0009-0009-8438-864X

ABSTRACT

Introduction: Yerba Mate (*Ilex paraguariensis*) is a traditional South American infusion known for its stimulant and antioxidant properties. Historically consumed for its energizing effects, it was also regarded as a medicinal remedy by indigenous cultures, used to treat fatigue, stress and digestive issues [1, 2]. In recent decades, Yerba Mate has gained global recognition and has garnered scientific interest due to its potential health benefits such as improving cardiovascular health, metabolic function and supporting physical performance [1–5]. Its rich content of polyphenols, xanthines and saponins may contribute to a range of protective and restorative effects on the human body [1, 8].

Purpose of the work: The aim of this study is to evaluate existing research on the effects of Yerba Mate consumption on human health and athletic performance, with a focus on its antioxidant activity, metabolic support and cardiovascular benefits.

Materials and methods: A comprehensive literature review was conducted using PubMed, Scopus, Google Scholar and Science Direct databases, encompassing clinical studies, randomized trials and relevant animal model research on the bioactive effects of Yerba Mate.

Results: This review indicates that Yerba Mate may support lipid metabolism, reduce oxidative stress and improve cardiovascular markers [3–5, 7, 8]. Furthermore, its caffeine content and phytochemical profile may serve as a natural alternative to synthetic stimulants used by athletes [1, 5, 13]. Nonetheless, more rigorous clinical trials are needed to fully establish its efficacy and safety profile in athletic and general populations.

Keywords: Yerba mate, *Ilex paraguariensis*, tea, health benefits, athletic performance, supplements, antioxidant

1. INTRODUCTION

Yerba Mate (*Ilex paraguariensis*) holds a prominent place in the cultural and medicinal traditions of South America, particularly among the indigenous Guaraní people of Paraguay, Argentina, Brazil and Uruguay. Traditionally, the Guaraní prepared mate infusions to restore energy after long hunts, alleviate digestive discomfort and support overall vitality, sharing the brew communally from hollowed calabashes via a bombilla [2]. The infusions were made by steeping leaves of the plant in hot water.

Historical accounts from European settlers in the 17th and 18th centuries describe Yerba Mate as a mild stimulant and remedy for gastrointestinal issues and fatigue. Jesuit missionaries, recognizing its economic and health potential, domesticated the plant and established plantations [1, 2]. Although Jesuit missions were suppressed in the late 18th century, local producers carried forward cultivation methods, leading to the export of mate throughout the Americas and eventually Europe and Asia by the 19th century [1].

In modern times, Yerba Mate has gained popularity worldwide. It is marketed in traditional loose form and as ready-to-drink bottled beverages, powders and dietary supplements. According to market analyses, global Yerba Mate consumption exceeded 2 million metric tons in 2023, with a compound annual growth rate of 5 % in European and North American markets [1]. Such popularity has spurred rigorous scientific investigation into its phytochemical composition and health benefits [1, 2].

Recent studies have highlighted Yerba Mate's potential in a wide range of health-related areas. Clinical and experimental data suggest it may contribute to improved lipid profiles, glucose metabolism, body composition and endurance performance [3–5, 7]. These effects are attributed to its rich phytochemical composition-particularly chlorogenic acids, caffeine, flavonoids and saponins-which interact with metabolic and inflammatory pathways [1, 2, 8]. Evidence also supports its possible role in supporting bone mineral density, especially among postmenopausal women [6], and reducing muscle damage and oxidative stress following intense physical activity [8].

This literature review aims to examine current evidence on Yerba Mate's cardiovascular and metabolic benefits, ergogenic effects, bone health support and safety considerations, drawing from both human clinical trials and relevant animal model research to assess its potential as a health-promoting and performance-enhancing natural supplement.

2. CHEMICAL COMPOSITION

Yerba Mate (Ilex paraguariensis) is recognized for its unique and complex chemical profile, which underpins its pharmacological and nutritional properties. The bioactive components present in the leaves and stems of the plant have been the focus of numerous biochemical and biomedical investigations. The main classes of compounds include xanthines, polyphenols, saponins, minerals, amino acids, and trace elements, each contributing to the plant's stimulatory, antioxidant, anti-inflammatory, and metabolic-modulatory effects.

2.1 Xanthines

The most well-known group of compounds in Yerba Mate are xanthines-purine alkaloids such as caffeine, theobromine and theophylline. They act primarily as central nervous system stimulants, bronchodilators and smooth muscle relaxants. Caffeine, the predominant xanthine in Yerba Mate, ranges from 65 to 130 mg per 250 mL infusion, depending on leaf concentration and preparation method [1]. Compared to coffee, this represents a similar amount of caffeine. However, traditional methods often involve the consumption of up to 500 mL per serving, resulting in approximately 260 mg or more of total caffeine, which can exceed caffeine intake from coffee.

Caffeine functions as an adenosine receptor antagonist, leading to increased neuronal activity and the release of neurotransmitters such as dopamine and norepinephrine, thereby enhancing alertness, reducing perceived exertion and improving physical performance [4].

Theobromine, while less potent as a CNS stimulant, has a longer half-life and produces diuretic, cardiostimulatory and vasodilatory effects, which may support circulatory health and assist in blood pressure regulation [13].

Theophylline, although present in smaller quantities, contributes to bronchodilation and has been used therapeutically in the management of asthma and chronic obstructive pulmonary disease (COPD) [13].

2.2 Polyphenols and Flavonoids

Yerba Mate is exceptionally rich in polyphenolic compounds, most notably chlorogenic acids (CGAs), which constitute up to 35% of its dry weight polyphenols [5]. CGAs are esters formed between caffeic acid and quinic acid, known for their antioxidant, antidiabetic, and lipid-modulating properties. They inhibit glucose-6-phosphatase and modulate lipid metabolism by activating AMPK, a key metabolic regulator, thus contributing to anti-obesity and hypoglycemic effects [5].

In addition to CGAs, Yerba Mate contains flavonoids such as quercetin, kaempferol, and rutin, compounds with well-established anti-inflammatory, vasoprotective, and anticancer activities. These flavonoids scavenge free radicals, inhibit lipid peroxidation, and modulate cytokine production, which contributes to the prevention of oxidative stress-related chronic diseases, including atherosclerosis and neurodegenerative disorders [8].

Studies have measured Yerba Mate's antioxidant capacity using assays such as ORAC (oxygen radical absorbance capacity), showing values comparable to or even higher than green tea. Its total phenolic content is typically quantified as 80–120 mg gallic acid equivalents per gram of dry matter, underscoring its potential as a dietary antioxidant source [10].

2.3 Saponins

Another important class of compounds found in Yerba Mate are triterpenoid saponins, primarily ursolic acid derivatives. They are believed to be responsible for the bitterness of Mate infusion. Saponins are glycosylated compounds known for their cholesterol-lowering, anti-inflammatory and immunomodulatory effects. In vitro and animal studies suggest that Yerba Mate saponins can inhibit NFκB signaling and downregulate pro-inflammatory cytokines such as IL-6 and TNF-α, indicating a role in modulating inflammatory pathways involved in obesity and metabolic syndrome [20].

2.4 Minerals and Trace Elements

Yerba Mate provides a range of essential minerals, including potassium, magnesium, calcium, manganese, and iron, in addition to trace elements such as selenium, zinc, and copper [2]. These micronutrients are essential for cellular signaling, enzymatic activity, antioxidant defenses (via enzymes like glutathione peroxidase), and bone mineralization.

For example, potassium and magnesium are critical in maintaining electrolyte balance, neuromuscular function, and cardiovascular health. Magnesium plays a central role in mitochondrial function and antioxidant enzyme activity, while selenium, though present in microgram quantities, is involved in redox balance and thyroid hormone regulation.

Recent research suggests that the bioavailability of these minerals from Yerba Mate may be enhanced due to its acidic infusion medium and coexisting polyphenols, which can facilitate certain mineral transport mechanisms in the intestines [2, 20].

2.5 Amino Acids and Other Phytochemicals

Yerba Mate also contains small quantities of amino acids such as arginine, lysine, leucine, and glutamic acid, which support nitric oxide production, protein synthesis and neurotransmitter balance [1, 2]. Although it is not a major protein source, these amino acids may synergize with xanthines and polyphenols to support neuromodulation and metabolic regulation [1, 8].

Additionally, volatile compounds including monoterpenes and sesquiterpenes are responsible for Yerba Mate's characteristic aroma and may contribute mild antimicrobial effects [1, 2]. Some varieties also contain carotenoids and tannins, which enhance the plant's antioxidant and anti-inflammatory potential [8].

3. CARDIOVASCULAR AND LIPID-MODULATORY EFFECTS

Cardiovascular diseases (CVDs), such as coronary artery disease and stroke, remain leading causes of mortality and morbidity globally. They are strongly associated with modifiable risk factors, including dyslipidemia, oxidative stress, systemic inflammation and endothelial dysfunction. In recent years, interest has grown in dietary interventions and phytochemicals that target these underlying mechanisms [5, 8]. Yerba Mate has shown promising cardiovascular effects due to its diverse array of bioactive compounds - particularly chlorogenic acids (CGAs), flavonoids, saponins and xanthines [1, 5]. These constituents act via multiple pathways, including inhibition of lipid absorption and synthesis, modulation of endothelial function and reduction of systemic inflammation [5, 8].

3.1 Lipid Profile Improvements in Human Subjects

One of the most significant cardiovascular benefits of Yerba Mate is its ability to improve serum lipid profiles. Elevated levels of low-density lipoprotein cholesterol (LDL-C), total cholesterol and triglycerides, along with low levels of high-density lipoprotein cholesterol (HDL-C), are well-established contributors to atherosclerosis and cardiovascular events.

In a clinical trial conducted by de Morais et al. (2009), 102 dyslipidemic subjects consumed 1 liter of traditional Yerba Mate infusion daily for 40 consecutive days, prepared using 50 g of dried mate leaves infused in hot water [3]. The results showed a mean 10% reduction in LDL-C, a 5% increase in HDL-C and a 6% decrease in total cholesterol. Notably, participants on concomitant statin therapy (simvastatin 20 mg/day) exhibited an even more substantial LDL-C decrease of 16%, suggesting a potential additive or synergistic effect between statins and Yerba Mate bioactives [3].

These outcomes are mechanistically supported by the known effects of chlorogenic acids (CGAs), which inhibit hepatic HMG-CoA reductase, the enzyme targeted by statins, thereby reducing endogenous cholesterol synthesis. Additionally, the presence of triterpenoid saponins in Yerba Mate likely enhances bile acid excretion and reduces intestinal cholesterol absorption, further contributing to improved lipid metrics [5]. This combination of actions places Yerba Mate in a unique position among functional beverages, offering both preventive and adjunctive benefits in lipid management.

3.2 Effects on Endothelial Function and Triglyceride Metabolism

Endothelial dysfunction is a precursor to atherosclerosis and other vascular diseases, characterized by reduced nitric oxide (NO) production, inflammation, and impaired vasodilation. The phenolic compounds in Yerba Mate, including quercetin, rutin, and chlorogenic acids, have demonstrated protective effects on vascular endothelial cells. These bioactives stimulate endothelial nitric oxide synthase (eNOS), reduce oxidative damage, and downregulate inflammatory mediators such as VCAM-1 and ICAM-1, thus promoting vascular homeostasis [1, 4].

While some animal and in vitro studies suggest that chlorogenic acids and flavonoids in Yerba Mate promote endothelial nitric oxide synthase (eNOS) activity and reduce vascular inflammation [1, 4, 8], human evidence is still limited. In a randomized crossover clinical trial, Filipini et al. (2024) found that acute ingestion of Yerba Mate infusion (500 mL) did not significantly improve endothelial function, hemodynamics or heart rate variability in healthy young adults [14]. These findings suggest that chronic intake, higher doses or targeted populations (e.g., individuals with metabolic syndrome or endothelial dysfunction) may be necessary to observe meaningful vascular effects. Further studies are warranted to clarify dose-response relationships, chronic effects and clinical significance.

3.3 Oxidative Stress, Lipid Peroxidation, and Antioxidant Enzyme Activation

Oxidative stress plays a key role in vascular injury, particularly through the oxidation of LDL particles, which then become pro-inflammatory and atherogenic. Yerba Mate contains a rich profile of polyphenols and xanthines with strong antioxidant properties, capable of neutralizing reactive oxygen species (ROS) and reducing oxidative damage.

In a 12-week clinical study by Rząsa-Duran et al. (2023), 48 middle-aged participants (aged 40–65) with moderate cardiovascular risk consumed daily three servings of 150 mL Yerba Mate. At the end of the study, researchers observed a 20% decrease in plasma malondialdehyde (MDA)-a marker of lipid peroxidation-and significant increases in antioxidant enzyme activities: superoxide dismutase (SOD) by 16% and glutathione peroxidase (GPx) by 12% [2]. The upregulation of these endogenous defense enzymes is biologically meaningful, as they form the first line of defense against oxidative stress in vascular tissues. SOD catalyzes the dismutation of superoxide radicals into oxygen and hydrogen peroxide, while GPx reduces hydrogen peroxide to water, limiting potential cellular damage. These findings suggest that habitual Yerba Mate consumption may reinforce antioxidant resilience, potentially protecting against the progression of atherosclerosis.

3.4 Blood Pressure Modulation and Hemodynamic Responses

Hypertension is a leading risk factor for stroke and myocardial infarction. While Yerba Mate contains caffeine, which can acutely raise blood pressure, it also provides polyphenols and theobromine - compounds known to support vasodilation and endothelial relaxation.

In animal studies, such as that conducted by Kang et al. (2012), mice fed a high-fat diet and treated with Yerba Mate extract (200 mg/kg) for 8 weeks experienced lower systolic blood pressure, improved endothelial-dependent vasodilation and decreased circulating levels of pro-inflammatory cytokines such as TNF-α and IL-6 [21]. These combined findings suggest that Yerba Mate has beneficial hemodynamic effects, particularly in individuals with early-stage hypertension or metabolic disturbances.

4. METABOLIC AND ANTI-OBESITY EFFECTS

As the prevalence of obesity and metabolic syndrome continues to rise globally, researchers are increasingly exploring natural plant-derived compounds that modulate insulin sensitivity and lipid metabolism. Yerba Mate (Ilex paraguariensis) is among the most promising candidates in this category, owing to its diverse array of biologically active molecules, which together exert regulatory effects on both central and peripheral metabolic pathways [5, 8, 21].

4.1 Regulation of Body Weight and Fat Mass

Yerba Mate's influence on energy balance and fat metabolism has been extensively studied in both preclinical and clinical settings. In a study by Kang et al. (2012), C57BL/6J mice fed a high-fat diet and treated with Yerba Mate extract (200 mg/kg) for 8 weeks exhibited significantly less body weight gain, smaller adipocytes and reduced leptin levels compared to mice fed the same high-fat diet without Mate supplementation, indicating both anti-obesity and anti-inflammatory activity [21].

Additionally, Gambero and Ribeiro (2011) reported that in human studies, supplementation with Yerba Mate led to modest but consistent reductions in BMI, waist circumference and fat mass, particularly when combined with mild caloric restriction [5].

These effects are attributed to Yerba Mate's ability to activate AMPK, upregulate β-oxidation genes, suppress lipogenic enzymes such as SREBP-1c and FAS, and modulate adipokine secretion [5, 21]. Together, these mechanisms suggest that Yerba Mate plays a role in reprogramming metabolic pathways, contributing to weight regulation and fat mass reduction.

4.2 Appetite, Satiety, and Gastric Mechanisms

Yerba Mate may also affect body weight indirectly by suppressing appetite and increasing satiety. This effect is believed to occur via several overlapping mechanisms: delayed gastric emptying, modulation of gut hormones like ghrelin and peptide YY, and stimulation of the central nervous system by caffeine and theobromine, which influence dopaminergic and adenosine receptor signaling pathways [1].

Heck and de Mejia (2007) reported that participants who consumed 330 mL of Yerba Mate tea three times a day for 60 days experienced reduction in subjective appetite ratings, which coincided with modest, but consistent decreases in daily calories intake [1]. The bitter nature of mate, attributed to its saponins and polyphenols, may also stimulate gastrointestinal taste receptors, contributing to early satiety signals and reduced meal size. These observations align with traditional uses of Yerba Mate to supress hunger between meals [1].

4.3 Enhancement of Thermogenesis and Energy Expenditure

The thermogenic potential of Yerba Mate is attributed primarily to its caffeine and polyphenol content. Caffeine is known to increase resting energy expenditure (REE) through stimulation of catecholamine release and activation of brown adipose tissue (BAT) thermogenesis. When combined with chlorogenic acids, as found naturally in Yerba Mate, this effect may be synergistically enhanced [1, 12].

Conforti et al. (2014) observed that postmenopausal women who regularly consumed 1–1.5 liters of Yerba Mate daily for more than 5 years had lower fat mass index and higher resting metabolic rate, despite no reported differences in physical activity or caloric intake compared to non-consumers. This suggests a metabolic adaptation involving basal thermogenesis, possibly mediated by increased mitochondrial uncoupling [6].

In a rodent study, Martinet et al. (2011) demonstrated that Yerba Mate extract upregulated UCP1 and PGC-1α expression in brown adipose tissue, confirming its capacity to enhance non-shivering thermogenesis and shift energy balance toward fat oxidation [12].

4.4 Insulin Sensitivity

Several components of Yerba Mate appear to support glucose metabolism, particularly by enhancing insulin sensitivity and reducing postprandial glucose spikes. In a study by de Morais et al. (2009), dyslipidemic patients consuming 1 liter of Yerba Mate infusion daily experienced not only improvements in cholesterol but also an approximate 8% reduction in fasting blood glucose after 40 days [3].

The proposed mechanisms include inhibition of glucose-6-phosphatase in the liver and α-glucosidase in the intestine, which collectively reduce hepatic gluconeogenesis and delay carbohydrate absorption. Heck and de Mejia (2007) reported that chlorogenic acids (CGAs) and caffeoyl derivatives found in Yerba Mate stimulate GLUT4 translocation in muscle tissue, leading to enhanced glucose uptake independent of insulin—a mechanism especially relevant in insulin resistance and prediabetes [1].

Additionally, saponins may contribute by enhancing pancreatic β-cell responsiveness and protecting against glucose-induced oxidative damage, as demonstrated in cellular models and high-fat-fed rodents [5, 8].

5. ERGOGENIC AND EXERCISE PERFORMANCE EFFECTS

In recent years, the integration of natural compounds into sports nutrition has attracted growing attention from both researchers and athletes. Yerba Mate (Ilex paraguariensis) has emerged as a potential ergogenic aid. Unlike isolated caffeine sources, Yerba Mate offers a complex phytochemical profile that may yield more stable energy, reduced fatigue perception, and improved physiological adaptations to training.

5.1 Fatigue Resistance

One of the most immediate and well-documented effects of Yerba Mate is its mild central nervous system stimulation, primarily attributed to its caffeine content, which typically ranges from 65–100 mg per 250 mL infusion, along with smaller amounts of theobromine and theophylline. These methylxanthines act as adenosine receptor antagonists, promoting increased dopaminergic and noradrenergic signaling in the brain. This neurochemical modulation results in enhanced alertness, improved reaction time and delayed onset of fatigue during physical exertion.

In a randomized crossover trial conducted by Areta et al. (2021), 12 trained male cyclists ingested 500 mL of Yerba Mate infusion (prepared with 5 g of dry leaves per 100 mL of water) 40 minutes prior to exercise. They then performed a time-to-exhaustion cycling test, compared against a non-caffeinated placebo condition. The Yerba Mate group demonstrated a 12% increase in time to exhaustion ($p < 0.05$), along with significantly lower ratings of perceived exertion (RPE) and reduced blood lactate concentrations during submaximal effort [4].

These findings suggest that Yerba Mate's phytochemical blend-unlike isolated caffein-may provide more stable cognitive stimulation, enhance central drive and buffer the perception of physical fatigue, making it a promising ergogenic aid in endurance sports.

5.2 Muscle Damage and Post-Exercise Recovery

In addition to enhancing acute performance, Yerba Mate may aid post-exercise recovery by attenuating muscle damage and reducing inflammatory responses. In a preclinical study by Kang et al. (2012), mice subjected to exhaustive treadmill exercise and treated with Yerba Mate extract (200 mg/kg) showed lower markers of oxidative stress, reduced serum creatine kinase (CK) levels and increased glutathione peroxidase (GPx) activity, suggesting enhanced protection against exercise-induced muscle injury [21].

In a randomized crossover study by Panza et al. (2016), twelve healthy male subjects consumed either Yerba Mate tea or water for 11 days, including during a period of resistance training designed to induce muscle damage. Participants who consumed Yerba Mate experienced an 8.6% improvement in strength recovery on the first day after performing resistance exercises that induced muscle damage, and had higher concentrations of circulating antioxidants, including uric acid and total polyphenols [12].

Together, this evidence suggests that regular Yerba Mate consumption may contribute to faster recovery, lower muscle soreness and enhanced antioxidant defense, particularly under oxidative or mechanical stress.

6. BONE HEALTH

While most Yerba Mate (Ilex paraguariensis) research focuses on cardiovascular and metabolic outcomes, recent studies highlight its broader systemic health roles, including support for bone health. Yerba Mate exhibits bioactivities that could mitigate age-related degeneration, support skeletal structure, and provide indirect benefits to organs such as the liver and kidneys.

6.1 Bone Mineral Density and Osteogenic Activity

Bone remodeling is a dynamic process influenced by oxidative stress, inflammation and nutrient availability. In a landmark study by Conforti et al. (2014), 146 postmenopausal women who consumed >1 liter of Yerba Mate daily for at least 5 years demonstrated significantly higher lumbar spine and femoral neck bone mineral density (BMD) compared to matched non-users. After adjusting for calcium intake, age and physical activity, differences of 8–10% in spine BMD and approximately 7% in femoral neck BMD remained statistically significant ($p < 0.05$), suggesting an osteoprotective effect independent of lifestyle variables [6].

Polyphenols such as quercetin, rutin and chlorogenic acids, which are abundant in Yerba Mate, are known to enhance osteoblast differentiation, promote collagen matrix deposition and inhibit osteoclast activity by modulating the RANK/RANKL/OPG signaling pathway [5, 8]. These mechanisms are further supported by in vitro studies, which demonstrate upregulation of alkaline phosphatase (ALP) and RUNX2—both key regulators of bone formation and mineralization [8].

6.2 Mineral Content and Micronutrient Delivery

Yerba Mate is a naturally rich source of bone-relevant minerals. Analytical studies such as Rząsa-Duran et al. (2023) report that 250 mL of traditional mate infusion contains approximately:

- Potassium: 100–200 mg
- Magnesium: 10–20 mg
- Manganese: 0.3–0.6 mg
- Calcium: ~15–25 mg
- Fluoride, zinc and selenium: in trace amounts [2]

These minerals play essential roles in bone matrix formation, collagen synthesis and oxidative balance. While Yerba Mate is not a substitute for dietary calcium, its high potassium and magnesium content may help buffer dietary acid load, thereby reducing urinary calcium excretion-a factor implicated in osteoporosis risk [1].

Additionally, manganese acts as a cofactor for Mn-superoxide dismutase (Mn-SOD) and other enzymes essential in osteogenesis. Even in small quantities, zinc supports bone tissue development by regulating alkaline phosphatase activity and stabilizing collagen fibers, both vital for bone matrix integrity [1, 2].

7. SAFETY CONSIDERATIONS AND POTENTIAL RISKS

Despite its broad range of health-promoting properties, Yerba Mate (Ilex paraguariensis) is not devoid of safety considerations. As with many bioactive plant preparations, potential risks depend on dose, frequency, preparation methods, and individual susceptibility. This section outlines the most relevant concerns associated with Yerba Mate consumption-including issues related to caffeine content, thermal injury, polycyclic aromatic hydrocarbons (PAHs), and drug interactions-while situating them within the context of current scientific evidence.

7.1 Caffeine and Stimulant-Related Effects

Yerba Mate (Ilex paraguariensis) typically delivers between 65–130 mg of caffeine per 250-330 mL serving, depending on the concentration of leaves, infusion time, and brewing temperature [1]. This places it roughly in the same stimulant range as strong black tea and slightly below that of brewed coffee. For most healthy adults, moderate caffeine consumption-up to 400 mg per day-is considered safe. However, sensitivity to caffeine varies widely. Some individuals may experience nervousness, elevated heart rate, restlessness, gastrointestinal discomfort, or difficulty sleeping, even at lower doses [20].

Caffeine metabolism is largely influenced by genetic differences in liver enzymes, particularly CYP1A2. Fast metabolizers tend to tolerate caffeine better, while slow metabolizers may accumulate it in the bloodstream, increasing the chance of side effects [21]. Factors such as age, medication use, hormonal status, and habitual intake also affect how individuals respond to caffeine [20, 21].

In physically active individuals and athletes-many of whom already consume pre-workout supplements or energy drinks-it is important to monitor total stimulant intake, as combining multiple sources of caffeine may amplify side effects and reduce performance benefits. Some research also suggests a blunted ergogenic response when habitual caffeine users consume additional caffeine acutely [21].

Special caution is advised during pregnancy and lactation, where guidelines from the European Food Safety Authority (EFSA) recommend limiting total daily caffeine to less than 200 mg to reduce the risk of low birth weight and other fetal health concerns [10].

It's also worth noting that Yerba Mate contains theobromine, a related methylxanthine also found in cocoa. While theobromine is a weaker stimulant, it has vasodilatory, diuretic, and smooth muscle relaxant properties. Its effects are typically milder and longer-lasting than caffeine, contributing to Yerba Mate's often described "gentler" stimulant profile [1].

7.2 Thermal Injury and Esophageal Cancer Risk

One of the most discussed safety concerns surrounding Yerba Mate (*Ilex paraguariensis*) consumption is its potential association with esophageal squamous cell carcinoma (ESCC), particularly when consumed at very high temperatures. Epidemiological studies conducted in Southern Brazil, Uruguay and Argentina have consistently reported a positive correlation between high-temperature mate intake (>65 °C) and elevated risk of ESCC [17, 19].

For example, a review by Loria et al. (2009) reported that individuals consuming more than 2.5 liters per day of hot aqueous Yerba Mate had a significantly increased risk of developing esophageal cancer, particularly when consumed at high temperatures [11].

Importantly, this association appears to be primarily temperature-dependent, rather than due to the chemical composition of Yerba Mate itself. Similar risk patterns have been observed for other very hot beverages, including black tea and coffee, suggesting that thermal injury to the esophageal epithelium-rather than beverage content-may play a primary role [17, 19].

The hypothesized mechanism involves epithelial inflammation, mucosal damage, and increased absorption of carcinogens, such as polycyclic aromatic hydrocarbons (PAHs)-particularly benzo[a]pyrene-that may be present in smoke-dried mate products [1, 19]. PAHs are recognized environmental carcinogens also found in grilled meats, cigarette smoke and polluted air. According to Heck & de Mejia (2007) and de Morais et al. (2009), PAH content in traditionally smoked Yerba Mate can range from 50 to 300 ng/g, depending on the drying method [1, 3].

Although typical dietary exposures are below toxic thresholds, chronic intake of smoke-dried mate at high temperatures may amplify cancer risk. In response, several producers have introduced air-dried, steam-dried, or infrared-dried Yerba Mate preparations, which contain 70-90% lower PAH levels while preserving bioactive compounds [1, 3].

7.3 Potential Drug Interactions

Due to its diverse phytochemical composition, Yerba Mate (*Ilex paraguariensis*) may interact with certain medications by influencing cytochrome P450 (CYP) enzymes, or through additive effects with stimulants and diuretics. While such interactions are generally mild and infrequent, they may become clinically relevant in sensitive populations, such as older adults or individuals taking multiple medications.

Caffeine, a major xanthine in Yerba Mate, can potentiate the effects of other central nervous system stimulants and bronchodilators such as theophylline and beta-agonists. This may lead to increased risk of nervousness, palpitations, insomnia or gastrointestinal upset, especially in caffeine-sensitive individuals or those consuming additional stimulant-containing products [1, 20, 21].

Additionally, flavonoids and saponins found in Yerba Mate have been shown to modulate the activity of hepatic CYP450 isoenzymes, including CYP1A2, CYP2E1 and CYP3A4 [1, 15]. These enzymes are responsible for metabolizing a wide array of drugs-such as warfarin, antiepileptics, selective serotonin reuptake inhibitors (SSRIs) and statins. Modulation of these pathways could alter plasma drug concentrations, potentially affecting therapeutic efficacy or increasing the risk of adverse effects.

Yerba Mate also exhibits a mild diuretic effect, primarily attributed to caffeine and theobromine, which may exacerbate fluid or electrolyte loss when consumed alongside medications such as loop diuretics, laxatives or angiotensin-converting enzyme (ACE) inhibitors [1, 20].

Although these interactions are not well-documented in large clinical trials, individual case variability underscores the importance of medical awareness. Patients with cardiovascular disease, hypertension, or polypharmacy should inform their healthcare provider of regular Yerba Mate consumption, to allow for appropriate monitoring and dose adjustments where necessary.

7.4 Tolerance, Allergies, and Adverse Reactions

Yerba Mate is generally well tolerated by most individuals when consumed in traditional amounts. Reported adverse reactions are rare and typically mild, including nausea, gastric reflux or mild diuresis [1, 20]. Allergic reactions are uncommon and more likely related to contamination or coexisting allergens rather than the plant itself [1, 2].

Unlike caffeine supplements or synthetic stimulants, Yerba Mate provides a slower-onset and longer-lasting stimulatory effect, often perceived as smoother and less anxiety-inducing. This is likely due to modulating effects of co-occurring compounds such as polyphenols, theobromine, and saponins, which may buffer the more acute effects of caffeine [1, 15, 20].

8. Conclusion

Yerba Mate (*Ilex paraguariensis*) has long been valued in South American cultures for its invigorating and restorative properties [1], and modern scientific research increasingly supports its multifaceted health benefits [1, 3–6]. This review has examined current evidence regarding its phytochemical composition, cardiovascular effects, metabolic regulation, ergogenic potential, and bone-supportive properties, while also addressing safety considerations and potential interactions [3–6, 8, 12].

Rich in xanthines, polyphenols, saponins, and essential minerals, Yerba Mate demonstrates promising antioxidant, anti-inflammatory, and lipid-modulatory effects [1, 5, 8]. Clinical trials and preclinical models suggest benefits for serum lipid profiles [3], weight management [5, 21], muscle recovery [12], and even bone mineral density in postmenopausal women [6]. Its unique composition may also offer advantages over isolated caffeine sources in enhancing physical performance and mental alertness, with fewer stimulant-related side effects [1, 20].

However, as with all functional plant-based products, context matters. The method of preparation (e.g., temperature, drying technique), dosage, and individual sensitivity can significantly influence both the benefits and risks. Of particular note is the association between hot mate consumption and esophageal cancer, likely driven by thermal injury and potential PAH exposure in smoke-dried varieties [11, 17, 19].

While current evidence is compelling, larger, long-term randomized trials in diverse human populations are necessary to further define Yerba Mate's clinical utility, optimal dosing strategies, and safety profile in specific groups-such as those with metabolic syndrome, cardiovascular disease, or multiple medication use [15].

In conclusion, Yerba Mate presents a promising natural supplement for supporting general health and athletic performance, provided it is consumed in moderation and with attention to preparation methods. Its growing global popularity justifies continued scientific exploration and public education, helping integrate this traditional beverage into modern, evidence-based wellness strategies [1].

Author's contributions

Conceptualization, MD and AR; methodology, AR, NP and SK; check, MD and AR; formal analysis; SK, NP, BR and WD; investigation, SK, MK and JL; resources, MD and JL; data curation, MK and WD; writing – rough preparation, MD, AR, SK, NP, BR, MK, WD and JL; writing – review and editing, MD, AR, SK, NP, BR, MK, WD and JL; visualization, MD and SK; supervision, MD, SK and NP; project administration, MK and JL;
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All data relevant to the study are included in the article. The dataset analysed during the current study are available
in the Eurostat Database: https://ec.europa.eu/eurostat/web/health/database, Statistics Poland: https://stat.gov.pl/en/topics/health/ and https://www.gov.pl. Further data are available from https://www.who.int/health-topics.

Conflict of Interest Statement

Authors declare no conflict of interest.

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