COMPOSITION AND BIOACTIVE PROPERTIES OF YERBA MATE
(Ilex paraguariensis A. St.-Hil.): A REVIEW

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Yerba Mate is a popular tea beverage produced and consumed in the South American countries of Argentina, Brazil, Chile, Paraguay, and Uruguay, and is processed from the leaves and stems of Ilex paraguariensis A. St.-Hil., a perennial shrub from the Aquifoliaceae family. Production occurs in six stages: harvesting older leaves and small stems, roasting by direct fire, drying under hot air, milling to specified size, aging to acquire optimal sensory attributes, and final packaging. While grown and consumed for centuries in South America, its popularity is increasing in the United States because of demand by consumers for healthier, more natural foods, its filling a niche for a different type of tea beverage, and for Yerba Mate’s potential health benefits—antimicrobial, antioxidant, antiobesity, anti-diabetic, digestive improvement, stimulant, and cardiovascular properties. Cultivation, production and processing may cause a variation in bioactive compounds biosynthesis and degradation. Recent research has been expanded to its potential use as an antimicrobial, protecting crops and foods against foodborne, human and plant pathogens. Promising results for the use of this botanical in human and animal health has prompted this review. This review focuses on the known chemical composition of Yerba Mate, the effect of cultivation, production and processing may have on composition, along with a specific discussion of those compounds found in Yerba Mate that have antimicrobial properties.

Key words: Antioxidant, antimicrobials, natural products, Yerba mate, tea.

Little research has been conducted on the bioactive and chemical composition of yerba mate (Ilex paraguariensis A. St.-Hil.) in comparison to other plant-based beverages such as green tea or coffee. However, within the last two decades, there has been an increased interest in this botanical for its use in human health. Ilex paraguariensis, a native South American holly shrub from the Aquifoliaceae family, is mainly produced and consumed in the countries of Argentina, Brazil, Chile, Paraguay, and Uruguay (Grigioni et al., 2004). Yerba mate, processed from the leaves and small stems of I. paraguariensis (Figure 1), is a non-alcoholic beverage consumed socially primarily in these countries, and like coffee, primarily for its caffeine content. Typical consumption of yerba mate is taken from a small cup or “mate”. Small amounts of hot water are regularly poured over a serving, ca. 50 g of packed tea. The beverage is then drunk by using a metal straw or “bombilla”, which has small holes that prevent the leaves from being consumed (Kubo et al., 1993; Heck and de Mejia, 2007; Heck et al., 2008).

Figure 1. Yerba mate (Ilex paraguariensis) plant grown in the greenhouse in Knoxville, Tennessee. Approximately 24-mo old and 1.2 m tall.

Argentina was the first significant exporter of yerba mate and is second behind Uruguay for highest per capita consumption (Heck and de Mejia, 2007). In 2004, the total value of mate production in the world was estimated at US$1 billion (Heck and de Mejia, 2007). Yerba mate is commercially produced from plants grown and harvested from plantations and natural forests (Heck et al., 2008). Once harvested, commercial yerba mate undergoes a series of processing steps before the final product is packaged: harvesting, roasting, drying, milling, and aging.
Specific steps vary depending on the geographic region where the tea will be consumed (Heck and de Mejia, 2007; Heck et al., 2008). Several recent studies have examined the phytochemical content of yerba mate under different growth and processing conditions (Schmalko and Alzamora, 2001; Esmelindro et al., 2002; Giulian et al., 2009; Isolabella et al., 2010). Growing and processing conditions both have been shown to have an effect on the chemical composition of the *I. paraguariensis* (Heck et al., 2008), thus influencing the pharmacological properties.

The composition of yerba mate has been partially characterized and it includes a variety of polyphenols, xanthines, caffeoyl derivatives, saponins, and minerals that may be responsible for pharmacological activity (Alikaridis, 1987; Gosmann and Schenkel, 1989; Carini et al., 1998; Clifford and Ramirez-Martinez, 1990; Filip et al., 2001; Bastos et al., 2006; 2007; Bravo et al., 2007; Cardozo et al., 2007; Heck and de Mejia, 2007; Marques and Farah, 2009) (Table 1). Studies have suggested that yerba mate leaves may have antioxidant (Gugliucci and Stahl, 1995; Carini et al., 1998; Filip et al., 2000; Bastos et al., 2006; Anesini et al., 2006; Bastos et al., 2007; Pagliosa et al., 2010), antiobesity (Andersen and Fogh, 2001), antidiabetic (Lunceford and Gugliucci, 2005), diuretic (Gorgen et al., 2005), chemopreventative, antifungal (Filip et al., 2010), and stimulant (Filip et al., 1998; Athayde et al., 2000) properties. It may also aid in digestion (Gorzalczany et al., 2001). Yerba mate has been recognized for a variety of pharmacological activities, but limited research has been conducted on its antimicrobial properties (Kubo et al., 1993; Hongpattarakere, 2000; Sari et al., 2007; Tsai et al., 2008; Burris et al., 2011).

The use of yerba mate as an antimicrobial in foods and for crop protection is a relatively new concept (Racanicci et al., 2009; Burris et al., 2011) and has not been fully studied and reviewed. Crude extracts, i.e. tea, and a variety of isolated compounds derived from yerba mate have been shown to be active against a broad spectrum of Gram-positive and Gram-negative bacteria (Kubo et al., 1993; Hongpattarakere, 2000; Sari et al., 2007; Tsai et al., 2008; Burris et al., 2011).

<table>
<thead>
<tr>
<th>Chemical compound</th>
<th>Dry weight composition ca. %</th>
<th>Known health benefits</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caffeoyl derivatives</td>
<td>10.000</td>
<td>Antioxidant, antimicrobial, anti-diabetic, analgesic</td>
<td>Filip et al., 2000</td>
</tr>
<tr>
<td>Chlorogenic acid</td>
<td>2.800</td>
<td>Antioxidant, antimicrobial</td>
<td>Filip et al., 2001</td>
</tr>
<tr>
<td>Caffeic acid</td>
<td>0.023</td>
<td>Antioxidant</td>
<td>Filip et al., 2000, 2001; Heck and de Mejia, 2007</td>
</tr>
<tr>
<td>3,4-DCQ</td>
<td>0.855</td>
<td>Anticancer, anti-inflammatory</td>
<td>Filip et al., 2001, Arbiser et al., 2005</td>
</tr>
<tr>
<td>3,5-DCQ</td>
<td>3.040</td>
<td>Anticancer, anti-inflammatory</td>
<td>Filip et al., 2001, Arbiser et al., 2005</td>
</tr>
<tr>
<td>4,5-DCQ</td>
<td>2.800</td>
<td>Anticancer, anti-inflammatory</td>
<td>Filip et al., 2001</td>
</tr>
<tr>
<td>Saponins</td>
<td>5 to 10</td>
<td>Anticancer, Anti-inflammation, antiparasitic</td>
<td>Taketa et al., 2004b, Puangpraphant et al., 2011</td>
</tr>
<tr>
<td>Xanthines</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Caffeine</td>
<td>1 to 2%</td>
<td>Anticarcinogenic, antiobesity, antioxidant, diuretic, stimulant, vasodilator</td>
<td>Ito et al. 1997; Heck and de Mejia, 2007</td>
</tr>
<tr>
<td>Theobromine</td>
<td>0.3 to 0.9%</td>
<td>Stimulant, diuretic</td>
<td>Ito et al., 1997; Heck and de Mejia, 2007</td>
</tr>
<tr>
<td>Theophylline</td>
<td>0 to trace</td>
<td>Stimulant, vasodilator</td>
<td>Ito et al., 1997; Heck and de Mejia, 2007</td>
</tr>
<tr>
<td>Rutin</td>
<td>0.060</td>
<td>Antioxidant, lipooxygenase-inhibitor, anticancer, anti-tumor, anti-ulcer</td>
<td>Arbiser et al., 2005; Heck and de Mejia, 2007</td>
</tr>
<tr>
<td>Quercetin</td>
<td>0.0031</td>
<td>Anticancer, anti-inflammation, antimicrobial</td>
<td>Rauha et al., 2000, Arbiser et al., 2005, Puangpraphant and de Mejia, 2009</td>
</tr>
<tr>
<td>Kaempferol</td>
<td>0.0012</td>
<td>Anti-inflammation, antimicrobial</td>
<td>Rauha et al., 2000, Puangpraphant and de Mejia, 2009</td>
</tr>
</tbody>
</table>

DCQ: Dicaffeoylquinic acid.

The objective of this paper was to review the composition of yerba mate, the effect of cultivation, production, and processing has on its composition, and focus on those compounds that have bioactive properties.

**CULTIVATION AND PROCESSING**

Yerba mate can be cultivated and processed in a variety of ways. Typically, yerba mate is grown in two different environments-plantations or natural forests. Plantations are the more popular growth environment because of ease of harvest and a more consistent production quality and quantity (Heck et al., 2008). Yerba mate processing occurs in six steps: harvesting, roasting, drying, milling aging, and blending/packing (Isolabella et al., 2010). The leaves and small stems are harvested mechanically, divided into 100 kg sacks, and transported to a processing facility. Roasting, which inactivates enzymes and preserves sensory qualities, occurs by direct contact with fire at temperatures between 250 and 550 °C for 2 to 4 min (Isolabella et al., 2010). Drying takes place by exposure to hot air until moisture content of 3% is attained. The drying process typically takes 12 to 14 h (Isolabella et al., 2010). There is little information on the effect of culture and processing conditions on bioactive properties of yerba mate. Heck et al. (2008) examined the effects of growing and drying conditions on the phenolic composition of yerba mate, and found that plantation grown yerba mate had higher levels of phenolic acids compared to forest grown-mate (Heck et al., 2008), demonstrating cultivation and processing can have a significant effect on the production and concentration of phytochemicals.

**Primary chemical composition of yerba mate**

**Phenolic compounds.** Structurally, polyphenols are comprised of a benzene ring that is bound with one or more hydroxyl groups. Polyphenols are derived from...
mate plants and are considered its major bioactive compounds. The level of polyphenolics in yerba mate extracts are greater than those of green tea and similar to levels found in red wine (Gugliucci et al., 2009; Gugliucci and Bastos, 2009). The polyphenols in yerba mate include caffeic acid, caffeine, caffeoyl derivatives, caffeoylshikimic acid, chlorogenic acid, feruloylquinic acid, kaempferol, quercitin, quinic acid, rutin, and theobromine (Carini et al., 1998; Chandra and De Mejia Gonzalez, 2004; Atoui et al., 2005; Bastos et al., 2007; Bravo et al., 2007) with caffeoyl derivatives accounting for approximately 10% of the dry weight (Filip et al., 2001) (Table 1). A number of growing and processing factors can affect the amount of polyphenols extracted from yerba mate (Heck et al., 2008; Isolabella et al., 2010). Additionally, the method of consumption can have an influence on extracted polyphenolics (Meinhart et al., 2010). A total infusion preparation with cold water, termed ‘terere’, demonstrated the extraction of almost all phenolics (Meinhart et al., 2010). It was found that green leaves contained significantly lower concentrations of active compounds, caffeoyl derivative, methylxanthines and flavonoids, as compared to those leaves that had undergone processing, drying and aging (Isolabella et al., 2010). Yerba mate extracts are highly rich in chlorogenic acids, and unlike green tea, contain no catechins (Chandra and De Mejia Gonzalez, 2004). According to (Dall’Orto et al., 2005), on average, approximately 92 mg equivalent chlorogenic acid was extracted from each gram of yerba mate leaves. Jaiswal et al. (2010) detected and characterized 42 chlorogenic acids isomers based from yerba mate using LC-MS-eight caffeoylquinic acids, five dicaffeoylquinic acids, six feruloylquinic acids, two diferuloyl quinic acids, five p-coumarylquinic acids, four caffeoyl-p-coumaroylquinic acids, seven caffeoyl-feruloylquinic acids, three caffeoyl-sinapoylquinic acids, one tricaffeoylquinic acid, and one dicafeoyl-feruloylquinic acid.

The polyphenolic content of yerba mate has been shown to be strongly related to its overall antioxidant capacity (Chandra and De Mejia Gonzalez, 2004) similar to green tea. Polyphenols are reducing agents and have been reported to provide body tissues protection from oxidative stress that causes aging, cancer, cardiovascular disease and inflammation (Ames et al., 1993; Scalbert et al., 2005).

**Saponins.** Saponins are glycosidic compounds that are generally water-soluble and foam upon shaking (Bastos et al., 2007). The primary saponins identified from yerba mate are matesaponin 1 through 5 (Gosmann and Schenkel, 1989; Gosmann et al., 1995; Kraemer et al., 1996). Matesaponin 1 was first discovered by Gosmann and Schenkel (1989) with a chemical structure of ursoic acid-3-0-[(β-D-glucopyranosyl-(1→3)-α-L-arabinopyranosyl)-(28→1)-β-D-glucopyranosyl ester. Gosmann et al. (1995) then discovered and structurally determined three more saponins, matesaponin 2 through 4. Yerba mate leaves have a relatively high saponin content, 5 to 10% of the total dry weight. Puangpraphant et al. (2011) quantified and purified saponins from dried mate leaves and obtained 10 to 15 mg g⁻¹ dry weight total saponins, mainly matesaponins 1 and 2 (Puangpraphant et al., 2011). The method of consumption of yerba mate influences the amount of xanthines extraction. Meinhart et al. (2010) determined that the highest quantities of xanthines were extracted from partial infusions with hot water. Saponins have been reported to provide a hypocholesteremic effect by inhibiting the passive diffusion of colic acid through the formation of micelles preventing absorption, anticancer, antiparasitic (Taketa et al., 2004a; 2004b), and anti-inflammatory properties.

**Xanthines.** Xanthines are a class of purine alkaloids found in many different plants. There are three xanthines found in yerba mate, caffeine, theobromine, and theophylline, and give yerba mate its characteristic bitter flavor and stimulant effects (Filip et al., 1998; Athayde et al., 2000; Gorgen et al., 2005). Of these, caffeine is present in the highest concentrations at 1 to 2% of total dry weight, followed by theobromine at 0.3 to 0.9% of total dry weight (Ito et al., 1997) (Table 1). The consumption of caffeine found in a cup of yerba mate (78 mg) is similar to that of a cup of coffee (85 mg); however, the typical method of yerba mate consumption involving repeatedly pouring additional hot water over in the ‘mate’ can yield intakes greater than 260 mg of caffeine per serving, attributed to percent stem or woody content and extraction rate. Processing by three-stage drying was shown to significantly decrease caffeine content by 30% (Schmalko and Alzamora, 2001). However, Bastos et al. (2006) found that dried leaves had significantly higher amounts of caffeine than fresh leaves.

**BIOACTIVE PROPERTIES AND HEALTH IMPLICATIONS**

**Antimicrobial and oral health**

Relatively limited research has been conducted on isolation and identification of compounds possessing antimicrobial activity derived from yerba mate (Kubo et al., 1993; Hongpattarakere, 2000; Sari et al., 2007; Tsai et al., 2008; Filip et al., 2010). Filip et al. (2010) identified caffeoyl derivatives, methylxanthines, and rutin from yerba mate aqueous extracts with antifungal activity. N-hexane extracts of yerba mate have been shown to be effective antimicrobial agents against the oral bacteriaum, Streptococcus mutans (Kubo et al., 1993). The 10 main compounds identified as potential antimicrobial components were limonol, α-ionone, β-ionone, α-terpineol, octanoic acid, geraniol, l-octanol, nerolidol, geranylactetone, and eugenol (Kubo et al., 1993). These
compounds have been shown to be active against a broad spectrum of Gram-positive and Gram-negative bacteria, with effective levels between 12.5 and 1600 μg mL−1 (Tanguchi et al., 1978; Kubo et al., 1991; 1993; Sari et al., 2007). The Gram-positive bacteria, Bacillus subtilis, Brevibacterium ammoniagenes, Propionibacterium acnes, Staphylococcus aureus, and Streptococcus mutans, and five fungi, Saccharomyces cerevisiae, Candida utilis, Pityrosporum ovale, Penicillium chrysogenum, and Trichophyton mentagrophytes, were inhibited by at least one of the ten identified compounds tested (Kubo et al., 1993). None of the extracts tested were effective against the Gram-negative bacteria, Pseudomonas aeruginosa or Enterobacter aerogenes and were found to be only weakly active against Escherichia coli (Kubo et al., 1993). Burris et al. (2011) determined that aqueous extracts from yerba mate demonstrated antimicrobial activity against S. aureus and E. coli O157:H7, indicating inhibition and inactivation of both Gram-positive and Gram-negative bacteria. This finding suggests that an additional compound is present in the aqueous extract that provides activity in addition to the 10 identified by Kubo et al. (1993).

While many of the major compounds found in yerba mate extracts are known (Kubo et al., 1993; Hongpattarakere, 2000; Heck and de Mejia, 2007), contradictory information is available on which compounds might contribute to antimicrobial activity and whether they may have additive or synergistic effects in combination. Polyphenols identified in yerba mate include caffeic acid, caffeine, caffeoyl derivatives, caffeoylshikimic acid, chlorogenic acid, feruloylquinic acid, kaempferol, quercetin, quinic acid, rutin, and theobromine (Heck and de Mejia, 2007; Marques and Farah, 2009) all of which contribute to the antimicrobial activity against foodborne pathogens. Caffeic and chlorogenic acids in their pure form have demonstrated activity against Gram-negative bacteria (Herald and Davidson, 1983; Puupponen-Pimia et al., 2001). However, Kubo et al. (1993) found that the three main compounds found in yerba mate, caffeine, ursoic acid and chlorogenic acid, did not demonstrate antimicrobial activity against Gram-negative bacteria, including E. coli and S. aureus. Further, Rauha et al. (2000) found caffeic acid did not demonstrate inhibitory activity against the Gram-positive bacteria, S. aureus, S. epidermidis, or Bacillus subtilis. However, Herald and Davidson (1983) demonstrated a reduction in viable S. aureus at pH 5.0 by p-coumeric acid. No inhibition against Streptococcus mutans has been observed with caffeine (Daglia et al., 2002), indicating caffeine was not contributing to activity observed by Kubo et al. (1993). Several of the flavonoids found in yerba mate have also been examined for their antimicrobial activity—kaempferol, quercetin, and rutin (Panizzi et al., 2002; Rauha et al., 2000). Kaempferol did not inhibit S. epidermidis (Rauha et al., 2000) or E. coli (Puupponen-Pimia et al., 2001); however, it demonstrated antimicrobial activity against S. aureus (Rauha et al., 2000). Similarly, quercetin exhibited strong inhibition against S. aureus, but unlike kaempferol, provided strong to moderate activity against S. epidermidis and B. subtilis respectively (Rauha et al., 2000). Results from Panizzi et al. (2002) were contradictory to these, where neither kaempferol nor quercetin demonstrated antimicrobial activity against S. aureus or E. coli. Rutin did not demonstrate any activity against S. aureus, S. epidermidis or B. subtilis (Rauha et al., 2000).

Caffeoylquinic acid derivatives have been shown to contribute to antimicrobial activity in other crude plant extracts (Chakraborty and Mitra, 2008) and have been found in yerba mate extract (Filip et al., 2000; 2010). It is likely a combination of compounds found in yerba mate extracts is contributing to the antimicrobial activity against Gram-negative and Gram-positive bacteria as evidenced by the ineffectiveness of activity of some individual compounds.

Antioxidant, anti-obesity, anti-inflammation
The pharmacological properties—antioxidant, anti-obesity and anti-inflammation—of yerba mate extracts and compounds have been previously reviewed (Bastos et al., 2007; Heck and de Mejia, 2007; Bracesco et al., 2010). Oxygen radicals are involved in many human diseases including cancer, inflammation, liver and cardiovascular disease (Ames et al., 1993; Halliwell, 1994). Yerba mate extracts have been previously shown to provide antioxidant activity and inhibition of low-density-lipoproteins oxidation (Gugliucci and Stahl, 1995; Filip et al., 2000; Chandra and De Mejia Gonzalez, 2004) in vitro (Gugliucci and Stahl, 1995; Filip et al., 2000) and in vivo (Gugliucci, 1996; Schinella et al., 2000; Lanzetti et al., 2008). Similarly, Martins et al. (2009) determined that mice fed yerba mate had lower thiobarbituric acid reactive substances in the liver, suggesting that treatment with yerba mate extract protected unsaturated fatty acids from oxidation and may especially protect the liver (Martins et al., 2009).

According to Andersen and Fogh (2001), in overweight patients, yerba mate extract significantly delayed gastric emptying, decreased the perceived time to fullness and ultimately induced a significant weight loss after 45 d. Arcari et al. (2009) demonstrated that treatment with yerba mate extract has potent anti-obesity effects in adipose tissue in vivo by controlling the expression of several genes related to obesity processes, such as inflammatory markers.

Inflammation is a factor in many human diseases: cancer, cardiovascular disease, obesity, and diabetes.

Lanzetti et al. (2008) determined that yerba mate reduced acute lung inflammation in mice exposed to cigarette smoke. Recently, Puangphracht and De Mejia (2009) investigated the potential anti-inflammatory effect of yerba mate extracts as well as some of its compound
and their interactions. Quercetin was determined the most potent inhibitor of pro-inflammatory responses at a concentration 10 times lower than that of other tested compounds (Puangpraphant and de Mejia, 2009).

CONCLUSIONS

Plants have been used as a source of bioactive compounds for thousands years. However, within the last decade, the want and need for more natural, bioactive compounds has grown. Research on extracts and isolated compounds from yerba mate to benefit human health has provided a number of pharmacological applications: antioxidant, antimicrobial, anti-inflammatory, antiobesity, and anticancer. With the potential use of yerba mate extracts as antimicrobials in foods, sensory qualities must be addressed. One common negative factor associated with the use of plant extracts as antimicrobial food preservatives is their effect on food sensory (flavor, odor) properties. The flavor of yerba mate infusions has been described in various terms, such as bitter, acid, astringent, hay, green, humid, toasted, and paper. However, use of yerba mate (dried and aqueous extracts) had no effect on the taste or smell of precooked chicken meat balls.

While the need for more research on the isolation and identification of bioactive compounds exists, evidence seems to demonstrate that yerba mate is a botanical with a variety of compounds that can be applied for use in human health. Research confirms the influence cultivation and processing have on the chemical composition of yerba mate and demonstrates their importance in the production of bioactive compounds. Further research can be explored to optimize growth and processing technologies to enhance bioactive compounds for use in foods, crops, cosmetics, nutraceuticals, and supplements to support human health.

Composición y propiedades bioactivas de la yerba mate (Ilex paraguariensis A. St.-Hil.): una revisión. Yerba mate es una infusión popular producida y consumida en Argentina, Brasil, Chile, Paraguay y Uruguay. Se procesa a partir de hojas y tallos de Ilex paraguariensis A. St.-Hil., un arbusto perenne de la familia Aquifoliaceae. El procesamiento ocurre en seis etapas: recolección de hojas maduras y tallos pequeños, tostado por fuego directo, secado por aire caliente, molienda, envejecimiento (dependiendo de los atributos sensoriales requeridos), y embalaje final. Si bien la yerba mate se ha cultivado y consumido por siglos en América del Sur, su popularidad en los Estados Unidos ha aumentado debido a la demanda por bebidas saludables y alimentos más naturales y por los potenciales beneficios para la salud de la yerba mate (antioxidante, antimicrobiano, acción contra la obesidad y diabetes, digestivo, estimulante). La yerba mate también se ha investigado como agente de prevención y causa de algunos tipos de cáncer, causando controversia entre investigadores. Investigaciones recientes han ampliado el espectro de uso de la yerba mate como agente antimicrobiano, protección de cultivos y acción contra patógenos transmitidos por alimentos. Resultados prometedores para el uso de esta planta en la salud humana y animal han llevado a esta revisión. Esta revisión se centró en la composición de la yerba mate, y el efecto que el cultivo y el procesamiento puede tener sobre sus propiedades.

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