CHAPTER 14

Innovative technology for high-quality functional alcoholic beverages based on tea-aromatic raw materials with antioxidant activity

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Abstract

The feasibility of using water-alcohol infusions of tea-herbal raw materials (*Ilex paraguariensis*, *Camellia sinensis*, *Citrus spp.*) for the production of alcoholic beverages has been substantiated. These components are characterized by high bioactivity, the stability of polyphenolic compounds in alcoholic media, appealing aroma, and favorable sensory properties, making them an effective basis for innovative functional beverages.

The antioxidant activity of the obtained infusions was determined. The highest reducing capacity (RE_{plant}) was observed in citrus peel infusions (up to 204.00 mV for orange peel), green tea (56.06 mV), and yerba mate (59.02 mV). This indicates the presence of a significant amount of bioactive compounds that retain antioxidant potential even in ethanol-containing systems.

The potential for modifying infusions based on tea-aromatic compositions within alcoholic beverage technology has been explored. It was established that the optimal mass ratio of components ω = 20/75/5% (mate/tea/citrus peel) provides a balanced flavor, reduces the bitterness of mate, enhances the aroma with fresh fruity notes, and increases the overall sensory evaluation score (up to 9.82 points – for mate/green tea/orange peel).

Sensory evaluation of the infusions confirmed their suitability for commercial development. All infusions received high sensory scores ranging from 9.63 to 9.82

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on a 10-point scale, indicating strong consumer appeal and potential for implementation in the restaurant industry for the creation of new-generation functional alcoholic beverages.

Optimized formulations for functional alcoholic beverages enriched with antioxidant tea-herbal infusions have been developed. The formulation includes:

– 38.49% of the infusion (mate/tea/citrus peel in a 20/75/5% ratio);
– 7.54% brandy;
– 53.08% sugar syrup;
– vanillin;
– citric acid;
– caramel coloring;
– ethanol/water to adjust the alcohol content to 20% vol.

This ensures a functional and sensory balance while maintaining market viability.

The integration of antioxidant-rich infusions based on *Ilex paraguariensis*, *Camellia sinensis*, and *Citrus spp.* into alcoholic beverage technology offers new opportunities for the restaurant industry to expand product offerings, enhance functional value, and cater to the growing demand for health-oriented and innovative beverages.

Keywords

Redox potential, blending, functional alcoholic beverage, water-alcohol infusions, antioxidant, tea-aromatic raw materials, *Ilex paraguariensis*, *Camellia sinensis*, *Citrus spp.*

14.1 Introduction

In recent years, there has been growing interest in the development of functional alcoholic beverages that combine sensory appeal with health-enhancing properties. Among such innovations, tea- and plant-based infusions enriched with bioactive compounds are gaining attention due to their potential antioxidant, adaptogenic, and tonic effects. Yerba mate (*Ilex paraguariensis*), various types of tea (*Camellia sinensis*), and citrus peels (*Citrus spp.*) have been widely recognized for their high content of polyphenols, flavonoids, and essential oils, which contribute both to health benefits and to the complexity of flavor and aroma.

Water-alcohol infusions made from these plant materials offer a promising basis for the creation of innovative liqueurs and spirits. However, the success of such products depends not only on their functional properties but also on their sensory characteristics, which are critical for consumer acceptance. Balancing the bitter, astringent, and aromatic components of ingredients like mate and tea requires careful formulation and optimization.

14.2 Tea-aromatic compositions

14.2.1 Varieties and geographical distribution of *Ilex paraguariensis*

Ilex paraguariensis, a plant of significant ethnobotanical and economic value, exists in two recognized morphological varieties: *Ilex paraguariensis Saint Hilaire var. paraguariensis*, which is widely used in industrial processing, and *Ilex paraguariensis var. vestita (Reisseck) Loes*, which, despite its taxonomic classification, has not found application in commercial use [1].

This evergreen species is indigenous to the subtropical regions of South America, predominantly found in Argentina, Uruguay, Paraguay, and Brazil [1, 2]. Its natural habitat spans the Upper Paraná Atlantic Forest biome, where it thrives under specific ecological conditions conducive to the development of its bioactive compounds.

The leaves and stems of *Ilex paraguariensis St. Hil.* are a rich natural source of caffeine and serve as a traditional stimulant beverage, often replacing or complementing tea (*Camellia sinensis*) and coffee (*Coffea spp.*) in the dietary practices of millions [1]. Various infusion methods of this plant have developed across the region, reflecting both cultural and functional preferences [1]:

– *chimarrão* (Brazil) or *mate* (Spanish-speaking countries) – a hot water infusion prepared from dried green leaves and young branches;

– *tererê* (Brazil) or *tereré* (Paraguay) – a cold infusion of the same plant material, particularly popular in warm climates;

– *chá-mate* or *mate tea* – an infusion of roasted leaves, commonly consumed hot in Brazil;

– *instant mate tea* – a soluble variant derived from processed roasted leaves for convenience consumption.

These forms underscore the versatility of Ilex paraguariensis as both a traditional and industrial ingredient in the production of functional beverages, contributing to its growing significance in global nutraceutical markets.

14.2.2 Bioactive constituents of Ilex paraguariensis

Ilex paraguariensis St. Hil. are an important source of biologically active compounds (**Fig. 14.1**) [2, 3]:

– phenolics [3–6] → simple phenols → phenolic acids [7] → hydroxycinnamic acids: caffeic acid [6, 8]; ρ-coumaric acid [8]; ferulic acid;

– phenolics [2, 9–11] → simple phenols → phenolic acids [12] → hydroxybenzoic acids: gallic acid [6, 8]; syringic acid;

– phenolics → polyphenols [11, 13] → flavonoids [1, 3] → flavonols [4] (rutin, quercetin, kaempferol) [3];

– phenolics → polyphenols → flavonoids → flavonols: catechins;

– phenolics → polyphenols → non-flavonoids → tannins [1, 2], which have an effect on health: inhibition of lipid-peroxidation, mutagenicity of carcinogens and tumor promotion, as well as host-mediated antitumor activity and antiviral activity;

– chlorogenic acids [1–5, 8] – a related polyphenol family of esters, including hydroxycinnamic acids (caffeic, ferulic, *p*-coumaric) with quinic acid. Chlorogenic acid derivatives [5, 6, 8, 11]:

a) caffeoylquinic acids (3-O-caffeoylquinic acid, 4-O-caffeoylquinic acid, 5-O-caffeoylquinic acid);

b) dicaffeoylquinic acids (3,4-dicafeoylquinic acid; 3.5-dicafeoylquinic acid; 4.5-dicafeoylquinic acid);

c) feruloyquinic acid;

d) *p*-coumaroylquinic acids.

Chlorogenic acids is a multiple health functions [14]: such as antiviral, anti-inflammation, hypoglycemic, hepatoprotective activities, antioxidation;

– purine alkaloids – methylxanthines [1–3, 5, 8]: caffeine; theobromine; theophylline;

– saponins [1–4], which affect the flavor of *mate* extract, provide hypocholesterolemic properties [2] – bind bile salts [15]; sapogenins [15];

– chlorophyll [2, 16] have properties to benefit the human body, such as antioxidant activity, antimutagenic activity, modulation of xenobiotic metabolizing enzymes, and induction of apoptotic events in cancer cell lines [16];

– organic acids, amino acids [3], fatty acids;

– mineral substances [3];

– vitamins [1, 3, 4]: A, B, C, E [1];

– free sugars, polysaccharides [17];

– volatile compounds (linalool, 3-allylguaiacol, O ± -ionone, OI-ionone, O ± -terpineol, octanoic acid, geraniol, 1-octanol, nerolidol, geranylacetone, eugenol, 2.6-dimethyl-1.7-octadien-3-ol, methyl salicylate) [18].

Mate infusion has a characteristic bitter taste that resembles strong green tea, a specific aroma [19] and a light green color.

Along with the traditional use of *mate* drinks, *Ilex paraguariensis* is used as an energy tea with other herbs, a weight loss agent, in the production of beer, creams, candy, and other non-traditional uses [1].

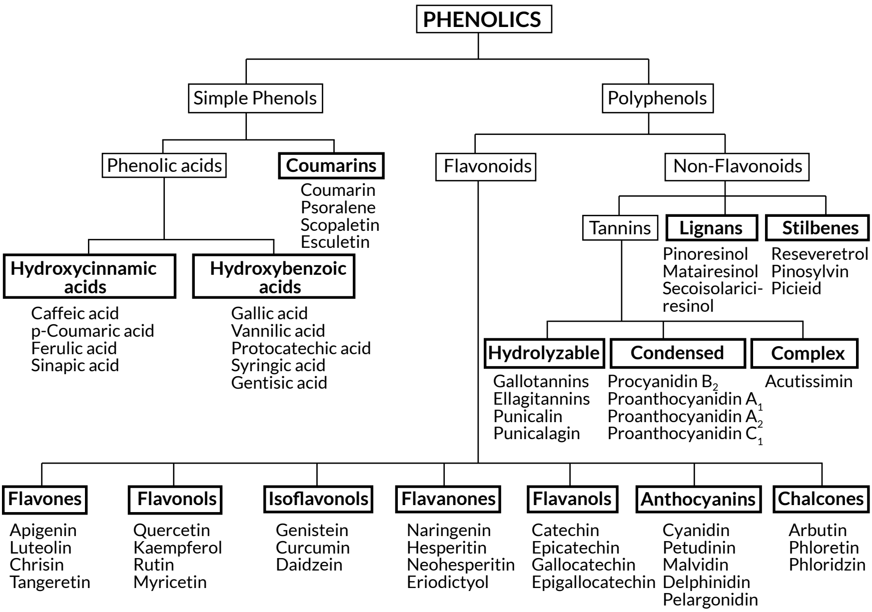


Fig. 14.1 Classification of phenolic compounds
Source: [9]

14.2.3 Properties of *Ilex paraguariensis*

Ilex paraguariensis St. Hil has many benefits for human health [3, 6, 19, 20], is used as a therapeutic agent [1], due to its supposed pharmacological, medicinal properties [1]:

– stimulating properties [1, 2, 15], due to the caffeine content in *mate* [2];
– anti-anxiety properties [20];
– immunomodulatory profile;
– vaso-dilating properties [1];
– cardioprotective properties [11];
– anti-inflammatory [3]; antibacterial; antimicrobial properties [6];
– antigenotoxic properties [21], showing antimutagenic effects [1] and subsequent DNA repair [20, 21];
– anti-cancer [3] and antitumor properties due to saponins in *mate* [22];
– anti-rheumatic properties [23];
– neuroprotective effects [20, 24];

– gastroprotection [17];
– detoxifying properties [15];
– diuretic properties [3];
– hypolipidemic – lipid-lowering properties [1]; hypocholesterolemic properties [3] – lowering cholesterol, thanks to saponins in *mate*, with an antiatherosclerotic effect;
– hepatoprotective [3];
– anti-glycation effects [1, 13], due to chlorogenic and caffeic acid in *mate*;
– antidiabetic properties [13];
– anti-obesity properties [3], for weight loss [1], due to the ability of caffeine in *mate* to increase thermogenesis;
– antioxidant properties [1–3, 7, 8, 10, 13, 21, 25, 26].

14.2.4 Antioxidant properties of *Ilex paraguariensis*

In biological systems, antioxidant defense systems are made up of agents that prevent the harmful effects of free radicals. Antioxidants are the agents, which scavenge free radicals [14] otherwise reactive oxygen species and prevent the damage caused by them, interfering with the oxidative/antioxidative potential of cells, by improving antioxidant status [27]. Free radicals have been associated with pathogenesis of various disorders like cancer, diabetes, cardiovascular diseases, autoimmune diseases, neurodegenerative disorders and are implicated in aging, chronic diseases [27]; cell and tissue damage induced by oxidative stress is related to the etiology of chronic diseases [8].

Antioxidants are beneficial and could display a useful role in human homeostasis, however, they could be pro-oxidants as well [12]. Homeostasis – relativity of dynamic constancy of composition and properties of internal environment and stability of basic physiological functions of an organism. Redox reactions affect the ratio of energy to support homeostasis.

Antioxidant activity of *Ilex paraguariensis St. Hil.* is related to the presence of several compounds:

– phenolics [27] → simple phenols → phenolic acids [12] → hydroxycinnamic acids: caffeic acid;
– phenolics → simple phenols → phenolic acids [12] → hydroxybenzoic acids: gallic acid [10];
– phenolics [10] → polyphenols → flavonoids [10] → flavonols: catechins [10], epicatechin [10];
– phenolics → polyphenols → flavonoids → flavonols: rutin;

– phenolics → polyphenols → non-flavonoids → tannins → condensed: procyanidin B2 [10];

– chlorogenic acids [14]: particularly caffeoyl derivatives;

– quercetrin [10];

– purine alkaloids – methylxanthines: caffeine [10]. On the contrary, caffeine induced lipid peroxidation of linoleic acid acting as a pro-oxidant compound.

Endogenous antioxidant mechanisms include antioxidant enzymes activities, such as glutathione peroxidase (GPx), superoxide dismutase (SOD), and catalase (CAT), and the reduced form of glutathione, among others [8]. However, endogenous antioxidant defenses are not always sufficient to completely counteract oxygen reactive species [8].

14.2.5 Characteristics of *Camellia sinensis*

Tea (*Camellia sinensis*) has gained much attention due to its health-promoting benefits, including antimutagenic, anticancer and antiapoptotic [28, 29], neuroprotective [30], hypoglycemic and antihyperglycemic, antioxidant [28, 29], antimicrobial, and inflammatory effects [31]. These biological activities [10] are associated in part to the antioxidant activity of chemical compounds present in teas, especially flavonoids and phenolic acids [10]. Classification of tea by oxidation (fermentation) level: fermented (black tea); partially fermented (red, yellow tea); unfermented (green, white tea).

14.2.6 Comparative characteristics of *Ilex paraguariensis* and *Camellia sinensis*

The content of the total phenolic compounds of the teas ranged from 672.87 mg GAE/L (*Ilex paraguariensis*) to 1034.48 mg GAE/L (*Camellia sinensis*) and the flavonoid content ranged from 176.04 mg CTE/L (*Ilex paraguariensis*) to 179.88 mg CTE/L (*Camellia sinensis*) (**Table 14.1**) [10]. This is confirmed by the data [13], the level of polyphenol in the extract of *Ilex paraguariensis* is higher than in green tea, this confirms the ability to inhibit the formation of glycation end products of *Ilex paraguariensis* compared to green tea [13] and prevents lipid peroxidation [21]. Green tea and *mate* tea present anti-carcinogenic activity [21].

The results showed that the inhibition of DPPH ranged from 49.66% (*Ilex paraguariensis*) to 68.60% (*Camellia sinensis*) of reduction, and the FRAP results varied from 5065.75 μmol TE/L (*Ilex paraguariensis*) to 10331.19 μmol TE/L (*Camellia sinensis*).

Table 14.1 Total phenolics, flavonoids, antioxidant capacity and chemical composition of teas

Name of indicators	Herbal species	
	Camellia sinensis	Ilex paraguariensis
Phenolic compounds		
– total phenolics (mg GAE/l)	1034.48 ± 416.24	672.87 ± 126.25
– flavonoids (mg CTE/l)	179.88 ± 32.41	176.04 ± 40.50
Antioxidant activity		
– DPPH (% reduction)	68.60 ± 22.40	49.66 ± 9.59
– FRAP (μM TE/l)	10331.19 ± 4802.91	5065.75 ± 298.61
Chemical composition (mg/l)		
– gallic acid	198.73 ± 78.02	n.d.
– epicatechin	68.55 ± 105.39	n.d.
– procyanidin b2	3.67 ± 8.77	n.d.
– quercitrin	21.13 ± 15.76	n.d.
– chlorogenic acid	5.22 ± 6.33	199.42 ± 149.38
– catechin	31.76 ± 58.49	6.67 ± 13.33
– caffeine	5485.23 ± 1637.22	1244.63 ± 711.13
– coumaric acid	n.d.	n.d.
– procyanidin b1	n.d.	n.d.
– quercetin	n.d.	n.d.

Note: results expressed as mean ± SD (n = 3); n.d. = not detected or values below LOD
Source: [10]

The contents of individual phenolic compounds varied within tea. Gallic acid (198.73 mg/L), epicatechin (68.55 mg/L), procyanidin B2 (3.67 mg/L) and quercitrin (21.13 mg/L) were found only in *Camellia sinensis* teas, and the contents of chlorogenic acid ranged from 5.22 mg/L (*Camellia sinensis*) to 199.42 mg/L (*Ilex paraguariensis*), catechin from 6.67 mg/L (*Ilex paraguariensis*) to 31.76 mg/L (*Camellia sinensis*), and caffeine from 1244.63 mg/L (*Ilex paraguariensis*) to 5485.23 mg/L (*Camellia sinensis*) [10].

Coumaric acid, procyanidin B1 and quercetin were not detected in *Camellia sinensis* and *Ilex paraguariensis* tea samples [10].

Thus, it is important to monitor the phenolic composition and the biological activity of teas consumed by a large part of the population in order to correlate their benefits with human health [10].

14.2.7 The ethanol extract of *Ilex paraguariensis*

The ethanol extract *Ilex paraguariensis St. Hil.* presents antimicrobial activity against food pathogens was effective in inhibiting *S. aureus*, *L. monocytogenes* and *S. Enteritidis*, to be related to the presence of compounds derived from chlorogenic acid [6]. The ethanol extract was active at pH 7 and at pH 8 [6]. *Ilex paraguariensis St. Hil.* is thus a potential source for the extraction of antimicrobial compounds for use by the food industry as a natural preservative in foods and beverages [6]. For antioxidant action of *Ilex paraguariensis St. Hil.* use of ethanol as extractor liquid should be considered for the extract procedure in order to obtain greater amounts of antioxidant compounds may be obtained.

14.2.8 Antioxidant properties and chemical composition of citrus peels (*Citrus spp.*)

Recent studies on *Citrus spp.* peel extracts have demonstrated significant antioxidant activity, with detailed characterization of bioactive compounds across three different varieties [32]. The findings highlight variations in phenolic content and radical scavenging potential, reinforcing the potential use of these peels as natural antioxidants in food and pharmaceutical applications.

14.2.9 Relevance of the research direction

Water-alcohol infusions are produced by extracting dried plant materials using a water-alcohol mixture – a technique widely employed in alcoholic beverage production within the restaurant industry. This process not only enhances the sensory characteristics of the beverage but also enriches it with bioactive compounds, significantly increasing its antioxidant capacity.

The relevance of this research lies in the development of innovative water-alcohol infusions based on tea-aromatic compositions containing *Ilex paraguariensis* (yerba mate), *Camellia sinensis* (tea), and citrus species (*Citrus* spp.), known for their rich phytochemical profiles and functional properties. These compositions demonstrate pronounced antioxidant activity, contributing to the protection of the human body from oxidative stress-induced damage, while also improving the nutritional value and overall quality of alcoholic beverages.

The aim of this research is to determine the antioxidant capacity of water-alcohol infusions prepared from tea-aromatic compositions based on *Ilex paraguariensis*, *Camellia sinensis*, and *Citrus* spp., and to evaluate their potential for developing innovative, high-quality functional alcoholic beverages within the restaurant industry.

To achieve this aim, the following objectives are set:

– to justify the feasibility of using water-alcohol infusions of tea-aromatic compositions containing *Ilex paraguariensis*, *Camellia sinensis*, and *Citrus* spp. in alcoholic beverage production;

– to determine the antioxidant capacity of the prepared infusions;

– to explore various modifications of infusions based on these plants within beverage technologies;

– to conduct sensory evaluation of the infusions and assess their suitability for commercial development of innovative beverages;

– to develop optimized formulations for functional alcoholic beverages enriched with antioxidant-rich tea-aromatic infusions.

The integration of antioxidant-rich infusions based on *Ilex paraguariensis*, *Camellia sinensis*, and citrus peels (*Citrus* spp.) into alcoholic beverage technology opens promising avenues for restaurants to diversify their product offerings, enhance the functional value of drinks, establish a differentiated market presence, and support the development of a favorable brand image.

14.3 Materials and methods

14.3.1 Materials

The study used samples of plant raw materials: *Ilex paraguariensis*; *Camellia sinensis* tea in three types – green, red, and black; as well as *Citrus spp.* (citrus peels) – lemon, orange, and mandarin. A 40% vol. water-alcohol mixture was used as the control sample.

14.3.2 Methods of obtaining water-alcohol infusions

Drying of plant raw materials was carried out until constant moisture content was achieved, ranging between 6–8%. Collected and inspected raw materials were spread out on clean white paper, each type separately. The plant materials were then cut with scissors into pieces approximately 3 × 3 mm in size. Samples weighing 4 g were placed into dark glass bottles and poured over with 100 ml of a 40% vol. water-alcohol mixture. The bottles were sealed and placed in a Durocell dry air thermostat at 40°C for 48 hours. The resulting infusions were cooled to room temperature, then filtered.

Subsequent analyses included measurement of active acidity (pH) using a pH meter equipped with a combined glass electrode. Redox potential (*RP*) was measured using a combined platinum redox electrode in potential measurement mode [26, 33–36].

14.3.3 Methods for determining active acidity and redox potential

The active acidity (*pH*) of the obtained water-alcohol herbal infusions was measured using a precision pH meter "pH-150 MA" equipped with a combined glass electrode "ESC 10601/4", providing high sensitivity and stability in aqueous-alcoholic environments. Redox potential (*RP*) was determined using the same instrument "pH-150M" in the potentiometric mode with a redox platinum electrode "ERP-105", ensuring reliable measurements of oxidation-reduction balance.

To assess the antioxidant properties of the herbal extracts, the *RP* method was applied according to protocols described by [26, 33–36]. This method is based on the evaluation of *RP* differences in water-alcohol media as an indicator of the redox state and antioxidant potential of the tested samples.

The advantages of this approach lie in its transparency, methodological simplicity, analytical specificity, reproducibility of results, and suitability for routine analysis. In addition, the method is applicable for assessing total antioxidant activity in complex multicomponent systems, including synergistic and multifunctional antioxidants commonly found in tea-aromatic compositions and citrus peel extracts. Its sensitivity to changes in oxidation-reduction balance enables the detection of even moderate antioxidant effects in experimental formulations, making it highly effective for research in functional beverage development.

14.3.4 Research of redox potential from hydrogen ion activity in water-alcohol infusions of vegetable raw materials

To evaluate the antioxidant potential of plant-based water-alcohol infusions, the relationship between the hydrogen ion activity (pH) and redox potential (*Eh*) of the medium is critically important. In a water-alcohol system, this relationship reflects the medium's tendency to accept or donate electrons, thus serving as a fundamental parameter for assessing antioxidant capacity.

According to experimental findings [34, 35], a shift of one *pH* unit in the water-alcohol mixture corresponds to an approximate change in redox potential of 42 mV, expressed by the following empirical equation

$$Eh_{\min} = 502 - 42\,\text{pH, mV.} \tag{14.1}$$

Within the pH range of 2.0 to 11.0, which corresponds to typical values observed in hydroalcoholic infusions, the calculated redox potential of the base solvent system ($Eh_{\min}$) ranges from 418 mV to 40 [34, 35]. This model provides a theoretical baseline for comparing the redox behavior of functional infusions.

The actual redox potential (Eh_{act}) of the obtained infusions was measured using a platinum redox electrode, and the difference between the theoretical and measured potentials was used to characterize the contribution of the plant material to the oxidative-reductive properties of the system. This difference, denoted as RE_{inf}, is calculated as [34, 35]

$$RE_{inf} = Eh_{\min} - Eh_{act},\ \text{mV.} \tag{14.2}$$

Furthermore, the net antioxidant capacity of the plant material (RE_{plant}), independent of the solvent background, was calculated as the difference between RE_{inf} and the redox effect of the control sample (RE_{sol}), according to [34, 35]

$$RE_{plant}=RE_{inf} - RE_{sol},\ \text{mV.} \tag{14.3}$$

This enhanced methodology enables the differentiation of antioxidant activity contributed specifically by the plant raw materials (*Ilex paraguariensis*, *Camellia sinensis* of various fermentation levels, and *Citrus spp.* peels). It is particularly effective in identifying multifunctional antioxidants in complex matrices and provides a reproducible, sensitive, and technically accessible framework for the development of functional beverages in the alcohol industry [34, 35].

14.3.5 Expert method of sensory evaluation

The sensory evaluation of the developed water-alcohol infusions was carried out using an expert method, which involves the participation of qualified and experienced specialists with heightened sensitivity to organoleptic characteristics of alcoholic beverages. This method is widely recognized for its reliability and reproducibility in assessing quality indicators such as clarity and color, aroma, taste, and overall score on a 10-point scale (**Table 14.2**).

The experts independently assessed the samples using standardized evaluation protocols, taking into account both quantitative and qualitative sensory attributes.

Table 14.2 Overall score assessment of quality for liqueur and vodka drinks based on a 10-point scale

Parameter	Description (organoleptic characteristic)	Score range	Score
Clarity and Color	Clear liquid with gloss and bright color typical for product type; cloudy/emulsion products have uniform consistency and color	1.9–2.0	Excellent
	Clear liquid without gloss, color typical but insufficiently expressed; cloudy/emulsion products uniform but less vivid color	1.8–1.9	Good
	Clear liquid without gloss, insufficient color; cloudy/emulsion products non-uniform consistency and weak color expression	< 1.8	Unsatisfactory
Aroma	Bright, characteristic of product type	3.8–4.0	Excellent
	Characteristic but weakly expressed	3.6–3.8	Good
	Weak or uncharacteristic	< 3.6	Unsatisfactory
Taste	Harmonious, balanced, characteristic of product type	3.8–4.0	Excellent
	Characteristic and pleasant	3.6–3.8	Good
	Insufficiently expressed or uncharacteristic	< 3.6	Unsatisfactory
Overall Score	Sum of parameters	9.5–10.0	Excellent
		9.0–9.5	Good
		< 9.0	Unsatisfactory

This approach has proven effective in differentiating subtle variations in flavor and aroma profiles associated with the type of herbal raw material used (e.g., *Ilex paraguariensis*, *Camellia sinensis* of different fermentation levels, and *Citrus spp.* peels), as confirmed in prior research [26, 33–37].

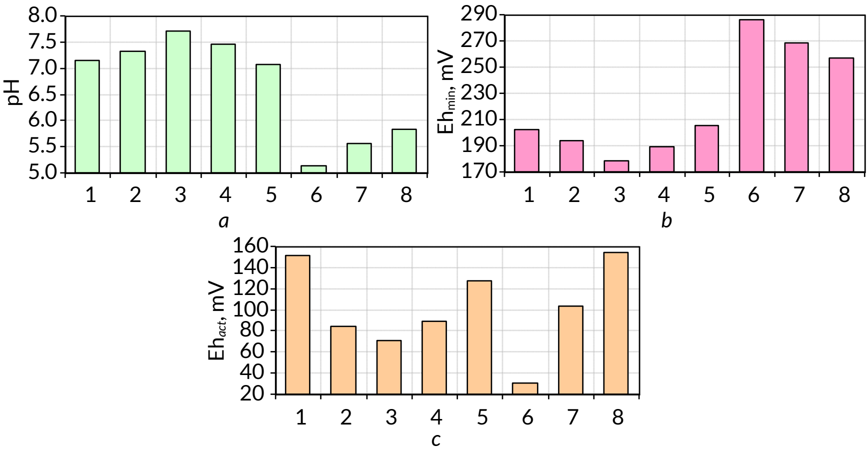
14.4 Results and discussions

14.4.1 Results of the study of the antioxidant capacity of water-alcohol infusions of tea-aromatic raw materials

Water-alcohol infusions of tea-aromatic raw materials (*Ilex paraguariensis*, *Camellia sinensis*, *Citrus* spp.) exhibit diverse physicochemical and organoleptic properties (**Fig. 14.2, 14.3**). These differences arise from the botanical diversity of the raw materials and their degree of fermentation, which significantly influence the content of phenolic compounds, essential oils, organic acids, and the dynamics of their extraction during infusion.

A water-alcohol mixture was used as a solvent: pH 7.14 units pH; Eh_{min} 202.12 mV; Eh_{act} 151.00 mV; RE_{sol} 51.12 mV; *S.e.* 9.61 points (color – colorless; aroma – alcoholic; taste – moderately burning, empty).

The *pH* range of the infusions (**Fig. 14.2, *a***) varied from 5.14 (orange peel) to 7.71 (green tea). Notably, citrus-based infusions (particularly orange, mandarin, and lemon peels) exhibited the lowest pH values (5.14–5.84), which can be attributed to the presence of significant amounts of organic acids (citric, malic, and ascorbic acids). This creates a mildly acidic medium favorable for the stability of certain flavonoids. In contrast, tea and mate infusions displayed a neutral or slightly alkaline environment (pH > 7), suggesting high buffering capacity due to the presence of tannins, alkaloids (e.g., caffeine, theobromine), and organic acid salts. These *pH* values are important for preserving antioxidant activity, as polyphenols demonstrate the highest stability in slightly alkaline conditions [38].

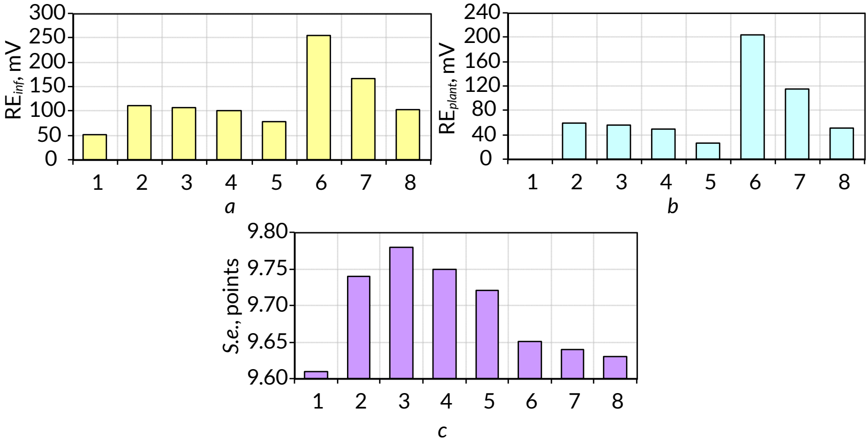


1 – water-alcohol mixture (control); 2 – water-alcohol infusion of mate;
3 – water-alcohol infusion of green tea; 4 – water-alcohol infusion of red tea;
5 – water-alcohol infusion of black tea; 6 – water-alcohol infusion of orange peel;
7 – water-alcohol infusion of mandarin peel; 8 – water-alcohol infusion of lemon peel

Fig. 14.2 Characteristics of water-alcohol infusions: *a* – active acidity (pH); *b* – the minimum theoretical value of *RP* (Eh_{min}); *c* – actual measured of *RP* (Eh_{act})

The minimum theoretical value of *RP* (Eh_{min}) for water-alcohol infusions was obtained, which has a value from 178.18 mV (green tea) to 286.12 mV (orange peel) (**Fig. 14.2, *b***). Redox potential (*Eh*) parameters provided valuable insight, with the lowest recorded actual redox potential (Eh_{act}) being – 31.00 mV in the orange peel infusion, indicating exceptionally high reducing power (**Fig. 14.2, *c***). This corresponds with literature data on the ability of flavonoids to lower the redox potential of the medium [39].

The highest infusion redox potential (RE_{inf}) was observed in orange peel (255.12 mV), indicating excellent reducing activity that surpasses that of tea infusions (**Fig. 14.3, *a***). Mate exhibited a relatively high RE_{inf} of 110.14 mV, though lower than the values for citrus infusions. This may be explained by the presence of chlorogenic acid, which exhibits antioxidant activity in aqueous solutions but is less effective in water-alcohol infusions [14]. Black tea showed the lowest RE_{inf} of 78.06 mV, reflecting decreased antioxidant potential due to fermentation of polyphenolic compounds, as confirmed by several studies [40].



1 – water-alcohol mixture (control); 2 – water-alcohol infusion of mate;
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5 – water-alcohol infusion of black tea; 6 – water-alcohol infusion of orange peel;
7 – water-alcohol infusion of mandarin peel; 8 – water-alcohol infusion of lemon peel

Fig. 14.3 Characteristics of water-alcohol infusions: *a* – recovery energy of infusions (RE_{inf}); *b* – the energy of reduction/oxidation of vegetable raw materials (RE_{plant}); *c* – sensory evaluation indicators (*S.e.*)

Interpretation of RE_{plant}, defined as the difference between RE_{inf} and the RE_{sol} of the control solution (water-alcohol mixture), allows evaluation of the additional reducing activity generated solely by the plant material (**Fig. 14.3, *b***). According to this parameter, orange peel (RE_{plant} = 204.00 mV), mandarin peel (RE_{plant} = 114.36 mV), and lemon peel (RE_{plant} = 51.60 mV) convincingly demonstrate their potential for developing functional beverages with pronounced antioxidant effects. In contrast, tea infusions showed RE_{plant} values below 60 mV (the lowest being 26.94 mV for black tea), indicating moderate additional antioxidant activity.

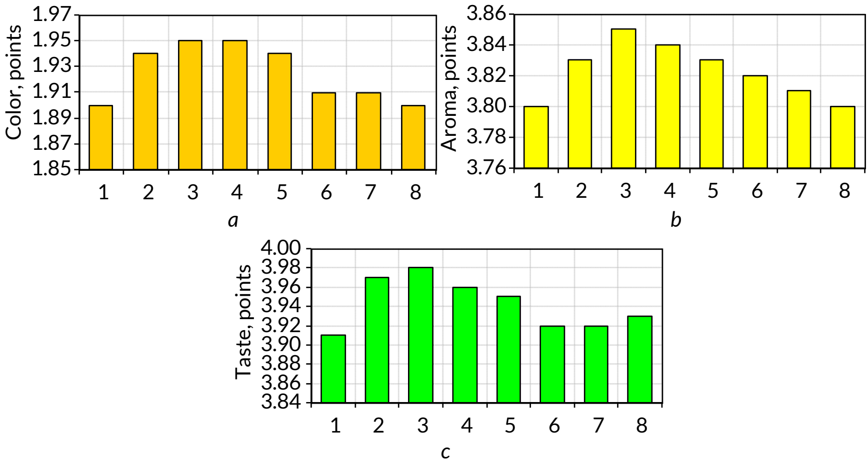
The analysis of the reducing activity (RE_{plant}) of water-alcohol infusions of tea raw materials reveals variability in antioxidant potential depending on the type of plant material. The highest additional reducing activity was demonstrated by the infusion of mate (*Ilex paraguariensis*), with RE_{plant} value of 59.02 mV, indicating a significant ability to lower the redox potential of the medium. Comparable results were observed for green tea (*Camellia sinensis*) infusion – 56.06 mV – which may be attributed to its high content of catechins and other non-oxidized polyphenols. The infusion of red tea showed a slightly lower RE_{plant} value of 48.98 mV, reflecting a partial reduction in antioxidant activity due to fermentation processes. The lowest RE_{plant} value was recorded for black tea – 26.94 mV – which, according to literature data, results from the extensive fermentation of the polyphenolic fraction. This is supported by research [10], which suggests that antioxidant efficiency depends on the type of tea and the content and type of phenolic compounds present in each type. The level of polyphenol in the extract of Ilex paraguariensis is higher than in green tea [13].

14.4.2 Organoleptic characteristics of water-alcohol infusions of tea-aromatic raw materials

The organoleptic evaluation of water-alcohol infusions of tea-aromatic raw materials (**Fig. 14.3, *c***) demonstrated a wide diversity in sensory parameters such as clarity and color (**Fig. 14.4, *a***), aroma (**Fig. 14.4, *b***), and taste (**Fig. 14.4, *c***), reflecting the botanical origin and chemical composition of each plant source. The sensory evaluation score (*S.e.*) ranged from 9.63 to 9.78 points, indicating a generally high level of acceptability across all samples.

The control sample (*S.e.* = 9.61) – a water-alcohol mixture – was colorless, had a pronounced alcoholic aroma, and a moderately burning, empty taste. In contrast, the infusion of mate was light brown in color with a woody aroma and a distinct sour-bitter taste accompanied by a long-lasting bitter aftertaste (*S.e.* = 9.74). The green tea infusion had a brownish-brown color, a fragrant tea-like aroma, and a sour-bitter, slightly astringent taste (*S.e.* = 9.78), receiving the highest overall score.

The red tea infusion was bright red, with a tea and spicy aroma and a characteristically bitter and astringent taste (*S.e.* = 9.75). The black tea infusion showed a dark brown color, tea-woody aroma, and a moderately burning, strongly astringent taste (*S.e.* = 9.72), indicating the impact of full fermentation on flavor profile.



1 – water-alcohol mixture (control); 2 – water-alcohol infusion of mate;
3 – water-alcohol infusion of green tea; 4 – water-alcohol infusion of red tea;
5 – water-alcohol infusion of black tea; 6 – water-alcohol infusion of orange peel;
7 – water-alcohol infusion of mandarin peel; 8 – water-alcohol infusion of lemon peel

Fig. 14.4 Characteristics of water-alcohol infusions:
a – clarity and color; *b* – aroma; *c* – taste

Citrus peel infusions demonstrated milder sensory properties. The orange peel infusion was transparent with a light-yellow hue, had a faint alcoholic yet fresh aroma, and a mild, slightly sweet taste (*S.e.* = 9.65). The mandarin peel infusion exhibited a similar color and a mandarin-like aroma, with a gentle, sweet taste (*S.e.* = 9.64). The lemon peel infusion was pale yellow in color, with a faint lemon-like aroma and a mild, slightly sweet taste with distinctive lemon notes (*S.e.* = 9.63).

These results suggest that citrus peel infusions are organoleptically more delicate and potentially more acceptable for a wide range of consumers, while tea-based infusions, particularly green and red teas, offer more pronounced and complex flavor profiles with a higher antioxidant potential.

Water-alcohol infusions of tea-aromatic compositions based on Ilex paraguariensis are promising semi-finished products for restaurant technology, which, due to increased antioxidant properties, are able to slow down negative processes in the human body [3, 6, 19, 20] and improve the sensory evaluation of finished products.

14.4.3 Recommendations for technological application

Despite the high antioxidant activity demonstrated by citrus peel infusions, green tea received the highest sensory evaluation score (*S.e.* = 9.78 points), which is attributed to its well-balanced aroma and rich, astringent flavor profile. Mate also showed a high score (*S.e.* = 9.74 points); however, its long-lasting bitter aftertaste may limit its application at high concentrations in beverage formulations.

The orange peel infusion demonstrated the highest antioxidant parameters – RE_{inf} = 255.12 mV and RE_{plant} = 204.00 mV – combined with favorable organoleptic characteristics, making it particularly promising for the development of liqueurs and spirit-based beverages. Its mild, slightly sweet taste and fresh citrus aroma offer significant potential for enhancing the functional and sensory qualities of alcoholic drinks.

14.4.4 Creation of tea-aromatic compositions

Creation of tea-aromatic compositions based on *Camellia sinensis*, *Ilex paraguariensis* and *Citrus sinensis*. Fig. 14.5 presents the results of a study on the influence of gradual replacement of green tea (*Camellia sinensis*) with yerba mate (*Ilex paraguariensis*) and the addition of orange peel (*Citrus sinensis*) on the physicochemical and sensory characteristics of water-alcohol infusions (**Fig. 14.6**).

The substitution experiment was conducted in six variants with increasing content of mate (from 0 to 100%) and corresponding decrease in green tea (from 100 to 0%). Orange peel was added at a constant level of 5% in intermediate blends (20–80% mate).

The pH values of the infusions decreased slightly with increasing mate content, indicating a moderate increase in acidity, with values ranging from 7.71 to 7.28 (**Fig. 14.5, *a***).

The calculated minimum redox potential (Eh_{min}) increased progressively from 178.18 mV to 196.35 mV, due to the shift in pH (**Fig. 14.5, *b***). The measured redox potential (Eh_{act}) also rose steadily with mate content, from 71.00 mV in the green tea variant to 84.00 mV in pure mate infusion (**Fig. 14.5, *c***).

The infusion redox effect (RE_{inf}) peaked at 115.15 mV (60% mate), suggesting that partial replacement with mate improves redox performance (**Fig. 14.5, *d***). The plant material contribution (RE_{plant}) to antioxidant capacity was highest at 64.03 mV (60% mate), indicating strong antioxidant potential of mate, especially in combination with orange peel (**Fig. 14.5, *e***).

Despite the increasing redox activity, the sensory evaluation (*S.e.*) remained consistently high across all samples, with scores between 9.74 and 9.82 points on a 10-point scale. The highest sensory score was recorded for the blend containing 20% mate, 75% green tea, and 5% orange peel, suggesting a balanced flavor and aroma profile.

These findings indicate that a combination of green tea, mate, and citrus peel can optimize both the antioxidant properties and sensory appeal of water-alcohol infusions, which is promising for the development of functional alcoholic beverages.

The addition of 5% citrus peel infusion to the blend of mate/green tea/orange peel at a ratio of $\omega = 20/75/5\%$ (**Fig. 14.5, *f***) significantly enhanced the sensory characteristics of the infusion (*S.e.* = 9.82 points). This modification reduced the intensity of bitterness and enriched the aromatic profile with fresh fruity notes, contributing positively to the overall evaluation of the water-alcohol infusion based on tea-aromatic raw materials (**Fig. 14.6**).

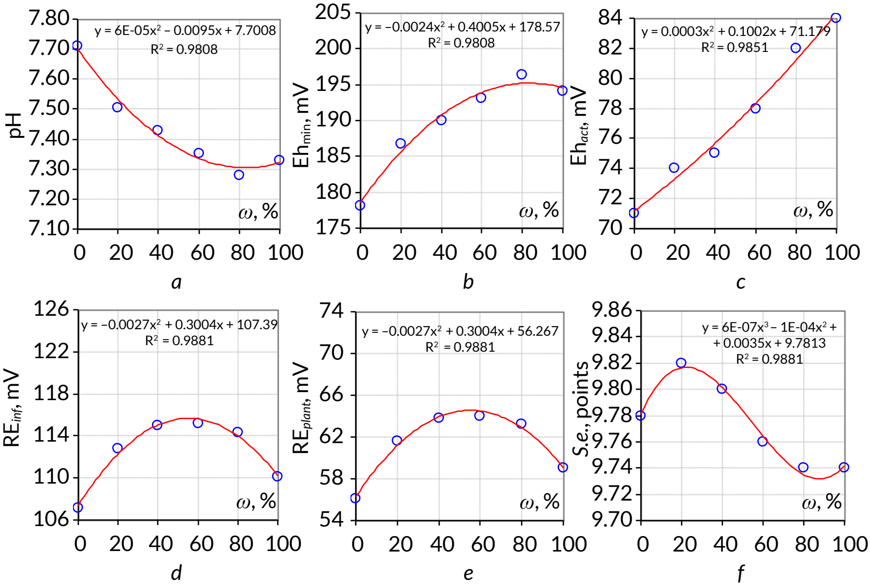


Fig. 14.5 Redox characteristics and sensory evaluation of water-alcohol infusions of tea-aromatic compositions as influenced by the mass fraction (ω) of mate, green tea and orange peel: *a* – active acidity (pH); *b* – the minimum theoretical value of RP (Eh_{min}); *c* – actual measured of RP (Eh_{act}); *d* – recovery energy of infusions (RE_{inf}); *e* – the energy of reduction/oxidation of vegetable raw materials (RE_{plant}); *f* – sensory evaluation indicators (*S.e.*)

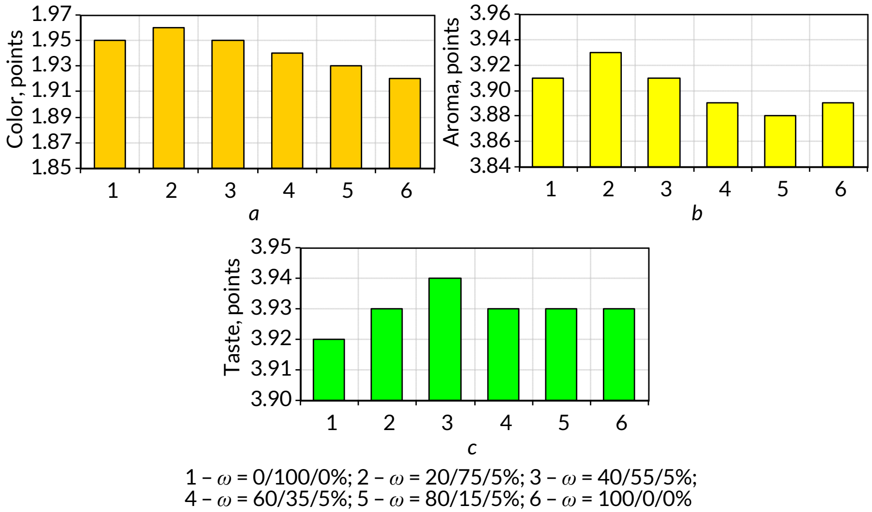


Fig. 14.6 Sensory evaluation of water-alcohol infusions of tea-aromatic compositions as influenced by the mass fraction (ω) of mate/green tea/orange peel: *a* – clarity and color; *b* – aroma; *c* – taste

Creation of tea-aromatic compositions based on *Camellia sinensis*, *Ilex paraguariensis* and *Citrus reticulate*. Fig. 14.7, **14.8** presents the physicochemical and sensory characteristics of water-alcohol infusions prepared using red tea (*Camellia sinensis*), yerba mate (*Ilex paraguariensis*), and mandarin peel (*Citrus reticulata*). The formulation involved six variants with a gradual increase in mate content (from 0 to 100%) and a corresponding decrease in red tea (from 100 to 0%). Additionally, 5% mandarin peel was included in the intermediate formulations containing 20–80% mate.

The pH level slightly decreased with the increase in mate content – from 7.45 (100% red tea) to a minimum of 7.26 (80% mate) – indicating a moderate increase in acidity due to the presence of mandarin peel (**Fig. 14.7, *a***). At 100% mate, the pH rose slightly to 7.33, possibly due to the absence of the more acidic mandarin peel.

The calculated minimum redox potential (Eh_{min}) increased from 189.10 mV to 197.10 mV with the rising proportion of mate up to 80%, which can be attributed to changes in the system's acidity (**Fig. 14.7, *b***). At 100% mate, Eh_{min} slightly decreased to 194.14 mV.

In contrast, the measured redox potential (Eh_{act}) decreased from 89.00 mV to 84.00 mV, indicating an increase in the reducing power of the infusions with higher mate content (**Fig. 14.7, *c***).

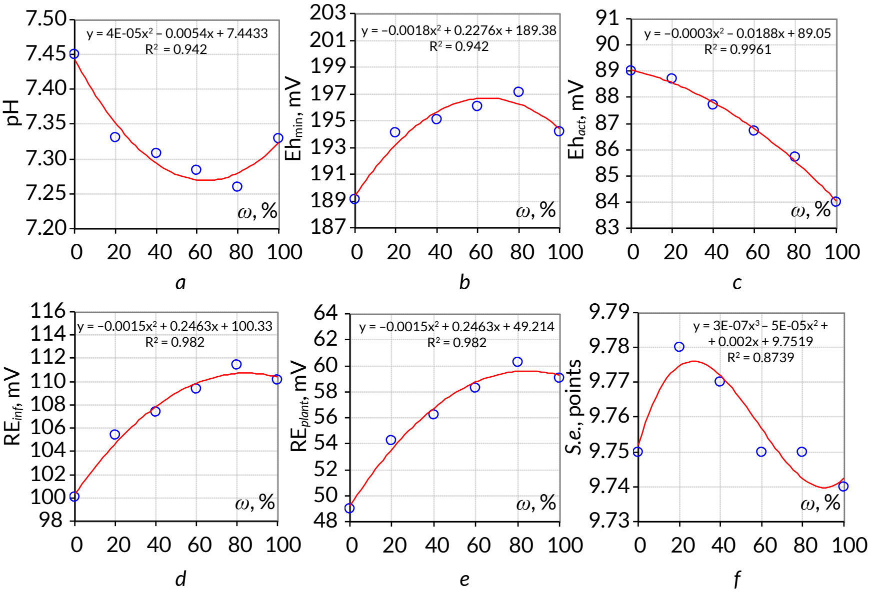


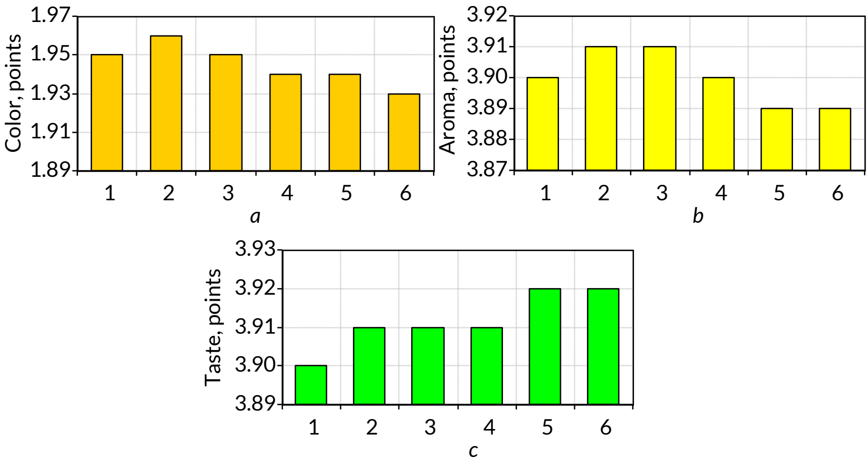
Fig. 14.7 Redox characteristics and sensory evaluation of water-alcohol infusions of tea-aromatic compositions as influenced by the mass fraction (ω) of mate, red tea and mandarin peel: *a* – active acidity (pH); *b* – the minimum theoretical value of RP (Eh_{min}); *c* – actual measured of RP (Eh_{act}); *d* – recovery energy of infusions (RE_{inf}); *e* – the energy of reduction/oxidation of vegetable raw materials (RE_{plant}); *f* – sensory evaluation indicators (*S.e.*)

The redox effect of the infusion (RE_{inf}) increased with the addition of mate, reaching a maximum of 111.40 mV at 80% mate, and slightly declined thereafter (**Fig. 14.7, *d***). This suggests that yerba mate significantly contributes to the redox activity of the blend.

The contribution of plant materials to antioxidant capacity (RE_{plant}) followed a similar trend, increasing from 48.98 mV (red tea) to a peak of 60.28 mV (80% mate), confirming the strong antioxidant potential of yerba mate, particularly in combination with mandarin peel (**Fig. 14.7, *e***).

Sensory evaluation (*S.e.*) remained consistently high across all samples, ranging from 9.74 to 9.78 on a 10-point hedonic scale (**Fig. 14.7, *f***). The highest score of 9.78 was recorded for the blend containing 20% mate, 75% red tea, and 5% mandarin peel (ω = 20/75/5%), reflecting a balanced taste and aroma profile (**Fig. 14.8**).

This composition exhibited an exceptionally harmonious taste and aroma. Taste – well-balanced, featuring a soft bitterness from mate, mellowed by the sweet-floral notes of red tea and citrus undertones from mandarin peel (**Fig. 14.8, *c***). A mild astringency, typical of semi-fermented tea, added depth without overwhelming the palate. Aroma – fresh and rich, with pronounced fruity-citrus nuances (**Fig. 14.8, *b***). Subtle essential oil notes from the mandarin peel created a delicate sweet base, while the red tea contributed warmth with its woody-honeyed accents. Mate provided a gentle herbal-grassy bouquet. Thanks to this balance, the infusion demonstrated high organoleptic integrity, a pleasant aftertaste, and an absence of sharp or dominant notes – qualities that are critical for the development of innovative functional beverages with strong market potential. Thus, the inclusion of yerba mate and mandarin peel into red tea-based infusions enhances antioxidant properties without compromising sensory appeal, making it a promising direction for the development of functional tea-aromatic drinks.



1 – ω = 0/100/0%; 2 – ω = 20/75/5%; 3 – ω = 40/55/5%;
4 – ω = 60/35/5%; 5 – ω = 80/15/5%; 6 – ω = 100/0/0%

Fig. 14.8 Sensory evaluation of water-alcohol infusions of tea-aromatic compositions as influenced by the mass fraction (ω) of mate, red tea and mandarin peel:
a – clarity and color; *b* – aroma; *c* – taste

Creation of tea-aromatic compositions based on *Camellia sinensis*, *Ilex paraguariensis* and *Citrus limon*. **Fig. 14.9**, **14.10** illustrates the physicochemical and sensory parameters of water-alcohol infusions composed of black tea (*Camellia sinensis*), yerba mate (*Ilex paraguariensis*), and lemon peel (*Citrus limon*). The formulations varied in the ratio of ingredients, increasing the proportion of mate from 0% to 100%, while reducing black tea from 100% to 0%. In variants containing 20–80% mate, 5% lemon peel was additionally introduced.

pH values showed a gradual increase from 7.07 (100% black tea) to 7.33 (100% mate), indicating a decrease in acidity with higher mate content. Notably, pH increased more steadily in comparison to the red tea-based samples, possibly due to lower acidity contribution from lemon peel (**Fig. 14.9, *a***).

Minimum redox potential (Eh_{min}) decreased with rising mate content – from 205.46 mV to 194.14 mV – suggesting that the system becomes more reductive with increased mate presence (**Fig. 14.9, *b***).

Actual redox potential (Eh_{act}) significantly decreased from 127.00 mV (100% black tea) to 84.00 mV (100% mate), indicating a pronounced increase in reducing capacity of the infusion as mate replaces black tea (**Fig. 14.9, *c***).

Infusion redox effect (RE_{inf}) increased from 78.06 mV to 110.14 mV as mate content rose, confirming the active redox potential enhancement due to mate incorporation (**Fig. 14.9, *d***).

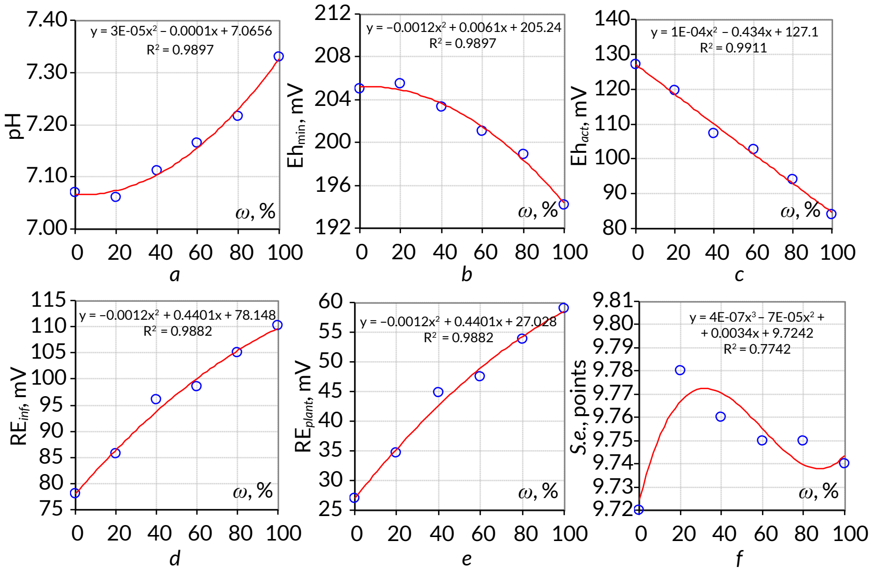


Fig. 14.9 Redox characteristics and sensory evaluation of water-alcohol infusions of tea-aromatic compositions as influenced by the mass fraction (ω) of mate, black tea and lemon peel: *a* – active acidity (pH); *b* – the minimum theoretical value of RP (Eh_{min}); *c* – actual measured of RP (Eh_{act}); *d* – recovery energy of infusions (RE_{inf}); *e* – the energy of reduction/oxidation of vegetable raw materials (RE_{plant}); *f* – sensory evaluation indicators (*S.e.*)

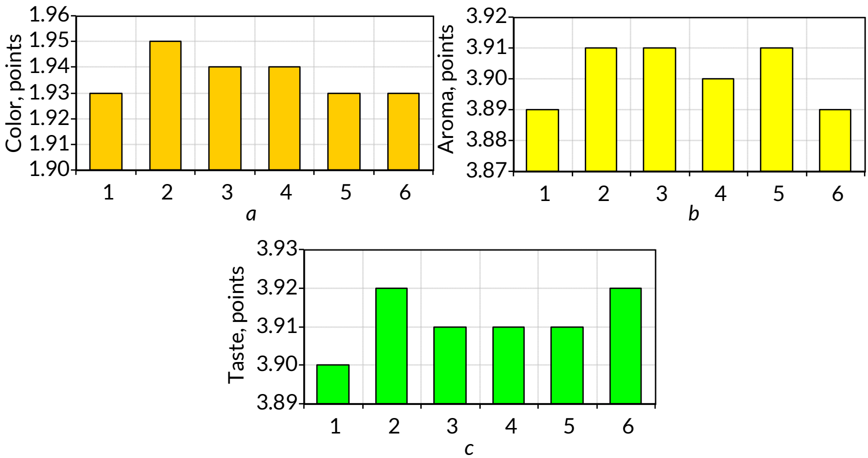
Plant-derived antioxidant potential (RE_{plant}) demonstrated a strong linear growth – from 26.94 mV at 100% black tea to a peak of 59.02 mV at 100% mate. This further affirms the significant antioxidant contribution of yerba mate, particularly in synergy with lemon peel (**Fig. 14.9, *e***).

Sensory evaluation (*S.e.*) scores remained high across all compositions, ranging from 9.72 to 9.78 points on a 10-point scale. The highest score of 9.78 was observed at 20% mate, 75% black tea, and 5% lemon peel (ω = 20/75/5%) (**Fig. 14.9, *f***). This composition offered an optimal balance of taste and aroma.

Taste-aroma profile. The sample with ω = 20/75/5% was especially notable for its well-rounded organoleptic properties.

Taste – smooth and structured, combining the robust body of black tea with the light herbal bitterness of mate (**Fig. 14.10, *c***). Citrus zest from lemon peel introduced freshness and slight tanginess that elevated the overall profile without overwhelming other notes.

Aroma – clean, bright, and refreshing (**Fig. 14.10, *b***). The essential oil components of lemon peel created an invigorating top note, while black tea contributed warm, malty undertones. Mate added a subtle vegetal-herbal character that enriched the aromatic complexity.



1 – ω = 0/100/0%; 2 – ω = 20/75/5%; 3 – ω = 40/55/5%;
4 – ω = 60/35/5%; 5 – ω = 80/15/5%; 6 – ω = 100/0/0%

Fig. 14.10 Sensory evaluation of water-alcohol infusions of tea-aromatic compositions as influenced by the mass fraction (ω) of mate, black tea and lemon peel: *a* – clarity and color; *b* – aroma; *c* – taste

The overall result is a harmonious beverage with high antioxidant activity and excellent sensory integrity, ideal for the development of functional drinks with enhanced health benefits and appealing taste.

14.4.5 Innovative technology of functional beverages

Water-alcohol infusions serve as intermediate products widely used in the production of liqueurs, functional beverages, and therapeutic-prophylactic drinks. They are obtained through maceration (infusion) of plant-based raw materials – both aromatic (tea products, spices, aromatic herbs) and neutral – into a water-alcohol solution with an ethanol concentration ranging from 40% to 90%. The technological process is carried out in accordance with the relevant technological instructions and current regulatory standards, complying with state sanitary norms and food safety regulations.

Infusion, as a core extraction method, ensures the qualitative transfer of valuable compounds from raw materials into the solvent, while the presence of ethanol acts as a stabilizing agent. This approach not only prolongs the shelf life of the resulting infusions but also creates a stable matrix for the development of complex beverage compositions with a controlled impact on metabolic processes in the human body.

The extraction process is driven by diffusion, which is governed by the kinetic energy of molecules – gradual concentration equalization occurs between the solvent (water-alcohol mixture) and the soluble substances located in the plant cell structure. The efficiency of extracting bioactive compounds is influenced by several key factors: the degree of raw material grinding, the mass ratio of plant material to extractant volume, the ethanol concentration in the solvent, the number of maceration cycles (single or double), the duration of infusion, mixing frequency, and extraction temperature.

Under industrial conditions, the most rational approach is the two-stage maceration method carried out at a temperature of 18–25°C. This method involves soaking the raw tea-aromatic material in a water-alcohol mixture for 5 to 14 days, depending on the type of raw material, followed by separation of the first infusion, re-soaking (second maceration), and repeated extraction. After the process is completed, the two extracts are combined, while the remaining raw material is either disposed of or subjected to secondary alcohol evaporation to recover residual ethanol.

As a result of macerating tea-aromatic raw materials in a water-alcohol medium, a wide range of biologically active compounds is extracted: polyphenols (catechins, flavonoids), tannins, caffeine, organic acids, vitamins (B, C, P groups), minerals, and essential oils. Due to the high solubility of ethanol and its ability to preserve the activity of components without oxidation, the final product exhibits stable antioxidant activity and has a significant effect on the redox balance of the body's internal environment. These properties make such infusions a promising bioactive base for the development of liqueurs, bitters, tinctures, and tonic beverages with targeted functional effects.

Thus, the optimization of maceration processes in water-alcohol systems opens up broad prospects for creating new types of alcoholic beverages with enhanced biological value, prolonged antioxidant action, and targeted modulation of redox processes in the human body. Technologically justified extraction and rational combination of formulation components not only preserve but also enhance the functional properties of the original plant material, contributing to the development of a new generation of functional beverages.

Based on the results of physicochemical and sensory evaluation studies of water-alcohol infusions prepared from tea-aromatic compositions, the optimal ratio was determined to be 20% mate, 75% tea (green, red, black), and 5% citrus peel (orange, mandarin, lemon) for further modeling of the functional alcoholic beverages of enhanced quality.

It was established that the mass ratio (ω = 20/75/5%) provides the highest sensory scores among all composition variants:

– or mate/green tea/orange peel – *S.e.* = 9.82 points;

– for mate/red tea/mandarin peel – *S.e.* = 9.78 points;

– for mate/black tea/lemon peel – *S.e.* = 9.78 points.

This result is due to the harmonious combination of taste and aromatic characteristics: the mild bitterness of mate is well-balanced by the sweet, floral notes of tea, while citrus peel adds freshness, lightness, and a fruity aroma. The indicated composition is considered promising for the development of functional beverages with antioxidant properties and high consumer appeal.

Formulation and blending of functional alcoholic beverages. Among liqueur and spirits products, fruit liqueurs (nalivkas) occupy a special place. These are alcoholic beverages with an alcohol content ranging from 15% to 35% and a total extract concentration of 15–50 g/100 cm^3. They are traditionally produced from fresh fruit raw materials or their semi-finished products, with the addition of various ingredients that define the taste, aroma, and functional properties of the final product.

To develop a liqueur with enhanced antioxidant properties and improved sensory characteristics, water-alcohol infusions based on tea-aromatic raw materials were used as the primary semi-finished ingredient. This approach allows the creation of a beverage that may help strengthen the immune system, improve metabolic processes, and positively affect cardiovascular function.

The formulation of the developed functional alcoholic beverage includes the following components (**Fig. 14.11**):

– water-alcohol infusion of a tea-aromatic composition (mate/tea/citrus zest in the mass ratio ω = 20/75/5%) – 38.49%;

– brandy – 7.54%;

– vanillin solution (1:10) – 0.01%;

– sugar syrup (65.8%) – 53.08%;

– citric acid – 0.28%;

– colorant ("caramel color") – 0.60%;

– ethanol and water – to adjust the final alcohol content to 20% vol.

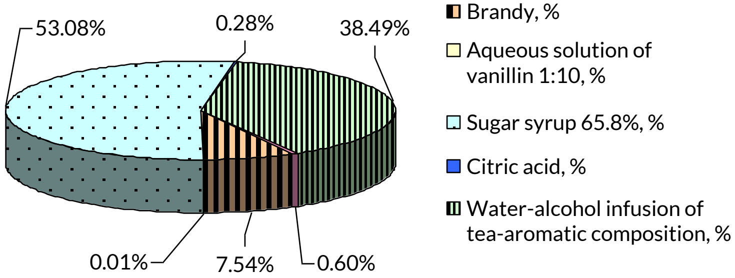


Fig. 14.11 Blending of alcoholic beverage

The proposed recipe enables the production of a functional alcoholic beverage with a balanced sensory profile and pronounced antioxidant activity. Through the synergistic combination of tea-aromatic infusions, brandy, and flavor-enhancing additives, the beverage acquires a smooth, pleasant flavor that aligns with contemporary trends in health-oriented drink production.

The diversity of alcoholic beverages is largely determined by the wide range of combinations possible between ethanol and natural ingredients. The use of tea-aromatic compositions in various proportions allows for the creation of novel flavor profiles while enriching the end product with bioactive properties [26, 33–36].

Such compositions not only enhance the organoleptic palette of the beverages but also contribute to their functional value. Of particular importance is their ability to modulate redox reactions in the human body, which can help reduce oxidative stress, regulate cellular metabolism, and support general homeostasis.

The developed tea-aromatic compositions provide a synergistic effect, resulting in a product with harmoniously balanced sensory properties and improved functional characteristics. This approach opens new avenues for the development of innovative functional alcoholic beverages.

These beverages represent a new generation of functional products, created from natural extracts and infusions of high-quality plant-based raw materials. Their optimized composition ensures high antioxidant activity, effectively protecting the body from the harmful effects of free radicals and supporting overall health. The innovative ingredient selection guarantees not only beneficial health effects but also excellent flavor and aroma characteristics, meeting the growing demand for health-oriented alcoholic beverages.

14.5 Conclusions

The feasibility of using water-alcohol infusions of tea-herbal raw materials (*Ilex paraguariensis*, *Camellia sinensis*, *Citrus spp.*) for the production of alcoholic beverages has been substantiated. These components are characterized by high bioactivity, stability of polyphenolic compounds in alcoholic media, appealing aroma, and favorable sensory properties, making them an effective basis for innovative functional beverages.

The antioxidant activity of the obtained infusions has been determined. The highest reducing capacity (RE_{plant}) was observed in citrus peel infusions (up to 204.00 mV for orange peel), green tea (56.06 mV), and mate (59.02 mV). This indicates the presence of a significant amount of bioactive compounds that retain antioxidant potential in ethanol-containing systems.

The potential for modifying infusions based on tea-aromatic compositions within alcoholic beverage technology has been explored. It was established that the optimal mass ratio of components ω = 20/75/5% (mate/tea/citrus peel) provides a balanced flavor, reduces the bitterness of mate, enhances the aroma with fresh fruity notes, and increases the overall sensory evaluation (up to 9.82 points – for mate/green tea/orange peel).

Sensory evaluation of the infusions confirmed their suitability for commercial development. All infusions received high sensory scores (ranging from 9.63 to 9.82 on a 10-point scale), indicating strong consumer appeal and potential for implementation in the restaurant industry to produce innovative functional alcoholic beverages.

Optimized formulations for functional alcoholic beverages enriched with antioxidant tea-herbal infusions have been developed. The formulation includes: 38.49% of the infusion (mate/tea/citrus peel in a 20/75/5% ratio), 7.54% brandy, 53.08% sugar syrup, as well as flavoring agents and colorants. The alcohol content is adjusted to

20% vol., ensuring a balance between functionality, taste characteristics, and consumer appeal.

The integration of antioxidant-rich infusions based on *Ilex paraguariensis*, *Camellia sinensis*, and *Citrus spp*. into alcoholic beverage technology offers new opportunities for the restaurant industry to expand product offerings, enhance functional value, develop a positive brand image, and tap into the growing segment of health-conscious and innovative beverages.

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