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BIOACTIVE COMPOUNDS AND QUALITY CONTROL OF MEDICINAL PLANTS, MARKETED IN THE CITY OF SANTA MARIA-RS

COMPOSTOS BIOATIVOS E CONTROLE DE QUALIDADE DE PLANTAS MEDICINAIS, COMERCIALIZADAS NA CIDADE DE SANTA MARIA-RS

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ABSTRACT

Brazilian flora is rich, and the use of medicinal plants in their natural form is a common practice. This study evaluated the physicochemical and microbiological quality, as well as the bioactive compounds of teas sold in pharmacies in Santa Maria, Rio Grande do Sul. Water activity, microbiological parameters, and the content of phenolic compounds and flavonoids were analyzed, along with antioxidant activity assessed by the 2,2'-diphenyl-1-picrylhydrazyl (DPPH) and 2,2'-azino-bis\[3-ethylbenzothiazoline-6-sulfonic acid] (ABTS) methods. The results revealed that all samples had water activity levels above the recommended limits and microbiological contamination exceeding acceptable standards, indicating shortcomings in quality control. Nevertheless, the teas showed high levels of bioactive compounds and significant antioxidant activity, suggesting potential health benefits. It is concluded that, although these teas have functional potential, improving inspection and production processes is essential to ensure safe consumptio n.

Keywords: Physical-chemical analysis; microbiological analysis; antioxidant activity.

RESUMO

A flora brasileira é rica, e o uso de plantas medicinais in natura é comum. Este estudo avaliou a qualidade físico-química, microbiológica e os compostos bioativos de chás vendidos em farmácias de Santa Maria-RS. Foram analisadas a atividade de água, parâmetros microbiológicos e o teor de fenóis e flavonoides, além da atividade antioxidante pelos métodos 2,2'-difenil-1-picril-hidrazil (DPPH) e 2,2'-azino-bis[3-etilbenzotiazolina-6-ácido sulfônico] (ABTS). Os resultados revelaram que todas as amostras apresentaram atividade de água acima do recomendado e contaminação microbiológica fora dos padrões, evidenciando falhas no controle de qualidade. Apesar disso, os chás demonstraram altos teores de compostos bioativos e relevante atividade antioxidante, o que sugere benefícios à saúde. Conclui-se que, embora apresentem potencial funcional, é fundamental aprimorar a fiscalização e a produção para garantir a segurança do consumo.

Palavras-chave: *Análise físico-química; análises microbiológicas; atividade antioxidante.*

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INTRODUCTION

Medicinal plants are widely used in Brazil for disease prevention and treatment. According to the World Health Organization (WHO, 2023), approximately 80% of the global population relies on traditional medicine, including herbal teas, underscoring their cultural and therapeutic significance. The growing demand for these plants has raised concerns about quality control, particularly regarding contamination and standardization (OLIVEIRA *et al.*, 2021; SANTOS *et al.*, 2022). Studies emphasize the need for stricter regulations to ensure the safety and efficacy of commercialized products such as teas (National Health Surveillance Agency-ANVISA, 2022).

The consumption of medicinal plants in the form of teas has shown significant global growth, with the herbal tea market projected to expand at a Compound Annual Growth rate (CAGR) of 6.8% from 2021 to 2028 (GRAND VIEW RESEARCH, 2023). In Brazil, this trend is particularly pronounced, driven by the population's easy access to phytotherapeutic products, the widespread belief in their safety, and their cost-effectiveness compared to conventional medicines (SANTOS *et al.*, 2022). Recent studies indicate that approximately 72% of Brazilian households regularly use herbal preparations, with teas being the most common form of administration (MINISTÉRIO DA SAÚDE, 2023).

Ethur *et al.* (2011) emphasize that the population served by primary health care prefers and trusts natural products, such as plants and herbal medicines, for the treatment of diseases. This new public interest is also due to the widespread dissemination of numerous research results in recent years through various communication channels, as well as the implementation of the National Program on Medicinal Plants and Herbal Medicines in the Unified Health System (SUS) through Decree No. 5,813 of 2006, which aims to introduce or expand the availability of medicinal plants in SUS (BRASIL, 2006b).

The National Policy on Medicinal Plants and Herbal Medicines, launched in 2006 by the Ministry of Health, recognizes that Brazil, with its vast genetic resources and cultural diversity, has the opportunity to establish a unique and sovereign development model in the health sector regarding medicinal plants (BRASIL, 2006a).

According to the Ministry of Health (2014), like any other medicine, plant-based drugs must prove their safety and efficacy based on clinical evidence and be characterized by consistent quality from cultivation to the final herbal medicine or phytotherapeutic product ready for commercialization or consumption (BRASIL, 2014).

The quality of medicinal plants is mainly determined by the content of active compounds responsible for therapeutic effects and the absence of contaminants (CARVALHO; COSTA; CARNELOSSI, 2010). In recent years, researchers have given special attention to biologically active ingredients, particularly alkaloids and phenolic compounds, in foods and beverages due to their positive effects on human health (DAMIANE *et al.*, 2014).

Antioxidant compounds are essential for maintaining the body's balance, as they act by scavenging free radicals produced in excess during the metabolic process and consequently prevent various diseases related to oxidative stress. In this context, there is growing interest in investigating antioxidants from natural sources, which are known to be less harmful than synthetic antioxidants (LI *et al.*, 2014).

However, the lack of mechanisms for monitoring contaminants in herbal medicine, such as bacteria and chemical substances, and the assessment of good professional practices among providers may pose health risks for users of herbal medicines (WORLD HEALTH ORGANIZATION, 2019). Microbiological analyses are fundamental for monitoring contamination, as toxicities related to extrinsic factors, usually associated with undesirable toxic substances - particularly contamination by microorganisms such as fungi and bacteria - have been a global concern for decades (ZHANG *et al.*, 2018).

Most of these contaminants can be minimized by paying sufficient attention to good agricultural practices, as well as preparation, collection, packaging, quality assurance, and control of herbal medicines. These practices not only affect the safety and efficacy of herbs but also the safety of consumers (WORLD HEALTH ORGANIZATION, 2003; EUROPEAN MEDICINES AGENCY, 2006).

According to the Brazilian Pharmacopoeia (BRASIL, 2019), quality assurance and production controls must ensure that microorganisms capable of proliferating and contaminating the product remain within the permitted limits for microorganisms in non-sterile plant materials. Thus, the objective of this study was to evaluate the physicochemical and microbiological quality, as well as the analysis of bioactive compounds in medicinal plants sold in pharmacies and drugstores in the city of Santa Maria, RS.

METHODOLOGY

SAMPLES

For this study, samples were selected in dried form and widely used by the population in the preparation of teas by infusion or decoctio n. The samples were purchased commercially from drugstores and pharmacies in Santa Maria, RS, in September 2021. The species were chosen based on recommendations from the sellers, opting for the species most consumed by the population: sample A: 30 herb blend tea (Mil Ervas®), sample B: Magreem Tea®, sample C: Ansiechá® tea, sample D: Cat's claw tea (*Uncaria tomentosa*), and sample E: Artichoke (*Cynara cardunculus var. scolymus*).

Five samples of plants and plant compounds from various brands were purchased, and approximately 150 grams of each sample were obtained. The samples were dry and packed in plastic bags and plastic-lined paper packages, sealed and labeled according to the date of manufacture and batch number. After the acquisition, the samples were sent to the Bromatology and Food Microbiology Laboratory at Universidade Franciscana for analysis.

ANALYSES

The physical-chemical, microbiological, and bioactive compound analyses were based on the reference methodologies described below.

Physical-Chemical Analyses

Moisture content, water activity, and ash content were analyzed in accordance with the Analytical Standards of the Adolfo Lutz Institute (2008), using the Aqualab® apparatus for water activity.

Microbiological analysis

The samples were analyzed microbiologically according to the recommended procedures outlined in Normative Instruction 62 (2003). Aerobic mesophilic bacteria, molds, and yeasts, Salmonella s p. , and Staphylococcus aureus were analyzed using the plating method, and total and fecal coliforms by using the multiple tube technique. (BRASIL, 2003).

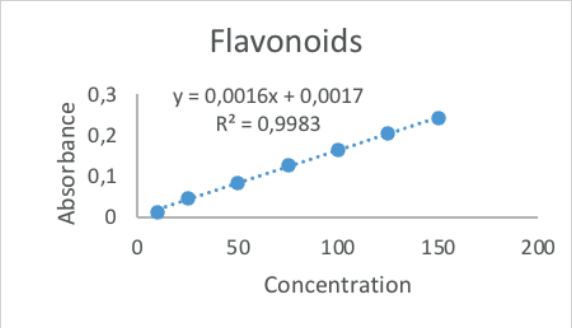
Analysis of Bioactive Compounds

TOTAL FLAVONOIDS

The analysis of flavonoids was conducted using the methodology described by Re *et al.* (1999). It was added to the sample: 2000 µL of water, 500 µL of sample, 150 µL of sodium nitrite, 150 µL of aluminum chloride, 1000 µL of sodium hydroxide, and 1200 µL of water; to the standard was added 2000 µL of water, 500 µL of the standard, 150 µL of sodium nitrite, 150 µL of aluminum chloride, 1000 µL of sodium hydroxide, and 1200 µL of water; and the blank was also prepared in the same way except for adding the sample or standard. After mixing the sample, standard, and blank, they were read in an Azzota® spectrophotometer at a wavelength of 510 nm.

To quantify total flavonoids, the straight line equation of the catechin curve was used, as shown in Figure 1.

Figure 1 - Catechin curve for flavonoid assay.

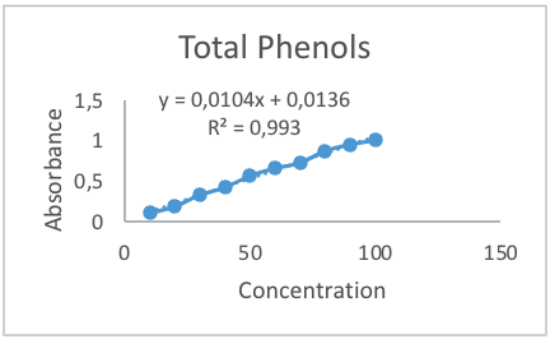


Source: Author's constructio n.

TOTAL PHENOLS

The content of total phenols present in the ethanolic extract samples of the studied species was determined by spectroscopy in the visible region using the Folin-Ciocalteu method with modifications, as described by Bertagnolli (2016). 500 µL of sample, 2500 µL of diluted Folin-Ciocalteu, and 2000 µL of sodium carbonate were added to the sample; 500 µL of the standard, 2500 µL of diluted Folin-Ciocalteu, and 2000 µL of sodium carbonate were added to the standard; and the blank was also prepared in the same way except for the addition of the sample or standard. After incubating the samples in a water bath at 50 °C for 5 minutes, the samples were cooled in a cold water bath before being read. They were then read in an Azzota® spectrophotometer at a wavelength of 760 nm. To quantify total phenols, the straight line equation of the gallic acid curve was used, as shown in Figure 2.

Figure 2 - Gallic Acid Curve for total phenols assay.



Source: Author's constructio n.

Determination of DPPH free radical scavenging capacity

Following the methodology of Roesler *et al.* (2007), 2.5 mL of 0.004% DPPH solution (prepared at the time of analysis) was added to 0.5 mL of the sample. At the same time, a control tube was made with 0.5 mL of methanol and 2.5 mL of DPPH. All the tubes were incubated for 30 minutes,

protected from light at room temperature, and then read at 517nm.m. The antioxidant activity was expressed as a percentage of inhibition in relation to the negative control, according to the equation:

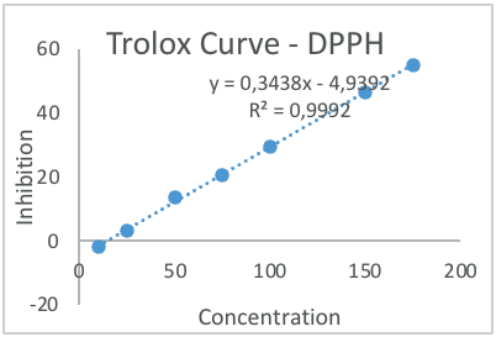
$$(1)\ \%\ \text{Inibição} = [(Ac - Aa)/Ac] \times 100 \qquad (1)$$

Ac = absorbance of the negative control (DPPH + Methanol solution); Aa = absorbance of the sample after 30 minutes.

6-hydroxy2,5,7,8-tetramethylchroman-2-carboxylic acid (Trolox®) was the substance used as the antioxidant control.

The Trolox curve (Figure 3) was used to calculate the concentration of the sample with anti-oxidant effect from the obtained absorbances.

Figure 3 - Trolox curve for the DPPH method



Source: Author's constructio n.

In addition, the IC50, defined as the final concentration of the extract required to decrease the DPPH oxidizing capacity by 50%, was calculated by drawing a trend line on a scatter plot, where the X-axis shows the extract concentration values (mg/mL) and the Y-axis shows the inhibition of DPPH radical oxidation (%).

Determination of ABTS free radical scavenging capacity

The method, as described by Re *et al.* (1999), is based on the generation of the ABTS radical. Its color is blue-green, by reacting ABTS with potassium persulfate, which has a maximum absorption at 734 nm. 88 µL of potassium persulfate (140 mM) was added to 5 mL of the ABTS solution (7 mM). This solution was then kept in the dark for 12-16 hours to ensure the formation of the ABTS radical. The following day, the solution was diluted with ethanol until an absorbance of approximately 0.7 at 734 nm was achieved. 2.5 mL of ABTS solution was added to 0.5 mL of the sample. At the same time, a control tube was prepared with 0.5 mL of distilled water and 2.5 mL of ABTS solution, and

the Trolox curve with 0.5 mL of the curve solution and 25 mL of ABTS solutio n. The tubes were incubated in a dark environment for 6 minutes at room temperature. The absorbance was then read at a wavelength of 734 mm. The samples were diluted in water because it was solid waste. The antioxidant activity was calculated using the following equation:

$$(1)\ AA\%=[Acn-AAm/Acn]\ *100 \qquad (1)$$

Acn and AAm are negative controls and sample absorbents, respectively.

RESULTS

PHYSICOCHEMICAL ANALYSES

Table 1 presents the physicochemical analyses of the 5 tea samples. The moisture content analysis showed that the results varied approximately from 10% to 16.25%, with the highest moisture content found in sample E. All samples exhibited water activity levels above 0.60 aw. Regarding the determination of total ash, the results indicate that all analyzed samples varied approximately from 4,5% to 13,41%

Table 1 - The results of the physicochemical analyses.

Samples	*Water Activity (aw) at 25ºC*	*Moisture Content*	*Ash Content*
A	0,685	10,24%	6,08%
B	0,761	12,20%	8,25%
C	0,678	10,12%	8,27%
D	0,746	12,90%	4,50%
E	0,716	16,25%	13,41%

Source: Author's constructio n.

MICROBIOLOGICAL ANALYSES

The results of the microbiological analyses performed on the teas are presented in Table 2.

Table 2 - Results of microbiological analyses: Sample (A), fecal coliforms (C.F), total coliforms (C.T), mesophilic aerobic microorganisms (M.M.A), molds and yeasts (M.Y), *Staphylococcus aureus* (Sa), and *Salmonella* s p. (Ssp).

Samples	*C.F NMP/g*	*C. T NMP/g*	*M.M.A UFC/g*	*BL UFC/g*	*Ss p. UFC/g*	*S a UFC/g*
A	$1,2x10^3$	$1,5x10^4$	$>3,0x10^6$	$5,7x10^4$	-	$<10^2$
B	$1,1x10^4$	$2,8x10^4$	$1,6x10^5$	$1,2x10^4$	-	$5,4x10^4$
C	$2,8x10^3$	$2,1x10^4$	$2,1x10^4$	$5,3x10^3$	-	$-2,2x10^5$
D	$2,0x10^4$	$2,1x10^4$	$2,5x10^3$	$1,6x10^5$	-	$-<10^2$
E	$>2,4x10^5$	$2,4x10^5$	$>3,0x10^6$	$2,8x10^5$	-	$-5,25x10^5$

Legend: *NMP/g: Most Probable Number per gram. UFC/g: Colony Forming Unit per gram; -: Absent.
Source: Author's constructio n.

The contamination by molds and yeasts in the analyzed herbal drugs ranged from $5.3x10^3$ to 2.8x10CFU/g, while the World Health Organization (1998) specifies the limit for plant materials intended for use as teas and infusions for internal use as 10^3 CFU/g.

Therefore, 60% of the samples exceeded the permitted limit. The contamination level by aerobic microorganisms was found to range from 5.0×10^3 to $> 3.0 \times 10$ CFU/g. In contrast, the World Health Organization (1998) specifies a limit of 10 CFU/g for plant materials intended for use as teas and infusions for internal consumptio n. Therefore, all samples exceeded the specified limits.

BIOACTIVE COMPOUNDS

Zielinski *et al.* (2014), evaluating several tea species, obtained results that ranged from 0.100 to 1.034 mg EAG/L-mL for phenolic compounds and 0.034 to 0.178 mg EC/mL for flavonoids. The results of the tea samples analyzed, as shown in Table 3, ranged from 0.317 mg EAG/L-mL to 0.862 mg EAG/L-mL for phenols and 0.042 mg EC/mL to 0.255 mg EC/mL for flavonoids.

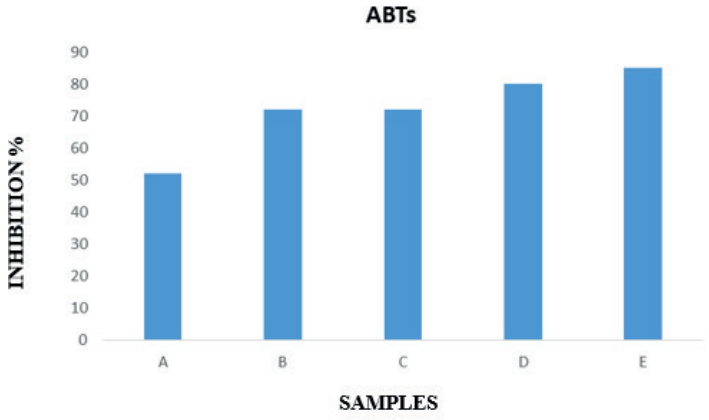
Table 3 - Experimental results of the bioactive compound analysis in tea samples.

Samples	*Phenols (mg/mL gallic acid equivalent)*	*Flavonoids (mg/mL catechin equivalent)*
A	0,317	0,0914
B	0,392	0,105
C	0,539	0,255
D	0,862	0,133
E	0,194	0,042

Source: Author's constructio n.

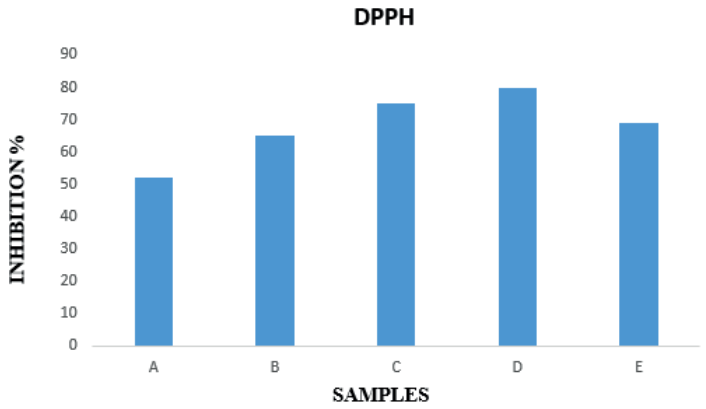
Plant extracts demonstrated high antioxidant activity, making them promising candidates for medicinal purposes as phytotherapeutics. The determination of the average for different sample concentrations in the radical scavenging capacity assays, ABTS and DPPH, showed percentages ranging from 52.08% to 85.13% and 52.28% to 79.41%, as described in Figure 4.

Figure 4 - Average percentage inhibition results of different tea samples using the ABTS method.



Source: Author's constructio n.

Figure 5 - Average % inhibition of oxidation results using the DPPH method.



Source: Author's constructio n.

The degree of reduction in absorbance measurement indicates the antioxidant activity of the extract against DPPH (AYOOLA *et al.*, 2008). The method involves a color change in the molecule's radical, which is dark violet, and after reaction with the antioxidant substance, it becomes yellow or light violet (SILVEIRA *et al.*, 2018).

The potential of different medicinal plant extracts in the form of teas to scavenge free radicals was expressed as the final concentration of the extract required to inhibit 50% of DPPH radical oxidation, and the results are described in Table 4. Antioxidant substances present in the extracts react with DPPH, which is a stable radical. The degree of discoloration indicates the antioxidant potential of the extract. An extract with a high radical scavenging potential has a low IC50 value. Thus, a small amount of extract can decrease the initial concentration of the DPPH radical by 50%, i.e., inhibit 50% of the radical's oxidation (ROESLER *et al.*, 2007). The IC50 values obtained from the DPPH method in the samples are described in Table 4.

Table 4 - IC50 values (mg/mL) for antioxidant activity assays using the DPPH method.

Samples	*IC 50 DPPH mg/mL*
A	15,43
B	15,79
C	22,3
D	15,40
E	15,86

Source: Author's constructio n.

DISCUSSION

PHYSICOCHEMICAL ANALYSES

The tea samples sold in Santa Maria-RS exhibit water activity levels above the permissible limit, creating favorable conditions for microbial growth and other chemical, physical, and enzymatic reactions that lead to food spoilage. In a study analyzing water activity in green tea, Firmino (2011) evaluated 25 brands and found that 10 exceeded the threshold of 0.600 aw. Similarly, all samples in our study showed water activity levels above 0.60 aw, a condition that, according to Park *et al.* (2008), promotes microbial proliferation and spoilage reactions. This issue demands attention, as deviations in product quality may pose health risks to consumers, particularly due to the potential presence of mycotoxins, such as aflatoxins, produced by certain fungi.

Mycotoxin ingestion can lead to toxicological effects ranging from acute toxicity to mutagenic, carcinogenic, teratogenic, and immunosuppressive consequences. The severity of these effects depends on factors such as mycotoxin type, dosage, exposure duration, and individual characteristics, including age, sex, nutritional status, and overall health (PEREIRA; SANTOS, 2011; LIMA, 2010).

Regarding the determination of total ash, the results indicate that all analyzed samples are within the ash content limits established by the Brazilian Pharmacopoeia (BRASIL, 2019), representing an adequate amount of inorganic material in the samples, which suggests that they do not contain excess soil or sand. For total ash, the reference value is a maximum of 14% (INSTITUTO ADOLFO LUTZ, 2008).

The sample E exhibited the highest moisture content (16.25%), exceeding the limit established by the Brazilian Pharmacopoeia (BRASIL, 2019), which sets a permissible range of 8% to 14% for herbal drugs. Excessive moisture in plant materials promotes microbial growth and hydrolysis, accelerating the degradation of bioactive compounds. While proper post-harvest drying prevents such deterioration, inadequate drying can lead to the loss of essential chemical constituents, microbial contamination, and reduced active principle content (BRASIL, 2019).

MICROBIOLOGICAL ANALYSES

Collegiate Board Resolution No. 10 of March 9, 2010, issued by the National Health Surveillance Agency (ANVISA), establishes that microbiological contaminant testing - including aerobic bacteria, fungi, *Escherichia coli*, other enterobacteria, *Salmonella* s p. , and aflatoxins - must comply with either the Brazilian Pharmacopoeia or World Health Organization (WHO) guidelines (BRASIL, 2010; 2019). The Brazilian Pharmacopoeia (BRASIL, 2019) does not specify limits for total coliforms but sets a maximum of 10^3 MPN/g for fecal coliforms in teas and similar products. All analyzed samples exceeded these permissible levels.

Microbiological analyses are essential for ensuring product safety by verifying the absence of pathogenic or harmful microorganisms, while also allowing for acceptable microbial limits in herbal drug quality (PINTO *et al.*, 2010). The WHO (2004) mandates that *Salmonella* s p. must be absent in medicinal plants for internal use. Although the analyzed samples tested negative for *Salmonella* s p. , its potential presence remains a critical concern, as it is a leading cause of foodborne illnesses globally, including in Brazil (SHINOHARA *et al.*, 2008).

While no legal thresholds exist for *Staphylococcus aureus* in medicinal plants, its detection renders the product unfit for consumption due to the risk of thermoresistant staphylococcal toxins persisting in teas (ROCHA *et al.*, 2013). Microbial contamination in non-sterile products can lead to spoilage, chemical alterations, and serious health risks, including infections (BRASIL, 2019). Kalumbi *et al.* (2020) similarly found microbial levels in plant samples exceeding WHO standards, underscoring the need for greater awareness among policymakers regarding bacterial contamination in herbal medicine.

Even when subjected to high-temperature preparations (e.g., boiling or infusions), certain microorganisms produce heat-stable enterotoxins that remain active in the final product (ROCHA *et al.*, 2008). Contaminated herbal materials can cause consumer illnesses, primarily bacterial infections, though fungi, parasites, and viruses also pose risks. Bacteria thrive in favorable conditions with adequate nutrients, temperature, pH, and moisture (ALVES, 2012). Despite the growing popularity of herbal medicine, commercialization often compromises product quality. Proper handling and storage are crucial, as microbiological contamination can have a severe impact on consumer safety (BITENCOURT *et al.*, 2024).

BIOACTIVE COMPOUNDS

In recent years, substantial evidence has highlighted the critical role of free radicals and other oxidants in aging and age-related degenerative diseases, including cancer, cardiovascular disorders, cataracts, immune system decline, and brain dysfunction (ATOUI *et al.*, 2005). To assess antioxidant activity, the ABTS radical scavenging assay is widely employed due to its versatility in evaluating

both lipophilic and hydrophilic compounds, such as flavonoids, carotenoids, and plasma antioxidants, through chemical, electrochemical, or enzymatic reactions (RE *et al.*, 2018; RUFINO *et al.*, 2007).

The efficacy of antioxidant capacity varies significantly depending on the tea species and the concentration/type of phenolic compounds present (ZIELINSKI *et al.*, 2014). Phenolic compounds, particularly tannins, are key contributors to this activity, as their hydroxyl and carboxyl groups enable metal chelation (e.g., iron and copper), neutralizing oxidative damage (MICHALAK, 2006). These phytochemicals not only scavenge free radicals but also modulate enzymes involved in detoxification and redox processes (SILVA *et al.*, 2017).

Herbal antioxidants - primarily polyphenols and flavonoids - play a vital role in mitigating oxidative stress (KHALAF *et al.*, 2008). For instance, studies using ABTS and DPPH assays report radical scavenging capacities ranging from 52.08% to 85.13% and 52.28% to 79.41%, respectively. However, the antioxidant potency of plants varies by type. Moraes *et al.* (2009) evaluated Brazilian teas via the DPPH method, identifying green tea (*Camellia sinensis*, IC50: 0.14 mg/mL), cinnamon (*Cinnamomum zeylanicum*, IC50: 0.37 mg/mL), and clove (*Eugenia aromatica*, IC50: 0.46 mg/mL) as having notably high antioxidant activity due to their phenolic content. In contrast, our study observed higher IC50 values (15.40-22.3 mg/mL), suggesting comparatively lower antioxidant efficacy in the tested samples.

LIMITATIONS OF THE STUDY

This study's primary limitation is the small number of tea samples analyzed, which may restrict the generalization of the results. The limited sample size hampers the extrapolation of data to different varieties, brands, or batches of the product, and may also influence the statistical validity of the conclusions. It is recommended that future research increase the number of samples and include greater diversity in the origins and processing methods of the tea.

CONCLUSION

The analyzed samples of medicinal plants sold in Santa Maria, RS, failed to meet microbiological standards required by legislation, as all tested plants intended for tea preparation showed contamination levels exceeding recommended limits. This contamination likely stems from inadequate practices during production stages such as irrigation with contaminated water, harvesting, storage, drying, and improper handling. To address this, hygienic-sanitary improvements, stricter inspections, regulatory compliance, handler training, and enhanced oversight of the entire production chain are urgently needed, especially given the widespread use of these plants as therapeutic resources. While the total ash and moisture content fell within established limits, the elevated water activity in all samples poses risks by promoting microbial growth and chemical/enzymatic reactions that degrade plant

quality. The sale of substandard medicinal plants is concerning, as users are exposed to pathogens and spoiled products. Despite these issues, the samples exhibited high levels of phenolic and flavonoid compounds associated with health benefits and demonstrated significant antioxidant capacity, as determined by DPPH and ABTS assays. These findings underscore the importance of characterizing such plants to guide consumers toward options with greater medicinal efficacy. This is particularly relevant given rising global demand for natural antioxidants, which combat free radicals, mitigate cellular aging, and aid in disease prevention, ultimately enhancing well-being.

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