

Analysis of bioactive compound content in lemongrass (*Cymbopogon citratus*) in its natural form and infusion extract

Análise do conteúdo de compostos bioativos em capim-limão (*Cymbopogon citratus*) em sua forma natural e extrato de infusão

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(Recebido em 05 de abril de 2025; aceito em 15 de maio de 2026)

Lemongrass (*Cymbopogon citratus*) is a widely used medicinal plant in traditional medicine, particularly in the Amazon region. whether in its natural form or as an infusion. Therefore, the present study aimed to compare the bioactive compound content of lemongrass in its natural form and as an infusion extract, assessing its phytochemical profile and the presence of major chemical groups. The study followed internationally accepted methodological standards. The analysis of fresh lemongrass leaves revealed the presence of 78.11 mg GAE/g of phenolic compounds, 69.46 mg/g of flavonoids, 18.29 mg/g of anthocyanins, 2.51 µg/100g of chlorophyll a, 3.27 µg/100g of chlorophyll b, and 17.11 mg/100g of vitamin C, along with an ABTS antioxidant potential of 511.52 ± 0.06 (µM Trolox/g). In contrast, the infusion extract showed a significant reduction in all bioactive compounds, with measured values of 23.25 mg GAE/g of phenolic compounds, 1.32 ± 0.102 mg/g of flavonoids, 0.65 ± 0.131 mg/g of anthocyanins, 0.019 ± 0.002 µg/100g of chlorophyll a, 0.021 ± 0.001 µg/100g of chlorophyll b, and 4.53 ± 1.515 mg/100g of vitamin C. These findings indicated that the combination of water and high temperatures negatively affected the functional properties of lemongrass. Fourier-transform infrared spectroscopy (FTIR) confirmed the presence of functional groups associated with structural and energetic compounds. Therefore, lemongrass was characterized as a medicinal herb with significant levels of bioactive compounds, which underwent partial degradation during the thermal infusion process.

Keywords: phytochemical profile, antioxidant activity, plant extract.

O capim-limão (*Cymbopogon citratus*) é uma planta medicinal amplamente utilizada na medicina tradicional, principalmente na região amazônica, seja na forma natural ou de infusão. Assim, o presente estudo teve como objetivo comparar o teor de compostos bioativos do capim-limão na forma natural e na forma de extrato de infusão, avaliando seu perfil fitoquímico e a presença dos principais grupos químicos. O estudo seguiu padrões metodológicos aceitos internacionalmente. A análise das folhas frescas de capim-limão revelou a presença de 78,11 mg GAE/g de compostos fenólicos, 69,46 mg/g de flavonoides, 18,29 mg/g de antocianinas, 2,51 µg/100g de clorofila a, 3,27 µg/100g de clorofila b e 17,11 mg/100g de vitamina C, juntamente com um potencial antioxidante ABTS de $511,52 \pm 0,06$ (µM Trolox/g). Em contraste, o extrato de infusão apresentou redução significativa em todos os compostos bioativos, com valores medidos de 23,25 mg GAE/g de compostos fenólicos, $1,32 \pm 0,102$ mg/g de flavonoides, $0,65 \pm 0,131$ mg/g de antocianinas, $0,019 \pm 0,002$ µg/100g de clorofila a, $0,021 \pm 0,001$ µg/100g de clorofila b e $4,53 \pm 1,515$ mg/100g de vitamina C. Esses achados indicaram que a combinação de água e altas temperaturas afetou negativamente as propriedades funcionais do capim-limão. A espectroscopia de infravermelho por transformada de Fourier (FTIR) confirmou a presença de grupos funcionais associados a compostos estruturais e energéticos. Portanto, o capim-limão foi caracterizado como uma erva medicinal com níveis significativos de compostos bioativos, que sofreram degradação parcial durante o processo de infusão térmica.

Palavras-chave: perfil fitoquímico, atividade antioxidante, extrato vegetal.

1. INTRODUCTION

Cymbopogon citratus, commonly known as lemongrass, citronella grass, or fever grass, depending on the region where it is cultivated, is a plant native to India and widely grown in tropical and subtropical regions worldwide, including South America, Africa, and Southeast Asia [1]. Its value is attributed to its medicinal properties and essential oil, which is used in a variety of cosmetic products, including perfumes, soaps, and cleaning agents, in addition to being a popular ingredient in culinary preparations, primarily in the form of tea [2].

In Brazil, *C. citratus* is widely used in traditional medicine, with its tea consumption deeply rooted in therapeutic cultural practices. It is predominantly prepared through homemade infusions, with the leaves being the most utilized part due to their phytochemical properties, as they contain classes of compounds associated with secondary metabolites, phytoconstituents, or phytochemicals that play important roles in plants. Phytochemical screening of plant materials is typically the starting point for the isolation and purification of natural compounds with bioactivity, providing data on their functionality [3-6].

These secondary metabolites are more commonly known as active principles. They are constituents derived from photosynthetic products that serve as a defense mechanism for the plant, ultimately providing medicinal effects upon human consumption. Secondary metabolites can be classified into three main groups: terpenoids, phenolic compounds, and nitrogen-containing compounds [7].

Among the most notable bioactive constituents of this plant are phenolic compounds such as flavonoids and pigments like chlorophyll a and b. Additionally, the presence of alkaloids, terpenoids, tannins, and citral, a compound found in its essential oil, has been reported [1, 8, 9].

Due to its broad range of bioactive compounds, lemongrass is considered promising for therapeutic applications, with potential to prevent and mitigate pathological conditions due to its anti-inflammatory and antioxidant properties (Figure 1). These properties can act within the human body and contribute to the treatment of various clinical conditions, such as hypertension and cellular oxidation, thereby helping prevent cancerous cells and cardiovascular diseases, which are classified as non-communicable chronic diseases (NCDs) with high mortality rates worldwide [10-12].

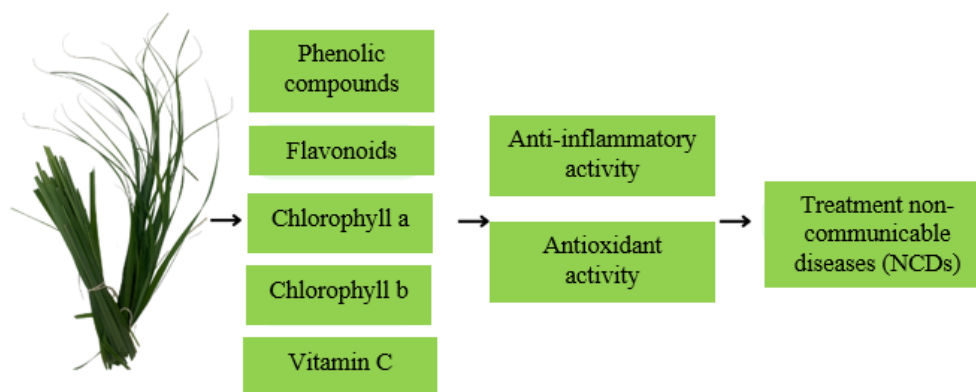


Figure 1: Bioactive compounds present in lemongrass and their functionalities

However, it is essential to consider the potential alterations induced by the preparation method of infusion (the predominant form of consumption) on the natural composition of its leaves. The introduction of the water-temperature binomial in the preparation process may modify the composition of its bioactive phytoconstituents.

Given the above, the objectives of this study was to analyse and compare the bioactive compound content in fresh lemongrass leaves and in their infusion extract, performs a phytochemical screening of the tea, and assess the spectroscopic pattern of fresh leaves following the preparation recommendations outlined in the Brazilian Pharmacopoeia [1] through experimental-based analyses.

2. MATERIALS AND METHODS

2.1 Sample Collection

Fresh lemongrass (*Cymbopogon citratus* (DC.) Stapf) samples were obtained from the Federal University of Pará (UFPA) in the municipality of Belém, Pará, Brazil (geographical coordinates: latitude -1.4699206 and longitude -48.4456609). The samples were transported to the Food Science Laboratory at the UFPA Faculty of Nutrition.

2.2 Biometric Analysis of Fresh Leaves

A biometric analysis of fresh lemongrass leaves was performed to characterize the physical properties of the plant material prior to the experimental procedures. The parameters evaluated included transverse length (cm), longitudinal length (cm), and fresh weight (g). Measurements were obtained using a ruler and a semi-analytical balance. All analyses were conducted in triplicate, and the results were expressed as mean values.

2.3 Preparation of Fresh Lemongrass Samples

The lemongrass leaves were selected and cut. They were then washed under running water and sanitized in containers with sodium hypochlorite diluted to 200 ppm (parts per million) for 15 minutes. Finally, the leaves were rinsed again under running water, dried at room temperature, and cut into smaller pieces (Figure 2).



Figure 2: Flowchart of the infusion sample preparation process.

2.4 Preparation of Lemongrass Infusion Extract (Tea)

For tea preparation, 3 grams of the cut fresh sample were placed in a beaker. Then, 150 mL of potable water was heated to approximately 80 °C and poured into the same beaker. The beaker was covered with aluminum foil and left to steep for five minutes [1]. Finally, the liquid was filtered and separated from the leaves, as illustrated in the flowchart in Figure 3.

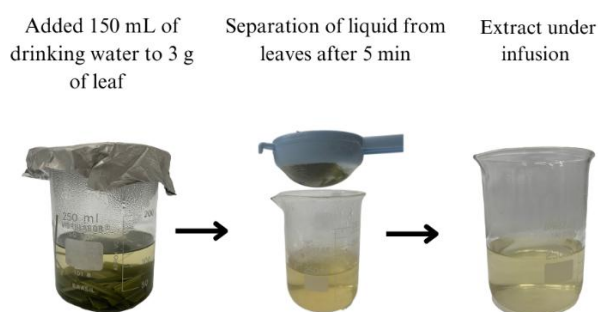


Figure 3: Flowchart of the infusion sample preparation process.

2.5 Physicochemical Characteristics Analysis

Water activity (A_w) was measured using the Labmaster-aw neo-Series 3TE by NOVASINA, with internal temperature control set at 25 °C. Moisture content was determined according to the methodology of the Adolfo Lutz Institute (1985) [13]. The hydrogen potential (pH) was analysed using method N°. 981.12 from AOAC (1997) [14]. Total titratable acidity (TTA) was assessed according to the analytical standards of the Adolfo Lutz Institute (1985) [13]. Total soluble solids (TSS) were determined through refractive index measurement following IAL (2008) [15]. All analyses were performed in triplicate.

2.6 Phytochemical Screening

The phytochemical screening was conducted using the qualitative methodology proposed by Matos (2009) [16] and applied to crude fractions of the aqueous extract to detect phenols and tannins (reaction with ferric chloride); anthocyanins, anthocyanidins, flavonoids, leucoanthocyanidins, catechins, and flavanones (pH variation using hydrochloric acid and sodium hydroxide); flavonols, flavanones, and xanthenes (reaction with metallic magnesium and concentrated hydrochloric acid). The analyses of anthraquinones, coumarins, saponins, and tannins followed the methodologies proposed by Costa (1986) [17] and Simões (2001) [18]. The results of each assay were qualitatively assessed based on color changes, foam formation, and precipitation reactions. A cross-test was applied to determine the absence (-) or presence (+) of the evaluated phytochemical class (Table 1).

Table 1: Phytochemical analyses and their methodologies.

Phytochemicals	Detection Methods and Indicators		
	Reagent	Methodology	Positive Reaction
Alkaloids	Dragendorff reagents	Extracts concentrated and dissolved in 3 mL of 2% hydrochloric acid. Divided into three equal portions, and Mayer's, Dragendorff's, and silicotungstic acid solutions were added dropwise.	Formation of a precipitate
Anthraquinones	Benzene and 10% ammonium hydroxide	0.5 mL of benzene was added to 1 mL of the extract at 0.2 mg/mL concentration and 6 mL of distilled water, followed by ten drops of 10% ammonium hydroxide solution.	Pink, red, or violet coloration in the aqueous phase
Catechins	Concentrated HCl	A wooden matchstick was moistened with the hydroalcoholic extract and concentrated HCl.	Red or reddish-brown coloration
Coumarins	Potassium hydroxide (KOH)	A drop of extract was placed on filter paper, followed by a drop of KOH solution.	Blue or green fluorescence
Saponins	Hydroalcoholic extract	The extract was shaken for 5 minutes, and the foam formation was observed for 30 minutes.	Stable foam layer for more than 30 minutes
Phenols and Tannins	Ferric chloride (FeCl_3)	Three drops of FeCl_3 solution were added to the extract.	Color change or precipitate formation

2.7 Analysis of Bioactive Compound Concentration

2.7.1 Total Phenolic Compounds

The total phenolic content was determined using the Folin-Ciocalteu assay, following the methodology of Ali Akbarian et al. (2011) [19], with adaptations. UV-Vis spectrophotometry (IL-592, KASUAKI) was performed at a wavelength of 760 nm. A standard curve using gallic acid was constructed, with $R^2 = 0.983$.

2.7.2 Flavonoids

Flavonoid content analysis was performed according to the methodology described by Lees and Francis (1972) [20], using a UV-Vis spectrophotometer (IL-592, KASUAKI) at a wavelength of 374 nm.

2.7.3 Analysis of Pigment Concentration

The methodology followed the model proposed by Nagata and Yamashita (1992) [21], with adaptations. The wavelengths used in the UV-Vis spectrophotometer (IL-592, KASUAKI) were 663 and 645 nm. The analyses for both samples were performed in triplicate and calculated using Equations 1 and 2:

$$\text{Equation 1: Chlorophyll A Content } (\mu\text{g/g}) = -0.999A_{663} + 0.989A_{654}$$

$$\text{Equation 2: Chlorophyll B Content } (\mu\text{g/g}) = -0.328A_{663} + 1.77A_{654}$$

2.8 Vitamin C Analysis

Vitamin C analysis was performed based on AOAC methodology (1997) [14], using a burette filled with 0.1% 2,6-dichlorophenol-indophenol (DCPIP) solution. A 10 mL aliquot of the aqueous extract from fresh and infusion samples was placed in an Erlenmeyer flask, followed by the addition of 50 mL of oxalic acid. The titration was carried out until a slight pink color persisted for 30 seconds. The results were obtained in triplicate for both samples and expressed in mg/100g, according to Equation 3.

Equation 3: Ascorbic Acid (AA) Calculation

$$AA = \frac{100 \times n'}{\frac{(n)}{5} \times P}$$

Where:

- n' : Volume of DCPIP used in the sample titration
- n : Volume of DCPIP used for standardization
- P : Sample mass in grams or volume used in titration

2.9 Antioxidant Activity Assay

The ABTS radical scavenging activity of the extracts was determined according to the method of Larrauri et al. (1997) [22], using a UV-Vis spectrophotometer (IL-592, KASUAKI) at a wavelength of 734 nm. A standard curve was generated using different concentrations of Trolox (100, 500, 800, 1000, and 2000 μM). The results were expressed as μM Trolox/g (Figure 4).

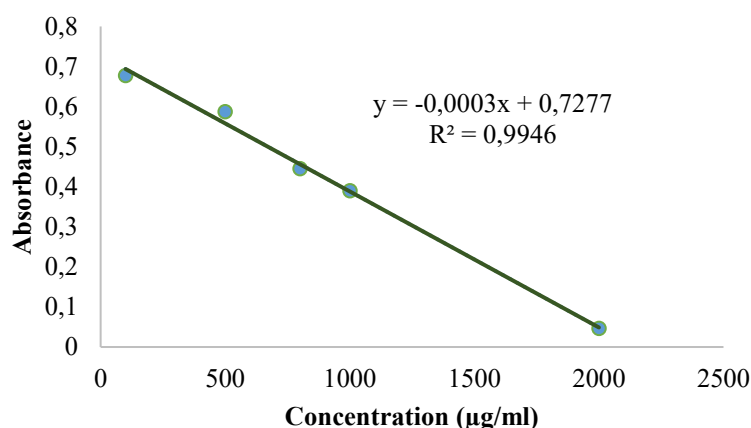


Figure 4 – Analytical curve at different Trolox concentrations.

2.10 Fourier Transform Infrared Spectroscopy (FTIR)

Absorption spectra of the samples were obtained using Fourier Transform Infrared Spectroscopy (FTIR) with a Perkin Elmer Frontier 98737 spectrometer (Waltham, MA, USA). Spectral absorption frequencies ranged from 4000 to 400 cm^{-1} . The samples were incorporated into potassium bromide (KBr) pellets, scanned 100 times at a resolution of 4 cm^{-1} .

3. RESULTS AND DISCUSSION

3.1 Biometric Analysis of Fresh Leaves

Table 2 presents some biometric parameters evaluated in this study, such as transverse length, longitudinal length, and weight.

Table 2: Biometric values of fresh lemongrass leaves.

Parameters	Maximum	Minimum	Mean $\pm$ Standard Deviation
Transverse (cm)	2.10	1.40	1.69 $\pm$ 0.91
Longitudinal (cm)	100.00	56.70	87.09 $\pm$ 13.51
Weight (g)	2.48	0.82	1.89 $\pm$ 0.52

A significant difference in standard deviation values between the means of longitudinal and transverse lengths can be observed, indicating that the leaves exhibit various sizes. This characteristic is commonly observed in many plant species and may be attributed to the adaptation of plants to different environments and biological functions influenced by edaphoclimatic factors [1, 23].

3.2 Physicochemical Characteristics Analysis

The results of the physicochemical analyses of fresh lemongrass (*C. citratus*) and its infusion extract (tea) are presented in Table 3.

Table 3 – Physical characterization of fresh lemongrass leaves and their infusion extract.

Analysis	FL	IE
Aw	0.89 ± 0.00	-
Moisture (%)	64.06 ± 2.12	-
pH	6.13 ± 0.04 ^b	7.66 ± 0.10 ^a
TTA (%)	1.89 ± 0.03 ^a	0.63 ± 0.01 ^b
TSS (°Brix)	0.86 ± 0.05 ^a	0.12 ± 0.01 ^b

Values are expressed as mean ± standard deviation (n = 3). Different superscript letters in the same row indicate significant differences between samples ($p < 0.05$) according to the Student's t-test. The symbol (-) indicates analysis not applicable to the infusion extract sample.

The physical characterization showed differences between the fresh leaves (FL) and the infusion extract (IE). The FL sample presented a water activity of 0.89 and moisture content of 64.06%, parameters that were not determined for the infusion extract. Regarding pH, the IE showed a significantly higher value (7.66) than FL (6.13), indicating a less acidic medium after infusion. In contrast, titratable acidity was significantly higher in FL (1.89%) compared to IE (0.63%). Similarly, total soluble solids were higher in FL (0.86 °Brix) than in IE (0.12 °Brix), suggesting a reduction in soluble constituents after the extraction process.

The FL sample presented a high *Aw* value of 0.89, similar to the results found by Santos et al. (2021) [24] who reported 0.91. This high *Aw* value suggests potential susceptibility to contamination, as well as a greater likelihood of undergoing chemical and microbiological alterations, which is particularly relevant for plant-based products [25]. The moisture content of FL was 64.06%, indicating a significant amount of water in its composition. Comparing this with the moisture content reported by Gomes et al. (2020) [26] for *C. citratus* leaves (79.3%), a higher value was observed in the cited study. This discrepancy may be attributed to differences in analytical techniques and may indicate a specific adaptation of the plant to the environmental conditions of the study location. However, both values confirm the high moisture content of the plant.

Regarding the pH of the samples, the FL sample showed a pH value close to those reported by Ani et al. (2022) [27] and Mabai et al. (2018) [28], who found values around 7, indicating neutrality. Meanwhile, the study by Campo-Fernández et al. (2020) [3] reported a pH of 6.73 for lemongrass infusion extract. These findings suggest that the infusion preparation process does not significantly influence pH changes compared to the fresh sample.

For total titratable acidity (TTA), both samples showed low values, which is expected for an alkaline plant. The small difference between the values corroborates previous findings [27]. The TSS analysis of fresh lemongrass leaves indicated a significant presence of soluble compounds, similar to the study by Santos et al. (2021) [24], which reported a value of 0.9. In contrast, the IE sample exhibited a lower concentration of these compounds (0.12 ± 0.01), comparable to the results of Oliveira et al. (2021) [4], who found 0.20. This reduction may be associated with dilution effects and the possible loss of soluble solids during the infusion preparation process.

3.3 Phytochemical screening

A phytochemical screening of the extracts was conducted (Table 4) to evaluate the possible classes of secondary metabolite groups.

Table 4: Phytochemical screening of fresh lemongrass leaves and their infusion extract.

Secondary Compound Class	FL	IE
Alkaloids	-	-
Anthraquinones	-	-
Catechins	+	-
Coumarins	+	-
Saponins	-	-
Phenols and Tannins	+	+

(+) Positive reaction, (-) Negative reaction, FL= Fresh leaves, IE = Infusion extract.

The preliminary phytochemical screening revealed the presence of catechins, coumarins, phenols, and tannins, and the absence of alkaloids, anthraquinones, and saponins in FL. The phytochemical profile of lemongrass leaves, including catechins, coumarins, phenols, and tannins, is highly promising. Catechins are known for their antioxidant properties, which help neutralize free radicals and protect cells from oxidative stress, contributing to cardiovascular health and cancer prevention [3]. Additionally, the coumarins found in lemongrass possess anti-inflammatory properties that may help alleviate symptoms of chronic inflammation, benefiting joint and muscle health [29]. Phenols and tannins also play important roles, providing astringent and antimicrobial effects, which can be beneficial for gastrointestinal health [30-33].

Environmental conditions play a crucial role in determining the chemical composition of plants, including lemongrass. Factors such as intense sunlight, water availability, temperature, and the presence of pathogens directly influence the production of secondary compounds such as alkaloids, anthraquinones, and saponins [34, 35].

On the other hand, the IE sample contained only phenols and tannins, with negative results for catechins, coumarins, alkaloids, anthraquinones, and saponins. These results demonstrate that the tea preparation process, which involves the water-temperature binomial, influences the presence of phytochemicals, leading to their degradation during infusion [36]. However, the presence of phenols and tannins in the tea indicates that these compounds are more stable and water-soluble, remaining present during the infusion preparation and maintaining their beneficial properties [37]. Thus, FL retains a greater diversity of phytochemicals.

3.4 Bioactive compounds analysis and ABTS antioxidant potential assay

Table 5 presents the bioactive compounds values: phenolic compounds, flavonoids, chlorophyll a and b, vitamin C, and ABTS antioxidant assay results for the studied samples.

Table 5: Characterization of bioactive compounds, vitamin C, and antioxidant assay in fresh leaves and infusion extract samples.

Bioactive Compounds	FL	IE
Phenolics (mg GAE/100g)	78.11 ± 2.86 ^a	23.25 ± 3.56 ^b
Flavonoids (mg/g)	69.46 ± 0.30 ^a	1.32 ± 0.10 ^b
Chlorophyll a (µg/100g)	2.51 ± 0.04 ^a	0.02 ± 0.00 ^b
Chlorophyll b (µg/100g)	3.27 ± 0.05 ^a	0.02 ± 0.00 ^b
Vitamin C (mg/100g)	17.11 ± 1.70 ^a	4.53 ± 1.51 ^b
ABTS (µM Trolox/g)	511.52 ± 0.06 ^a	0.82 ± 0.20 ^b

Values are expressed as mean ± standard deviation (n = 3). Different superscript letters in the same row indicate significant differences between samples (p < 0.05) according to the Student's t-test. FL= Fresh leaves, IE = Infusion extract

The analysis of bioactive compounds revealed that the fresh leaves (FL) showed significantly higher concentrations of all evaluated compounds compared to the infusion extract (IE). Total phenolic compounds were markedly higher in FL (78.11 mg GAE/100 g) than in IE

(23.25 mg GAE/100 g), indicating a substantial reduction after the infusion process. Irfan et al. (2022) [37] reported high phenolic values for *C. citratus* (55.2 mg GAE/g), supporting the results observed in FL, while Aboagye et al. (2021) [38] found lower values in tea samples (10.52 mg GAE/100 mL), consistent with the reduction observed in IE.

A similar trend was observed for total flavonoid content, with FL presenting 69.46 mg/g, while IE showed only 1.32 mg/g. Irfan et al. (2022) [37] reported high phenolic values for *C. citratus* (55.2 mg GAE/g), supporting the results observed in FL, while Aboagye et al. (2021) [38] found lower values in tea samples (10.52 mg GAE/100 mL), consistent with the reduction observed in IE.

Chlorophyll contents were also considerably greater in FL, with chlorophyll a and chlorophyll b values of 2.51 and 3.27 $\mu\text{g}/100\text{ g}$, respectively, whereas IE presented negligible amounts (0.02 $\mu\text{g}/100\text{ g}$ for both pigments). Vitamin C content was significantly higher in FL (17.11 mg/100 g) compared to IE (4.53 mg/100 g). Yassien et al. (2022) [39] reported 38.4 mg GAE/100g for *C. citratus*, supporting the elevated levels in FL, while Reis et al. (2019) [40] observed low flavonoid content in tea samples (1.52 mg/g), in agreement with the values obtained for IE. This behavior is associated with the instability of chlorophyll under heat and its transformation into degradation products, in addition to its limited stability in aqueous systems [41]. Yaman (2020) [42] observed lower vitamin C values in tea (0.61 mg/100g), supporting the trend identified. Additionally, pH may influence stability, as vitamin C degrades more rapidly in less acidic conditions [43].

Likewise, antioxidant activity measured by ABTS assay was substantially greater in FL (511.52 μM Trolox/g) than in IE (0.82 μM Trolox/g), demonstrating that the fresh leaves retained a much higher antioxidant potential than the infusion extract. This difference reflects the loss of bioactive compounds responsible for antioxidant activity, particularly phenolics and flavonoids, which are degraded or insufficiently extracted during the process [44]. Consequently, the lower antioxidant capacity of IE demonstrates that the infusion process reduces the efficiency of radical neutralization [45].

Overall, the results indicate that the infusion process reduced the concentration of bioactive compounds and antioxidant capacity, likely due to dilution and partial degradation or limited extraction of these constituents into the aqueous medium. This reinforces the relationship between compound preservation and functional potential, as these substances play an important role in neutralizing free radicals associated with cellular damage and chronic diseases [46, 47].

3.5 Chemical group analysis by Fourier Transform Infrared Spectroscopy (FTIR)

Figure 5 presents the prominent chemical groupings in fresh lemongrass leaves.

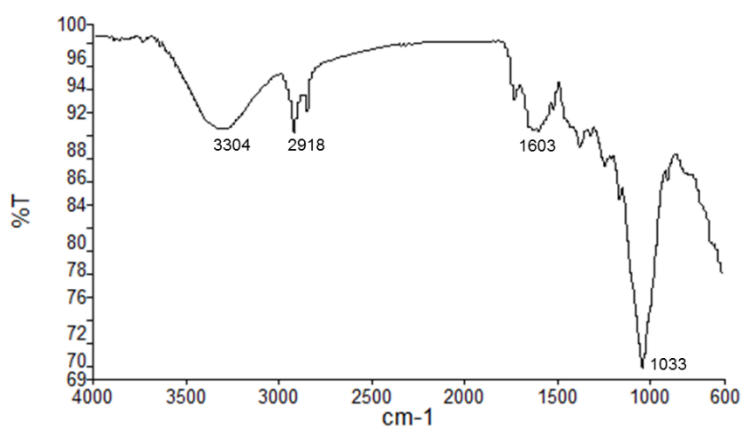


Figure 5: FTIR profile of the FL sample.

Spectral analyses indicate that the broad bands at 3,304 cm^{-1} and 1,603 cm^{-1} correspond to the stretching vibrations of -OH groups, commonly found in cellulose membranes and water [48]. The bands observed at 2,918 cm^{-1} and 1,033 cm^{-1} may be associated with CH_2 bending in hemicellulose and CH vibrations, typical in carbohydrates and lignin - substances abundant in plant materials such as lemongrass leaves [49].

These bands confirm the presence of fundamental energy constituents necessary for cellular metabolic pathways, including carbohydrates and fiber-based structural components such as cellulose and hemicellulose.

4. CONCLUSION

The analyzed data revealed the phytochemical characteristics of lemongrass (*Cymbopogon citratus*) in its fresh form and as an infusion extract. The findings evidenced a high content of bioactive compounds in fresh leaves, with notable concentrations of flavonoids, chlorophyll a and b, and vitamin C, while a comparative reduction was observed in the infusion extract.

These discoveries highlight the potential of fresh leaves as a valuable source of compounds with antioxidant and nutritional properties, suggesting that their direct consumption in food may be an effective strategy for promoting health and preventing diseases. Furthermore, the study emphasizes the importance of considering different preparation methods for medicinal plants and their effects on the concentration of bioactive compounds. Understanding how preparation methods affect the chemical composition of plants is crucial for maximizing their therapeutic and nutritional potential.

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