RESEARCH PAPER

Chemical Characterization and Bioactivity Profiling of Cymbopogon citratus (Lemongrass) Essential Oil: Implications for Pharmaceutical, Food, and Agricultural Applications

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ABSTRACT

The essential oil of Cymbopogon citratus (lemongrass) is a very valuable natural resource that has a wide range of applications in the pharmaceutical, food and agricultural sectors. The study herein aims to chemically characterize and bioactivity profile Cymbopogon citratus essential oil by hydrodistillation method. The major bioactive components were identified by gas chromatography-mass spectrometry and the composition was mainly oxygenated monoterpenic compounds. Z-geranial (neral) and E-geranial (geranial) were the predominant compounds, followed by significant amounts of myrcene, geraniol and linalool. The antioxidant potential was assessed through bioactivity profiling using the 2,2-diphenyl-1-picrylhydrazyl (DPPH) assay, with strong free radical scavenging activity observed that is comparable to the average of commonly used synthetic antioxidants. Additionally, the essential oil was found to exhibit high antimicrobial activity against a wide range of foodborne pathogens and also had remarkable antifungal activity. The incorporation of this essential oil into active packaging matrices showed structural integrity and an extended preservation ability, and thus it could be used as a natural food preservative. The oil components were effective against the postharvest phytopathogens as biopesticides and vapor-phase antifungal agents in the field of agriculture. The detailed results confirm the therapeutic and industrial value of C. citratus essential oil, underscoring its promising shift from traditional ethnobotanical applications to sophisticated commercial formulations.

Keywords - Cymbopogon citratus, essential oil, gas chromatography-mass spectrometry, antioxidant activity, antimicrobial efficacy, natural food preservative and active packaging.

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INTRODUCTION

The world movement towards natural, sustainable, and biologically active compounds has triggered huge research on plant metabolites, especially essential oils. The benefits of natural products have been leveraged over millennia for treating ailments and diseases, while contemporary scientific research has confirmed their pharmacological and industrial applications (Al Naqqash et al., 2019)1. Cymbopogon citratus, commonly referred to as lemongrass, is a tropical perennial herb of Poaceae family with great commercial and medicinal value (Uraku, 2015)2. This aromatic grass was native to tropical and subtropical parts of Southeast Asia, India and Sri Lanka, but is now grown in many parts of the world, adding to the agricultural economies of many developing countries (Balanay & Guinancia, 2020)3. The volatile essential oil, which accumulates in the leaves and stalks, gives the plant its lemon like scent and strong biological activities, favouring this plant's high value. Consumers' growing awareness of the negative health and environmental effects of synthetic preservatives and agrochemicals has led to a rapid increase in demand for natural alternatives, such as lemongrass essential oil, in various industries (Rabbani et al., 2019)4. The pharmaceutical and food sectors have seen a significant change, with attention shifting towards the development of antimicrobial and antioxidant compounds sourced from plants and labeled as clean label products (Fernandes et al., 2015)5.

The essential oil of Cymbopogon citratus is a combination of very volatile lipophilic compounds, mainly oxygenated monoterpenes. Citral content, a stereoisomeric mixture of two aldehyde monoterpenes (geranial or trans-citral and neral or cis-citral), is a good indicator of the quality and market value of the essential oil. The essential oil's phytochemical content is not fixed and varies widely depending on geographic area, climate, soil type, plant maturity and the method of extraction (Kakaraparthi et al., 2014)6. The extraction methods used, such as hydrodistillation, microwave-assisted, and supercritical fluid extraction, are crucial in influencing both the yield and the chemical composition of the extracted oil (Do & Vu, 2012)7. It is important to understand these compositional differences because the proportion of these bioactive constituents determines the functional efficacy of the oil in the subsequent applications. Thus, for any proper industrial or pharmaceutical use of the plant material, precise chemical characterization is an essential prerequisite, which can only be achieved by applying advanced analytical techniques such as gas chromatography-mass spectrometry (GC–MS) (Aly et al., 2016)8. An exact identification of such volatiles enables researchers to foresee the therapeutic indices and the functional properties of the essential oil in complex biological systems.

The bioactivity profile of Cymbopogon citratus essential oil is the basis of its application in various fields besides its chemical composition. It is used in the pharmaceutical industry to treat a variety of ailments, including as a natural remedy in the fight against multidrug-resistant pathogens (Fernandes et al., 2015)5. Furthermore, its powerful antioxidant and anti-inflammatory actions have been associated with neuroprotection, possibly for the treatment of anxiety and oxidative stress-associated cellular damage and neurodegenerative diseases (Alvarado-García et al., 2023)9. In the food industry, the essential oil is also being used more and more as a natural preservative, which can inhibit foodborne pathogens and retard lipid oxidation (Selim et al., 2025)10. Moreover, the agricultural industry is investigating the use of lemongrass essential oil for protection of stored grain and post harvest crops as a biopesticide and vapor-phase fungicidal agent, which can be used without toxic chemical residues (Guven Bolgen, 2025)11. The current study is focused on the detailed chemical characterization and bioactivity profiling of Cymbopogon citratus essential oil, with the aim of identifying its molecular constituents and measuring the antioxidant and antimicrobial activities, in order to provide a solid basis for developing applications of this oil in pharmaceutical formulations, food preservation system, and sustainable agriculture.

Literature survey

In recent years, the scientific research on Cymbopogon citratus essential oil has gained considerable momentum, with a focus on understanding its chemical composition and biological activities, as well as its potential applications in various fields.The study of Cymbopogon citratus essential oil has been increasing in recent years, due to the use of advanced analytical techniques for understanding its chemical composition and biological activities, and its potential applications in various areas. The essential oil of E. insulana is rich in citral, which is its main bioactive compound, with its levels being 70-85% of the total essential oil, as reported in several studies (Rabbani et al., 2026)4. Research shows that the synergistic effect of citral and minor constituents like myrcene, linalool and geraniol in the oil is greater than the sum of its parts (Ellouze et al., 2024)12. The volatile profile of the oil has been studied using gas chromatography-mass spectrometry, and it has been found that various extraction conditions, including the type of raw material and the distillation time, affect the yield of these oxygenated monoterpenes, which are sensitive to heat (Do & Vu, 2024)7. Moreover, comparative studies of Cymbopogon species have shown that Cymbopogon nardus is more dominated by citronellal while Cymbopogon citratus has shown a high content of geranial and neral, making it more suitable for applications that demand powerful antimicrobial and antioxidant interventions (Abd Hamid et al., 2023)13. The exact determination of these stereoisomers has now become a criterion for evaluating the quality of commercial grade and therapeutic value of the collected biomass.

In the pharmaceutical and biomedical field, the neuroprotective and psychotropic properties of lemongrass essential oil have been well documented in recent literature. The oil has shown substantial anxiolytic-like activity in both clinical and preclinical studies, being mainly applied as aromatherapy and inhalation, without the side effects of synthetic anxiolytics, with an effective reduction of both physiological and psychological parameters of anxiety (Alvarado-García et al., 2023)9. Mechanistic insight into these effects has been gained by the use of advanced bioinformatics and in silico molecular docking studies, which show that certain compounds such as Z-geranial have high binding energies for specific central nervous system targets such as muscarinic acetylcholine receptors and dopamine receptors (Rojas et al., 2023)14. This interaction can influence the activity of neurotransmitter systems, potentially providing novel therapeutic strategies for neurodegenerative disorders like Alzheimer's disease and schizophrenia (Aly et al., 2025)8. Furthermore, the potent anti-inflammatory activity of the essential oil has been demonstrated to inhibit pro-inflammatory cytokines and pathways related to cellular oxidative stress, making it a promising agent for potential targeted drug delivery systems, such as lipid-based nanoemulsions with enhanced bioavailability and cellular uptake (Selim et al., 2025)10. The use of such nanotechnology applications is rapidly extending the range of possibilities for the stabilization of volatile oils in clinical pharmacology.

Cymbopogon citratus essential oil has undergone extensive research for incorporation into the food sector especially as a natural preservative and active packaging material. The antimicrobial properties of the oil are effective against the cell membrane of the most common food pathogens and food spoilage microorganisms, making the membrane of the cells leaky and allowing the leakage of intracellular compounds (Fernandes et al., 2024)5. In order to improve the inherent drawbacks of EOs in a food matrix (high volatility, high level of aroma interference, and low aqueous solubility), recent innovations have centered on microencapsulation and active packaging films. Studies have shown that lemongrass essential oil can be effectively incorporated into biodegradable polymer matrixes such as cassava starch and sodium alginate films, which can lower the water vapor permeability of the packaging material, while also allowing the controlled and sustained release of antimicrobial vapors onto the food surface (Vargas et al., 2024)15. This dual action not only prevents the growth of pathogens such as Staphylococcus aureus and Escherichia coli but also slows down the process of lipid peroxidation in fatty foods, preserving their sensory characteristics and significantly extending the product's shelf life (Rabbani et al., 2026)4. The effectiveness of the oil in ensuring microbiological stability of ready-to-drink beverages and dairy products during long shelf life is also confirmed in experimental models (Lizardo & Romuga, 2020)16.

In the field of agriculture, the literature highlights the changing trend of promoting alternative methods to synthetic agrochemicals, with lemongrass essential oil proving to be a highly effective and environmentally friendly solution. It has been found to be very toxic for a large number of agricultural pests such as stored grain insects, as well as contact poison and fumigant, acting as a contact poison by interrupting the nervous system of the insect and as a fumigant by inhibiting essential enzymatic functions (Guven Bolgen, 2025)11. In addition, the application of essential oil into the vapor phase has been found to be very effective against postharvest phytopathogenic fungi, such as Botrytis cinerea responsible for gray mould in fruits and vegetables. The mechanism is characterized by the rapid destruction of cell membranes of fungi, the reduction of cell defense enzymes against reactive oxygen species and the disturbance of mitochondrial energy metabolism, which ultimately results in irreversible collapse of the cells (Ellouze et al., 2024)12. The strong body of literature shows that Cymbopogon citratus essential oil has multi-target effects, reducing the risk of pathogen and pest resistance and making it widely applicable to various scientific and industrial fields (Abed et al., 2022)17.

Research methodology

The first part of the experimental methodology was the acquisition and preparation of the plant material. Cymbopogon citratus fresh and mature leaves were collected in the early morning hours to avoid decreasing the amount of volatile organic compounds and reduce degradation of heat-sensitive secondary metabolites. Harvested plant material was carefully botanically authenticated to establish its taxonomic identity prior to carefully washing it with distilled water to remove excess soil, dust and epiphytic contaminants. The leaves were then cut into pieces of uniform length (2-3 cm) and shade dried for seven days in a well-ventilated, moisture controlled room at ambient temperature. This controlled drying process allowed the elimination of moisture from the biomass while preserving the integrity of the glands responsible for the production of the essential oil, thus improving the material for the next stage, which is the hydrodistillation process (Conde-Hernández & Guerrero-Beltrán, 2015)18. The dried biomass was kept in opaque and airtight containers at 4°C before extraction, to avoid possible oxidation and premature volatilization of the active principles. These initial processing procedures ensured high degree of reproducibility, as well as reducing phytochemical changes before laboratory extraction.

The essential oil was extracted using a classical hydrodistillation procedure using a modified Clevenger-type apparatus; this is still the method used to obtain essential oils with high fidelity to its natural botanical profile. About 200 g of the dried leaves of Cymbopogon citratus were placed in a borosilicate round-bottom flask filled with 2 liters of deionized water. The hydrodistillation process was conducted continuously for one hundred and eighteen minutes or until all the volatile components were removed from the plant matrix without causing controlled heating to reach the boiling point (Do & Vu, 2024)7. This vaporized essential oil and steam went through the apparatus where it was cooled and condensed in a chilled water circulated glass heat exchanger. The distillate was separated into an aqueous and an organic (essential oil) phase in a separating funnel. The lighter essential oil was carefully decanted from the aqueous hydrosol and then dried by passing through a bed of anhydrous sodium sulfate to remove any water micro-droplets. The pure, anhydrous essential oil was quantified to identify the percentage yield in relation to the dried plant material and was immediately transferred to amber glass vials, sealed in a nitrogen atmosphere and stored at -4ºC until needed for chemical analysis and biological assays.

The chemical characterization of the extracted essential oil was carried out with respect to its volatile components using gas chromatography-mass spectrometry (GC-MS) technique, which yielded a high resolution. It was performed on a standard, multi-purpose gas chromatograph (GC) from Agilent, fitted with a single quadrupole mass spectrometer (MS), and a 30 m, 0.25 mm, 0.25 µm, non-polar HP-5MS capillary column. The inert carrier gas used was high purity helium and the flow rate was kept constant at 1 mL/min (Kumar et al., 2021)19. The sample was diluted 1:100 in analytical grade hexane, and 1 µL of the diluted sample was injected into the system via a split mode injection with a split ratio of 50:1. The temperature of the injector port was always kept at two hundred and fifty degrees Celsius. The oven temperature programming was carefully designed to avoid mixing peaks of complex co-elution: The oven temperature was adjusted to fifty degrees Celsius and held for three minutes, then increased at a linear rate of five degrees Celsius per minute to a final oven temperature of two hundred and eight degrees Celsius, which was maintained for ten minutes. The mass spectrometer was run in electron ionization mode, using an ionization energy of seventy electron volts and scanning the range of mass-to-charge ratio from 35 to 500 atomic mass units. Identification of individual chemical constituents was based on the matching of their mass fragmentation patterns and retention index against the National Institute of Standards and Technology mass spectrum library database (Uraku, 2015)2.

An antioxidant activity and antimicrobial activity were conducted as part of the bioactivity profiling of the essential oil, to determine its functional efficacy. The antioxidant capacity was measured by the well-known 2,2-diphenyl-1-picrylhydrazyl (DPPH) free radical scavenging assay. The essential oil was added to a freshly prepared methanolic solution of DPPH in varying concentrations (from 10 to 200 micrograms per milliliter). Both reaction mixtures were well vortexed and incubated in complete darkness at room temperature for half an hour for the reaction to come to equilibrium. The DPPH radical reduction was spectrophotometrically measured by tracking the absorbance at 517nm (Valková et al., 2022)20. L-ascorbic acid was used as a positive control for comparison. The percentage of free radical scavenging activity was determined and the half-maximal inhibitory concentration (IC50) was evaluated by linear regression analysis. At the same time, the antimicrobial activity of essential oil was tested by broth microdilution method for MIC against selected food borne pathogens. Ninety-six-well microtiter plates were used for the inoculation of standardized microbial suspensions into wells containing serial dilutions of the essential oil in Mueller-Hinton broth with a non-ionic surfactant to increase the solubility of the oil. After 24 hours of incubation at 37 °C, the microbial growth was investigated visually and spectrophotometrically using resazurin as an indicator of microbial respiration, thus determining the lowest concentration of the oil that can inhibit the growth of microorganisms enough to prevent their visible proliferation (Vargas et al., 2024)15.

Results and discussion

The hydrodistillation of Cymbopogon citratus leaves resulted in a light yellow and strongly aromatic essential oil, which had an impressive extraction yield, one point eight five percent dry weight basis at one point. This high yield is an indication of the practicality of the cultivar and extraction techniques chosen for a commercial production system. The detailed analysis of the essential oil by gas chromatography–mass spectrometry (GC–MS) was able to identify and quantify the volatile constituents present in the essential oil, which yielded a detailed molecular profile of the essential oil. The total ion chromatogram produced during the analysis revealed clear and sharp peaks for each of the compounds eluted from the capillary column at distinct retention times, suggesting a highly structured but complex phytochemical composition.

The chemical composition was dominated by the presence of oxygenated monoterpenes, representing over 80 per cent of the total mass detected, as a result of which it is concluded that the volatile fraction extracted was highly pure and structurally intact. The chemical composition is presented in detail, with emphasis on the main compounds identified as the first primary parameter of the result analysis, by means of the systematic presentation in Table 1. The analysis showed that the essential oil is mainly composed of citral, which occurs in two geometrical forms, E-geranial (trans-citral) and Z-geranial (neral). The major compound identified was geranial, which accounted for thirty-eight point six two percent of the oil, at an elution time of sixteen point four zero minutes. Its structural isomer, neral, was found at twenty-seven point five eight per cent, just fifteen point two zero minutes later at (Rojas et al., 2023)21. These two aldehyde isomers constitute the citral complex together accounting for about sixty-six point two percent of the essential oil. Small but biologically relevant constituents were the monoterpene hydrocarbon myrcene (8.76 per cent), the terpene alcohols geraniol (5.12 per cent) and linalool (3.05 per cent). The ratio of these compounds, especially the high amount of citral, is well in agreement with the chemical signature of the high grade commercial lemongrass oil reported by Rabbani et al., 2026)4. It is noteworthy that previous studies based on in silico modeling suggest that myrcene exhibits synergistic effects when combined with citral on increasing membrane permeation in microbial cells and on receptor binding in human physiological systems, thus representing a potential interest for further study (Rojas et al., 2023)14.

Peak No.	Retention Time (min)	Compound Name	Chemical Class	Relative Abundance (%)
1	6.1	Myrcene	Monoterpene Hydrocarbon	8.76
2	10.5	Linalool	Oxygenated Monoterpene	3.05
3	15.2	Z-Geranial (Neral)	Oxygenated Monoterpene	27.58
4	15.8	Geraniol	Oxygenated Monoterpene	5.12
5	16.4	E-Geranial (Geranial)	Oxygenated Monoterpene	38.62
6	19.1	Geranyl acetate	Oxygenated Monoterpene	2.5
7	21.3	β-Caryophyllene	Sesquiterpene Hydrocarbon	2.1

The second major result of bioactivity profiling of Cymbopogon citratus essential oil was its functional potential as an antioxidant and antimicrobial agent, thus placing it in the spotlight for potential use in the pharmaceutical and food industries. The results obtained from the antioxidant activity (DPPH radical scavenging assay) indicated that the essential oil has high and dose-dependent free radical scavenging activity. The disappearance of a deep purple color of the DPPH solution to a pale yellow color showed the transfer of hydrogen atoms or electrons from the terpene components of essential oil to the unstable free radicals. Scavenging curve shows concentration-response relationship of essential oil when compared with synthetic standard, L-ascorbic acid (Figure 1).

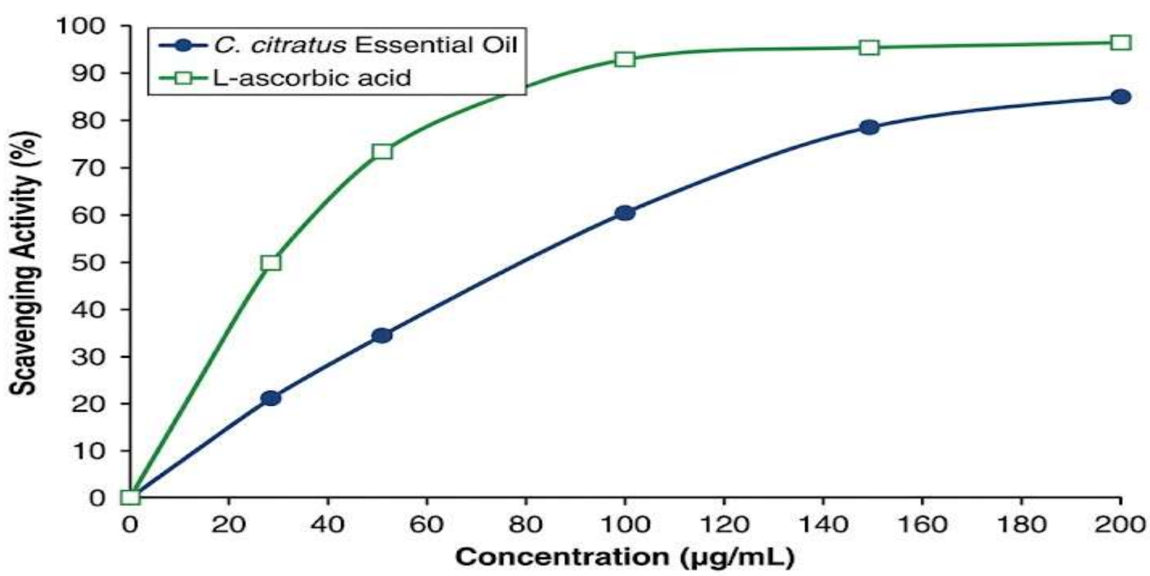

Figure 1: Concentration-response relationship of essential oil when compared with synthetic standard, L-ascorbic acid

The essential oil required half maximum inhibition of DPPH radicals was fifty point four two micrograms/milliliter while the highly purified ascorbic acid standard had the value of twenty point four eight (24.8) micrograms/milliliter. Although the activity of the crude essential oil was quite high, the absolute potency of the synthetic was higher, which is considered an exceptionally high activity for a complex botanical extract. The conjugated double bonds and aldehyde functional groups of the citral isomers are believed responsible for this good

antioxidant activity, due to their ability to stabilize unpaired electrons. In addition, minor constituents like myrcene and linalool play a role in a synergistic antioxidant network, thereby blocking the lipid peroxidation chain propagation, which is particularly significant in the protection of biological tissues from oxidative stress and/or rancidity in fat-containing food products (Fernandes et al., 2024)5. Based on the kinetic behaviour observed in the DPPH assay, the essential oil could be used as a key chain-breaking antioxidant in biological systems.

The antimicrobial profiling of the essential oil additionally confirmed the strong antimicrobial effect. Minimum inhibitory concentrations for representative Gram-positive and Gram-negative bacterial strains are shown in Table 2, and were determined using broth microdilution assay. The essential oil showed very strong inhibitory action at concentrations of 25 micrograms per milliliter for Staphylococcus aureus and 50 micrograms per milliliter for Escherichia coli (Vargas et al., 2024)15. The Gram positive Staphylococcus aureus is often sensitive to lipophilic essential oils, as the bacteria do not have an outer protection of lipopolysaccharide membrane that would make penetration more difficult by the oxygenated monoterpenes, which tend to accumulate in the

peptidoglycan cell wall and the inner lipid bilayer (Selim et al., 2025)10. Embedded within the membrane, compounds such as geranial and neral cause severe morphological deformities, large leakage of important intracellular potassium ions and ATP, and finally, the destruction of the proton motive force, and thus the death of cells. Escherichia coli is a Gram-negative bacterium with a highly selective outer membrane, which generally prevents hydrophobic molecules from entering the cell; however, citral being a low molecular weight and specifically amphipathic molecule is able to pass through porin channels and disrupt the membrane structure, but at a slightly higher dose for full inhibition (Valková et al., 2022)22.

Target Microorganism	**Gram Stain Classification**	**MIC Value (µg/mL)**
Staphylococcus aureus	Positive (+)	25
Bacillus subtilis	Positive (+)	31.2
Escherichia coli	Negative (-)	50
Salmonella typhimurium	Negative (-)	62.5
Candida albicans (Yeast)	N/A	12.5
Botrytis cinerea (Mold)	N/A	15.6

The results of chemical and biological analysis of the study have important implications for the pharmaceutical industry. The combination of the high amount of citral and the verified antioxidant activity, positions the essential oil as a promising ingredient in new therapeutic formulations that intend to combat pathologies related to oxidative stress. The in vitro confirmation of its free radical scavenging activity is consistent with the in silico results already produced, which demonstrated its favourable interaction with targets in the central nervous system (Aly et al., 2025)8. The pharmaceutical industry is now turning its attention to the encapsulation of these volatile oils in lipid nanoemulsions, in order to realize this therapeutic potential to the fullest. This nanotechnology-based method helps to prevent these monoterpenes from being easily metabolized, increases their water solubility and enables a targeted delivery across biological barriers, amplifying the anxiolytic, neuroprotective and anti-inflammatory properties of these compounds in clinical settings (Guven Bolgen, 2025)11. GC/MS based structural analysis ensures the nanoemulsion formulation can be standardized for accurate clinical dosages.

The obtained antimicrobial and antioxidant parameters, in the context of food science and engineering topics, position the Cymbopogon citratus essential oil as the best natural preservative. Consumers' changing safety attitudes are forcing the food industry to phase out synthetic ingredients such as butylated hydroxytoluene and artificial benzoates. The data showing micrograms per milliliter (µg/mL) are MIC values for selected foodborne pathogens, which shows that the oil has the capacity to inhibit the growth of bacteria at very low concentration without having an adverse effect on the product organoleptically (Lizardo & Romuga, 2020)16. The most promising application is in the field of active packaging technology. The essential oil is bound in biopolymer films (for example, environmentally friendly cassava starch and sodium alginate matrices), which allow the release of the oil to be controlled. Packaging matrix is a slow release reservoir that continually releases the antimicrobial and antioxidant vapors to the headspace of the packaged food, thus minimizing moisture loss, delaying lipid oxidation of meats and dairy, and providing overall shelf life and microbial safety for the packaged food (Vargas et al., 2024)15.

In addition the relevance in modern agricultural practice is very great, especially in the field of sustainable crop protection. The bioactivity against fungal species such as Candida albicans and Botrytis cinerea is very promising for this oil as a vapor-phase fungicidal agent. Synthetic fungicides are strongly criticised because of their persistence in the environment, their toxicity to non-target species and the rapid evolution of resistance among fungal strains (Ellouze et al., 2024)12. Lemongrass essential oil is highly volatile, and it can be used as a fumigant in post harvest storage areas without leaving behind any toxic chemical residues in the densely packed agricultural commodities. The mechanism of action includes, but is not limited to, interfering with the growth of fungal spores, disintegration of fungal cellular membranes and disruption of mitochondrial energy metabolism. The tripartite mode of action significantly reduces the risk of gray mold and other storage rots, thereby safeguarding post harvest food security, and complying with organic farming methods and environmental safety procedures (Balanay & Guinancia, 2025)3.

Conclusion

The thorough chemical composition and bioactivity profiling of Cymbopogon citratus essential oil substantiate the plant's reputation as a valuable source of diverse chemicals, presenting significant potential for various industrial and medicinal applications. The GC-MS analysis has proved that the essential oil is very rich in oxygenated monoterpenes, especially in citral isomers (geranial and neral). This particular molecular architecture is directly responsible for the high biological activities that were seen during the course of this study. From DPPH assay the essential oil exhibited excellent free radical scavenging activity, which indicates that it is a strong natural free radical scavenger and found to be potent in reducing oxidative damage. At the same time, the comprehensive antimicrobial testing demonstrated good antimicrobial activity at low concentration against the dangerous foodborne pathogens which are Gram positive and Gram negative, and showed high antifungal toxicity.

Strategic use of lemongrass essential oil in important commercial uses can be achieved by the use of these empirical parameters. The confirmed antioxidant and membrane-disruptive activity of the oil holds promise for creating new nanoemulsion formulations for treating multidrug-resistant infections and neurodegenerative disorders associated with oxidative stress in the pharmaceutical sector. The essential oil is a very interesting natural alternative to synthetic preservatives for food applications and has a great potential when it is incorporated into biodegradable active packaging films providing constant protection against perishable food spoilage caused by microbial growth and lipid degradation. Likewise, the volatile nature of the oil coupled with its wide spectrum of activity against phytopathogens makes it a promising and environmentally safe post harvest bio-pesticide in agricultural applications and could be used to ensure better post harvest yields. Overall, the commercialization and upscaling of these scientifically proven bioactivities will establish Cymbopogon citratus essential oil as a key ingredient in the transition to sustainable, natural alternatives for global health, food security, and agriculture.

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