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Comparative Evaluation of Phytochemical Composition, Bioactivity, and Industrial Applications of *Cymbopogon citratus* and *Cymbopogon nardus*

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Abstract

This study aims to compare the two prominent species of the Cymbopogon citratus and Cymbopogon nardus in terms of their morphological characteristics, phytochemical composition, bioactivity, and industrial utility. While previous research has explored each species independently, comprehensive comparative studies remain limited. This study bridges that gap by synthesizing findings from multiple primary sources to examine their differences in essential oil content, biological activities, and functional applications. Qualitative data were analyzed from phytochemical screenings, antioxidant and antimicrobial assays, and literature reviews. Results reveal that C. citratus possesses a higher citral concentration, contributing to superior antioxidant and broad-spectrum antimicrobial effects, while C. nardus contains higher levels of citronellal and geraniol, enhancing its insect-repellent and antifungal properties. The study also highlights their distinct industrial roles, with C. citratus favoring culinary and medicinal use, and C. nardus predominantly employed in pest control and aromatherapy. These findings offer new insights into the species-specific benefits and potential applications of Cymbopogon, supporting informed selection in cultivation, extraction, and product development strategies across pharmaceutical, food, and cosmetic industries.

Keywords: *Cymbopogon citratus*, *Cymbopogon nardus*, phytochemical comparison, bioactivity, industrial application

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INTRODUCTION

The genus *Cymbopogon* comprises a diverse group of aromatic grasses known by various common names, including lemongrass, barbed wire grass, silky heads, Cochin grass, Malabar grass, oily heads, citronella grass, and fever grass. Species within this genus exhibit a broad geographical distribution, occurring in more than 40 countries worldwide, and are primarily indigenous to tropical and subtropical regions of Asia, Africa, Australia, and various oceanic islands (Soenarko 1977; Toungos 2019; Tibenda *et al.,* 2022). The genus *Cymbopogon*, belonging to the family Poaceae and commonly referred to as lemongrass, comprises approximately 54 species. The majority of these species are distributed across Africa, with additional occurrences in Australia and South Asia. Members of this genus are characterized as tall, perennial grasses bearing elongated and narrow leaves, typically exhibiting serrated margins with silica-based spines along the leaf edges. These species are predominantly native to warm temperate and tropical regions of the Old World and Oceania (Bishyohi *et al.,* 2016; Karami *et al.,* 2021).

The genus *Cymbopogon* has been extensively utilized across numerous countries for a wide range of applications. Its species are commonly employed as medicinal plants, as well as for insect repellent and insecticidal purposes (Oladeji *et al.,* 2019). Among these, *Cymbopogon citratus* is one of the most frequently used species, where it is traditionally associated with multiple pharmacological properties, including calmative, antidepressant, blood purifying, sedative, analgesic, antifungal, antimicrobial, anti inflammatory, and diuretic effects. Another widely recognized species is *Cymbopogon nardus*, which is commonly used in traditional practices for the management of fever (Karami *et al.,* 2021).

Cymbopogon citratus (DC.) Stapf commonly known as lemongrass is one of the main medicinal and aromatic plants (Boukhatem *et al.,* 2014). The chemical composition of lemongrass is characterized by a diverse profile of bioactive secondary metabolites. This botanical species contains significant concentrations of myrcene, a monoterpene noted for its analgesic and antimicrobial properties, alongside citronellal, citronellol, and geraniol. The essential oil fraction is predominantly composed of citral, a thermolabile volatile compound responsible for the plant's characteristic citrus aroma (Manvitha & Bhushan, 2014). *Cymbopogon citratus* serves as a significant industrial raw material with substantial economic value. It is widely utilized as a flavoring agent in the food industry and as a primary aromatic constituent in fragrance and cosmetic formulations (Negrelle & Gomes, 2007).

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Cymbopogon nardus exhibits significant bioactivity, particularly as an antioxidant, anti-inflammatory, and antimicrobial agent (Pontes *et al.,* 2018).

Phytochemical analysis revealed the presence of secondary metabolites in the form of flavonoids, terpenoids, saponins, and tannins (Solekha *et al.,* 2024). Its main volatile components consist of monoterpenoid compounds such as citronellal, citronellol, geraniol, nerol, and citral (Weng *et al.,* 2015). This essential oil has significant commercial significance due to its wide application as an active ingredient in various industrial sectors. Its uses include the flavor and fragrance industry, cosmetic formulation, sanitation products, tobacco, and the pharmaceutical sector (Ganjewala, 2009).

Considering the huge potential cultivation of *C. nardus* and *C. citratus*, this review presents the botanical characteristics, phytochemical composition, biological activities, and industrial applications of these aromatic grass plants. Despite belonging to the same genus and sharing similar morphological characteristics, lemongrass and citronella differ considerably in their phytochemical composition and primary applications. Therefore, this review aims to provide a comprehensive comparison between lemongrass (*Cymbopogon citratus*) and citronella (*Cymbopogon nardus*).

LITERATURE REVIEW

Taxonomy and Botanical Classification

The genus *Cymbopogon* belongs to the family Poaceae, one of the major families of flowering grasses. Within this family, *Cymbopogon* is generally associated with the tribe Andropogoneae and is recognised as an important group of aromatic grasses because many of its species accumulate essential oils with economic, medicinal, and industrial value. These oils have supported the use of *Cymbopogon* species in food products, cosmetics, perfumery, insect repellents, traditional medicine, and phytopharmaceutical research (Tibenda *et al.,* 2022). The genus is taxonomically broad, comprising approximately 144 species, including *Cymbopogon citratus* (DC.) Stapf and *Cymbopogon nardus* (L.) Rendle, two species that are frequently discussed in ethnobotanical, phytochemical, and pharmacological studies (Tibenda *et al.,* 2022).

Cymbopogon citratus (DC.) Stapf, widely known as lemongrass, is a perennial aromatic herb belonging to the grass family. It has long been valued both as a culinary plant and as a medicinal resource. Du *et al.* (2024) describe *C. citratus* as a gramineous perennial herb with extensive food and medicinal applications, particularly in tropical and subtropical regions. The species is reported to occur widely across tropical and

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subtropical Asia and is also cultivated in other regions, including South Africa and southern China (Du *et al.,* 2024). In traditional Chinese medicine, *C. citratus* is recorded under the name *Xiangmao*, indicating that its recognition is not limited to culinary use but also extends to established medicinal traditions (Du *et al.,* 2024). Ethnobotanical studies report that *Cymbopogon* species are known by several common names, including lemongrass, fever grass, barbed wire grass, Cochin grass, Malabar grass, oily heads, and citronella grass, although these vernacular names may differ among regions and may sometimes refer to different species within the genus (Tibenda *et al.,* 2022).

Cymbopogon nardus (L.) Rendle, commonly known as citronella grass or Ceylon citronella, is another perennial aromatic grass in the same genus. *C. nardus* is primarily recognized for citronella oil production, whereas *C. citratus* is more strongly associated with lemongrass oil and citral-rich chemical profiles. Danata *et al.* (2023) describe *C. nardus* as a perennial aromatic plant of the Poaceae family, originating from South India and Sri Lanka and now cultivated in many tropical and subtropical regions, including Asia, Africa, America, Sri Lanka, India, Taiwan, Burma, and Indonesia. The commercial value of citronella oil is strongly influenced by citronellal, citronellol, and geraniol, which contribute to its characteristic aroma and industrial importance (Danata *et al.,* 2023). *C. nardus* is locally recognized in Indonesia as serai wangi. Ethnobotanical research in Batang Kulur Village, Kotabaru, further describes this species as a perennial herb with short rhizomes, fibrous roots, simple leaves, and a distinctive aroma, reflecting its local importance as both an aromatic and economically valuable plant (Nadirah, Destiara and Istiqamah, 2022).

The taxonomic placement of *C. citratus* and *C. nardus* is broadly similar because both species belong to the same genus and tribe. However, they different at the species level, particularly in their common names, essential oil profiles, geographical associations, and patterns of use. Their taxonomic hierarchy can be summarised in Table 1.

Table 1. Taxonomic of *Cymbopogon citratus* and *Cymbopogon nardus*

Taxonomic rank	***Cymbopogon citratus* (Magotra *et al.*, 2021)**	***Cymbopogon nardus* (Danata *et al.*, 2023)**
Kingdom	Plantae	Plantae
Division	Angiosperms / Magnoliophyta	Angiosperms / Magnoliophyta
Class	Monocotyledonae / Liliopsida	Monocotyledonae / Liliopsida

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Order	Poales	Poales
Family	Poaceae / Gramineae	Poaceae / Gramineae
Tribe	Andropogoneae	Andropogoneae

Genus	*Cymbopogon*	*Cymbopogon*
Species	*Cymbopogon citratus* (DC.) Stapf	*Cymbopogon nardus* (L.) Rendle
Common names	Lemongrass, fever grass, *Xiangmao*	Citronella grass, Ceylon citronella, *serai wangi*

Both species are also related to other aromatic taxa within the genus, including *Cymbopogon flexuosus*, *Cymbopogon martinii*, *Cymbopogon winterianus*, *Cymbopogon giganteus*, *Cymbopogon schoenanthus*, and *Cymbopogon densiflorus* (Tibenda *et al.,* 2022). These species share the general characteristic of aromatic oil production, but they are not interchangeable in scientific interpretation. The chemical and economic profiles of these plants vary significantly based on species identity, cultivation environment, and post-harvest management. Tibenda *et al.* (2022) note that the same *Cymbopogon* species may occur in several countries, yet its chemical composition may not necessarily be identical across locations. This observation is important for essential oil research because environmental and agronomic factors can influence oil yield and phytochemical composition.

Consequently, accurate taxonomic identification is fundamental in studies involving *Cymbopogon*. Misidentification may affect the interpretation of phytochemical findings, pharmacological activity, ethnobotanical relevance, and safety evaluation. This distinction is particularly important because *C. citratus* is commonly associated with lemongrass oil and citral-related compounds, whereas *C. nardus* is more closely associated with citronella oil, especially citronellal, citronellol, and geraniol (Danata *et al.,* 2023; Du et *al.,* 2024). The use of complete scientific names with author citations, therefore, helps ensure clarity, comparability, and reproducibility across botanical, pharmacological, agricultural, and essential oil studies.

Morphology Characteristics and Plant Anatomy

Citronella (*Cymbopogon nardus*) and lemongrass (*Cymbopogon citratus*) are closely related aromatic perennial grasses belonging to the family Poaceae. Their close

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taxonomic relationship is reflected in shared grass-like characteristics, including dense clump-forming growth, fibrous root systems, long and narrow leaves, overlapping leaf sheaths, and culms that support vegetative growth and development (Arpiwi *et al.,* 2020; Madi *et al.,* 2022). The two species may appear morphologically similar due to their placement within the same genus; however, they can be differentiated based on stem characteristics. *Cymbopogon nardus* generally has a whereas *Cymbopogon citratus* typically develops a broader stem base that is whitish in color (Rafi *et al.,* 2022).

Lemongrass is generally characterized by a dense, tufted growth habit, forming compact clumps that consist of numerous tillers arising from the basal portion of the plant. Several external morphological traits, including plant height, leaf length, leaf width, stem diameter, and total tiller number, are commonly used as measurable indicators to assess vegetative growth (Setiadi *et al.,* 2024). The leaves are typically elongated, narrow, linear, green, and highly aromatic, reflecting the typical characteristics of grasses in the genus *Cymbopogon*. The distinctive lemon-like fragrance of lemongrass is mainly related to the presence of citral in its essential oil, particularly the monoterpene aldehyde isomers geranial and neral, which contribute significantly to its characteristic aroma and economic value (Madi *et al.,* 2022; Majewska *et al.,* 2019). Citronella is distinguished by a stronger and sharper citronella-like fragrance, which is closely related to the chemical composition of its essential oil. This characteristic aroma is mainly produced by the high concentration of volatile compounds such as citronellal, citronellol, and geraniol. These compounds are considered important chemical markers because they strongly influence the aroma profile, commercial quality, and overall value of citronella oil (Arpiwi *et al.,* 2020; Danata *et al.,* 2023).

Lemongrass displays several diagnostic anatomical features that are typical of grasses in the Poaceae family. These include closed vascular bundles, specialized oil cells, graminaceous-type stomata, phytolith deposits, bulliform cells, bundle sheath cells, sclerenchyma tissues, micro-hairs, and prickle hairs (Madi *et al.,* 2022). The occurrence of oil cells in the leaves and culms of *Cymbopogon citratus* is particularly important because these cells serve as storage sites for essential oils, which are responsible for the plant's distinctive aroma and contribute to its medicinal and economic value (Madi *et al.,* 2022). Sclerenchyma tissue also functions as structural and mechanical support, helping lemongrass maintain the strength and rigidity of its long, narrow leaves and stems, especially when exposed to wind or other environmental pressures (Madi *et al.,* 2022). Bulliform cells, which are located in the leaf epidermis, also play an important adaptive role because they are involved in leaf folding or rolling

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and help regulate water loss. Therefore, these anatomical features not only support the physical structure of lemongrass but also contribute to its ability to adapt to dry, bright, or stressful environmental conditions (Madi *et al.,* 2022).

The leaves of *Cymbopogon nardus* are considered the main organs for essential oil production because its volatile compounds are largely accumulated and extracted from leaf tissues. Through steam distillation, citronella leaves have been shown to produce citronella oil containing important bioactive and aromatic compounds, particularly citronellal and geraniol, which contribute to the characteristic fragrance and quality of the oil (Arpiwi *et al.,* 2020). Citronella leaves contain epidermal structures such as stomata and trichomes that support gas exchange, transpiration control, surface protection, and responses to environmental or pathogen-related stress (Solekha *et al.,* 2023). Changes in stomatal and trichome density under infection indicate that the leaf epidermis is responsive to biotic stress and may contribute to plant defense mechanisms (Solekha *et al.,* 2023). Secretory tissues in *C. nardus* leaves play an important role in the formation, accumulation, and storage of secondary metabolites, including essential oil constituents and defense-related compounds (Solekha *et al.,* 2024). Environmental factors such as shading can also influence plant growth, physiological responses, stomatal characteristics, essential oil yield, and oil quality, showing that citronella morphology and anatomy are closely linked to environmental adaptation and production performance (Danata *et al.,* 2023).

Overall, citronella and lemongrass have several anatomical similarities because both species are aromatic grasses belonging to the family Poaceae. However, they can be distinguished by differences in their external morphology and essential oil composition. Characteristics such as stem color, stem diameter, leaf form, the presence of oil-storing or secretory tissues, stomatal features, trichome distribution, and dominant volatile compounds provide important diagnostic criteria for comparing the two species. Therefore, both morphological and anatomical observations, together with chemical profiling of their essential oils, are useful for scientifically differentiating citronella and lemongrass and explaining their biological and economic characteristics (Arpiwi *et al.,* 2020; Madi *et al.,* 2022; Rafi *et al.,* 2022).

Chemical Composition of Essential Oils

Lemongrass (*Cymbopogon citratus*) and citronella (*Cymbopogon nardus*) essential oils are both classified as aromatic plant oils containing high levels of volatile terpenoid compounds, particularly monoterpenes and oxygenated monoterpenes, but

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their chemical profiles are different enough to be used as distinguishing characters between the two species (Dangol *et al.,* 2023; Mukarram *et al.,* 2021). Lemongrass essential oil is widely recognized as a citral-rich oil because citral is usually its major component. Citral consists of two aldehyde isomers, geranial or citral A and neral or citral B, which are mainly responsible for the oil's fresh lemon-like aroma (Kusuma *et al.,* 2024). These compounds are also important because they contribute to several biological activities of lemongrass oil, including antimicrobial, antifungal, antioxidant, and other pharmacological effects (Kusuma *et al.,* 2024; Mukarram *et al.,* 2021). Chemical analysis using GC–MS on *C. citratus* leaves from Eastern Nepal, reported geranial at 53.1% and neral at 36.1%, showing that these two compounds can form the largest fraction of lemongrass essential oil (Dangol *et al.,* 2023). Chemical analysis of Egyptian lemongrass oil also identified citral as the principal component, with geranial at 42.86%, neral at 36.83%, and myrcene at 8.05%. This finding supports that citral commonly remains dominant even when lemongrass is cultivated in different regions (Soliman *et al.,* 2017). Besides citral, lemongrass oil can contain minor compounds such as myrcene, geraniol, geranyl acetate, citronellal, citronellol, germacrene-D, elemol, limonene, and linalool, which may influence aroma quality, oil stability, and biological activity (Mukarram *et al.,* 2021). Overall, the chemical composition of lemongrass essential oil is affected by plant maturity, plant part, geographic origin, drying conditions, extraction method, and analytical technique (Dangol *et al.,* 2023; Mukarram *et al.,* 2021).

Citronella essential oil has a different chemical profile from lemongrass oil because it is more strongly associated with compounds such as geraniol, citronellal, citronellol, and geranyl acetate. These volatile constituents give citronella oil a fragrance that is generally floral, fresh, citrus-like, and slightly woody, rather than the sharp lemon-like aroma commonly found in lemongrass oil (Kaur *et al.,* 2021; Nakahara *et al.,* 2013). Chemical analysis of *Cymbopogon nardus* essential oil has reported geraniol as a major component at 35.7%, followed by trans-citral at 22.7%, cis-citral at 14.2%, geranyl acetate at 9.7%, citronellal at 5.8%, and citronellol at 4.6%, showing that both alcohols and aldehydes are important volatile constituents (Nakahara *et al.,* 2013). A more recent GC–MS and physicochemical study of steam-distilled citronella oil identified 21 chemical constituents, with trans-geraniol as the dominant compound at 70.65%, followed by geranyl acetate at 7.70%, β-citronellol at 3.17%, and citronellal at 1.78% (Ramadhan *et al.,* 2026). These results suggest that citronella oil can be strongly dominated by geraniol in certain samples, although citronellal, citronellol, and geraniol are still commonly recognized as the main chemical markers of C. nardus essential oil

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(Kaur *et al.,* 2021; Ramadhan *et al.,* 2026). The chemical profile of lemongrass oil is mainly defined by citral, whereas citronella oil is primarily characterized by geraniol, citronellal, and citronellol (Dangol *et al.,* 2023; Kaur *et al.,* 2021). Therefore, GC–MS-based chemical profiling is useful for identifying the major constituents of both oils and for explaining their differences in aroma characteristics, oil quality, industrial application, economic value, and biological activity (Nakahara *et al.,* 2013; Ramadhan *et al.,* 2026).

Extraction Techniques of Essential Oils

The extraction of lemongrass (*Cymbopogon citratus*) and citronella (*Cymbopogon nardus*) essential oils focuses on isolating volatile aromatic compounds from plant tissues, especially leaves, because these organs contain oil-producing structures and bioactive terpenoids that can evaporate with steam or hot water vapor (Majewska *et al.,* 2019; Fauzi *et al.,* 2020). Steam distillation is one of the most frequently applied methods for extracting lemongrass essential oil. In this process, steam passes through fresh or dried plant material, disrupts and softens the plant tissues, and carries the volatile oil compounds in vapor form without requiring the oil to be directly boiled (Majewska *et al.,* 2019). Cooling in the condenser converts the steam and essential oil vapor into liquid form, after which the essential oil can be collected separately from the water layer because the two phases are poorly soluble in each other and have different densities (Majewska *et al.,* 2019). This makes steam distillation a relatively simple, efficient, and practical method for both laboratory-scale and industrial-scale essential oil production. Steam distillation is especially appropriate for lemongrass because many of its major constituents, including citral-related compounds, are volatile and may be sensitive to prolonged exposure to high temperatures (Majewska *et al.,* 2019).

Hydrodistillation is another commonly used extraction method for lemongrass oil. Hydrodistillation involves immersing chopped plant material directly in water and heating it until the essential oil evaporates together with water vapor. However, compared with steam distillation, hydrodistillation may require a longer extraction time and can increase the possibility of hydrolysis or thermal degradation of heat-sensitive compounds (Majewska *et al.,* 2019). An optimization study on *C. citratus* hydrodistillation showed that several operating conditions, including distillation duration, particle size of the raw material, water quality, and water-to-plant material ratio, strongly affect oil yield and citral concentration (Do & Vu, 2024). The study reported that optimal extraction was achieved using a distillation time of 180 minutes, plant material size of 2–3 mm, reverse-osmosis or distilled water, and a water-to-material ratio of 5:1 mL/g. These findings indicate that

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proper preparation of plant material and careful control of extraction parameters are important for improving essential oil recovery and maintaining the quality of lemongrass oil (Van & Vu, 2024).

Steam distillation is also widely applied to citronella (Cymbopogon nardus) because its major essential oil constituents, including citronellal, citronellol, and geraniol, are volatile compounds that can be released from plant tissues through heat and transported with steam (Fauzi *et al.,* 2020; Hamzah et *al.,* 2014). The leaves are generally considered more suitable than the stems for essential oil extraction, as studies using two hours of steam distillation have shown higher oil yield from leaf material. Citronella leaf oil also contains important aromatic compounds such as citronellol, citronellal, D-limonene, and geraniol, which contribute to its characteristic fragrance and oil quality (Fauzi *et al.,* 2020). Several improved extraction methods have been investigated alongside conventional distillation to increase extraction efficiency and preserve oil quality. Microwave-assisted hydrodistillation is one promising technique because microwave energy heats water and plant tissues more rapidly, promotes the rupture of oil-containing cells, and reduces extraction time (Diana *et al.,* 2024; Haqqyana *et al.,* 2022). Microwave-assisted hydrodistillation of citronella oil has been reported to produce higher total amounts of citronellal, citronellol, and geraniol than conventional methods, which suggests that extraction technology can affect not only yield but also chemical quality (Diana *et al.,* 2024). Other studies on *C. nardus* leaves also found that microwave-assisted hydrodistillation can provide relatively high citronella oil yield in a shorter processing time, making it a greener and more efficient alternative (Haqqyana *et al.,* 2022).

Ultrasound pretreatment before hydrodistillation has also been proposed for citronella leaves because ultrasonic cavitation can damage plant cell walls, improve water movement into the tissues, accelerate essential oil release, and reduce long heating exposure that may degrade sensitive volatile compounds (Kumoro *et al.,* 2021). Comparative extraction studies further show that the heating system affects energy efficiency and oil recovery. For example, ohmic-heated hydrodistillation can produce higher oil yield per unit of energy than conventional hydrodistillation and steam distillation, while the dominant compounds remain citronellal, citronellol, and geraniol (Hamzah *et al.,* 2014). Therefore, the choice of extraction method for lemongrass and citronella essential oils should consider plant part, raw material size, moisture content, distillation duration, water-to-material ratio, heating technique, and protection of volatile compounds, because these factors strongly determine oil yield, aroma characteristics,

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chemical profile, and biological potential (Diana *et al.,* 2024; Kumoro *et al.,* 2021; Majewska *et al.,* 2019; Van & Vu, 2024).

Biological and Pharmacological Activities

Lemongrass (*Cymbopogon citratus*) and citronella (*Cymbopogon nardus*) are aromatic grasses belonging to the Poaceae family, and their biological and pharmacological properties are largely associated with bioactive compounds extracted mainly from their leaves. Extraction techniques such as hydrodistillation, steam distillation, infusion, and solvent extraction are commonly used because they help release both volatile essential oils and non-volatile phytochemicals that contribute to therapeutic activity (Cortes-Torres *et al.,* 2023; Mukarram *et al.,* 2021; Rohmawaty *et .al.,* 2025). Lemongrass essential oil is particularly known for its high citral content, which consists of the isomeric compounds geranial and neral. In addition, it may contain other important constituents such as geraniol, geranyl acetate, citronellal, citronellol, germacrene-D, and elemol. These compounds, especially oxygenated monoterpenes, play a major role in determining the pharmacological potential of lemongrass oil (Mukarram *et al.,* 2021). Lemongrass oil demonstrates antibacterial, antifungal, antibiofilm, and antioxidant activities, indicating its ability to inhibit microbial growth, interfere with biofilm formation, and help protect cells from oxidative damage caused by free radicals (Valková *et al.,* 2022).

The antimicrobial activity of lemongrass essential oil is mainly linked to citral and other lipophilic bioactive compounds that can interact with the cell membranes of microorganisms. These compounds may disrupt membrane structure, increase membrane permeability, and disturb essential metabolic processes, which can eventually inhibit the growth of bacteria and fungi (Mukarram *et al.,* 2021; Gao *et al.,* 2020). Lemongrass essential oil and citral have also shown activity against polymicrobial biofilms, which is important from a pharmacological perspective because biofilms are usually more resistant than free-living microbial cells and are commonly associated with chronic or persistent infections (Gao *et al.,* 2020). Besides its antimicrobial effects, lemongrass essential oil also demonstrates antioxidant properties by helping to neutralize reactive oxygen species and reduce cellular damage caused by oxidative stress. However, the level of antioxidant activity may differ depending on factors such as plant origin, extraction method, and chemical composition of the oil (Cortes-Torres *et al.,* 2023). Lemongrass also has anti-inflammatory potential, as studies using zebrafish models showed that its essential oil can reduce inflammation and stress-related

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responses. This suggests that lemongrass does not only act directly against microorganisms but may also influence biological pathways involved in inflammation (Duarte *et al.,* 2024). Furthermore, studies on lemongrass leaf infusion showed that aqueous extracts can inhibit lipopolysaccharide-induced nitric oxide production and reduce inducible nitric oxide synthase expression in immune cells, indicating that water-soluble polyphenols also contribute to the pharmacological activity of lemongrass (Figueirinha *et al.,* 2010).

Polyphenol-rich extracts obtained from lemongrass leaves, particularly fractions containing flavonoids and tannins, have been reported to lower inflammatory mediators while maintaining normal cell viability. This indicates that the therapeutic potential of lemongrass is not only related to its volatile essential oil components but also to its non-volatile phytochemicals (Figueirinha *et al.,* 2010). In vivo studies also show that lemongrass infusion and its phenolic fractions may reduce inflammation and peripheral pain, suggesting possible anti-inflammatory and analgesic effects. However, further clinical studies are still required before lemongrass can be developed or recommended as a standardized medicinal product (Garcia *et al.,* 2015). The leaves of *Cymbopogon nardus* are the main source of citronella essential oil, which contains several important bioactive compounds, including citronellal, geraniol, citronellol, citral, and nerol. These constituents help explain the oil's characteristic aroma and its biological properties, such as insect-repellent, antimicrobial, antioxidant, and anti-inflammatory activities (Bayala *et al.,* 2020; de Toledo *et al.,* 2016). The major compounds commonly reported in *C. nardus* oil include citronellal, geraniol, nerol, elemol, and delta-elemene, showing that citronella oil is composed of both monoterpenes and sesquiterpenes. This chemical diversity supports its broad biological functions and contributes to its pharmacological and industrial value (Bayala *et al.,* 2020).

Citronella essential oil is widely investigated for its insect-repellent activity, particularly against *Aedes aegypti*, because its volatile compounds can disrupt mosquito host-seeking behavior and reduce landing or biting activity (Arpiwi *et al.,* 2020). Lotion formulations containing citronella oil have shown concentration-dependent protection, with a 5% citronella oil lotion reported to provide the highest repellent effect while remaining non-irritating, supporting its potential use in topical repellent products (Arpiwi *et al.,* 2020). Citronella oil also exhibits antimicrobial activity by inhibiting oral pathogens such as Candida albicans, *Streptococcus mutans*, and *Streptococcus sobrinus*, with stronger effects at higher concentrations (Kamal *et al.,* 2020). *C. nardus* essential oil and citronellal show important antifungal and antibiofilm properties, which are relevant

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because *Candida* biofilms are resistant microbial communities that need targeted agents to suppress growth and biofilm development (Trindade *et al.,* 2022).

Citronella essential oil has been reported to show antioxidant and anti-inflammatory activities, although these effects are often considered moderate compared with standard reference compounds. Therefore, citronella may be better understood as a supportive natural source of bioactive compounds rather than a direct substitute for established drugs (Bayala *et al.,* 2020). Besides its essential oil, ethanol extract of *Cymbopogon nardus* contains non-volatile phytochemicals such as phenolics, flavonoids, tannins, and alkaloids, which can influence oxidative stress and inflammation markers, including HIF-1α, IL-6, and COX-2 in 3T3-L1 cells (Rohmawaty *et al.,* 2025). The biological activity of citronella depends on the type of compounds extracted, with essential oil constituents and solvent-soluble polar phytochemicals both contributing to its pharmacological potential (Rohmawaty *et al.,* 2025). Overall, lemongrass is mainly associated with citral-rich oil and antimicrobial, antioxidant, anti-inflammatory, and analgesic effects, while citronella is more closely linked to citronellal-, citronellol-, and geraniol-rich oil with mosquito-repellent, antimicrobial, antioxidant, and anti-inflammatory activities (Bayala *et al.,* 2020; Mukarram *et al.,* 2021; Rohmawaty *et al.,* 2025). Thus, both plants are valuable medicinal aromatic species, but their effectiveness depends on species, plant part, extraction method, chemical composition, concentration, formulation, and safety evaluation (Arpiwi *et al.,* 2020; Rohmawaty *et al.,* 2025; Valková *et al.,* 2022).

Agricultural and Environmental Aspects

Lemongrass (*Cymbopogon citratus*) and citronella (*Cymbopogon nardus*) are perennial aromatic grasses with high agricultural value because their leaves and vegetative biomass can be harvested repeatedly for essential oil production, herbal products, flavoring agents, and plant-based bioactive formulations (Setiadi *et al.,* 2024; Arpiwi *et al.,* 2020). Both species are well adapted to tropical cultivation because they grow in clumps, produce numerous tillers, and can be managed through repeated harvesting. Therefore, plant height, tiller number, leaf length, leaf width, fresh biomass, dry biomass, and oil yield are important indicators for assessing productivity (Setiadi *et al.,* 2024; Sihotang *et al.,* 2023). The productivity of lemongrass can be improved through balanced fertilization, particularly by combining inorganic fertilizers with compost to enhance herbage yield, dry biomass, essential oil production, and the content of valuable chemical components (Premathilake *et al.,* 2018). Compost also supports

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sustainable soil management by improving nutrient availability and enhancing the efficiency of inorganic fertilizer use (Premathilake *et al.,* 2018). Water availability is another important factor because drought stress can reduce vegetative growth and biomass production, although moderate water stress may increase essential oil percentage and affect major compounds such as geranial and neral (Mahmoud *et al.,* 2022). Therefore, irrigation management should balance biomass production and essential oil quality, especially in areas with limited rainfall or seasonal drought (Mahmoud *et al.,* 2022).

Drought stress can alter the physiological and biochemical responses of lemongrass, including changes in antioxidant-related compounds. This shows that environmental stress may influence not only plant growth and biomass production but also the functional quality of the harvested leaves (Junanto *et al.,* 2025). Light availability is an important environmental factor in citronella cultivation because shading can influence photosynthetic activity, stomatal characteristics, biomass production, essential oil content, and the quality of key compounds such as citronellal, citronellol, and geraniol (Danata *et al.,* 2023). Studies on different shade levels indicate that higher shading generally reduces citronella oil concentration, so open or lightly shaded areas are more suitable when the main goal is high essential oil production (Danata *et al.,* 2023). However, citronella can still be cultivated in agroforestry systems. Field observations in Gayo Lues showed that citronella grown under pine stands produced longer and wider leaves, while plants grown in open areas had more tillers, higher fresh and dry herb weight, and better oil yield (Sihotang *et al.,* 2023). Therefore, agroforestry cultivation can support land diversification, but shade intensity, soil condition, altitude, and planting arrangement must be carefully managed when citronella is cultivated mainly for essential oil production (Sihotang *et al.,* 2023).

Citronella also shows promising potential for cultivation on marginal or rehabilitated land. Studies conducted in rehabilitated post-mining land indicate that cultivation system plays an important role in determining citronella oil yield, as Sitrona 2 Agribun grown in monoculture produced better oil yield than plants grown under agroforestry systems (Juliarti *et al.,* 2020). This suggests that citronella can support the productive use of degraded land, although its performance depends on appropriate variety selection, planting arrangement, and cultivation management (Juliarti *et al.,* 2020). From an environmental perspective, lemongrass and citronella are important aromatic plants because their essential oils contain volatile bioactive compounds that can act as botanical repellents, antimicrobial agents, and natural pest-control materials.

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These properties make both plants relevant for more environmentally friendly agricultural practices (Majewska *et al.,* 2019; Arpiwi *et al.,* 2020). For example, citronella oil has shown concentration-dependent repellent activity against Aedes aegypti, highlighting its value as a natural product with both environmental and public-health benefits (Arpiwi *et al.,* 2020). Citronella-based botanical pesticides have been studied for insect pest control, indicating their potential role in integrated pest management programs to reduce dependence on synthetic pesticides (Telaumbanua *et al.*, 2021).

Lemongrass also has important environmental potential, particularly in phytoremediation, because *Cymbopogon citratus* has been reported to tolerate metal-contaminated growing media and to accumulate or stabilize certain heavy metals. This suggests that lemongrass may be used as a candidate plant for managing polluted soils, especially under controlled or carefully monitored conditions (Gautam *et al.,* 2017). Studies on lemongrass grown in soils amended with red mud and biowastes indicate that suitable amendments can enhance soil properties, reduce the phytoavailability of toxic metals, and increase lemongrass biomass, suggesting the potential to combine aromatic crop production with land rehabilitation (Gautam *et al.,* 2017). Other studies have reported that lemongrass can tolerate heavy-metal-contaminated soils while maintaining essential oil production, indicating that aromatic grasses may offer economic value alongside environmental rehabilitation. However, safety evaluation of the harvested biomass remains essential when cultivation occurs in contaminated environments (Gautam *et al.,* 2017). Hydroponic studies in wastewater treatment have shown that C. citratus can reduce the concentration of several heavy metals and improve selected effluent quality parameters, suggesting its potential use in low-cost biological treatment systems (Ajanya *et al.,* 2025). Lemongrass leaf residues also have environmental value because agricultural by-products can be reused as sources of essential oil with antioxidant and antibacterial properties, helping to reduce waste and increase the economic value of crop residues (Adhawati *et al.,* 2025). Overall, lemongrass and citronella can be understood as multifunctional agricultural crops. They produce biomass and essential oils for industrial use, respond strongly to nutrient, water, light, and planting-system management, and also support environmental objectives such as botanical pest control, waste valorization, productive use of marginal land, and phytoremediation (Adhawati *et al.,* 2025; Danata *et al.,* 2023; Juliarti *et al.,* 2020; Mahmoud *et al.,* 2022; Premathilake *et al.,* 2018).

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CONCLUSION

Cymbopogon citratus and *Cymbopogon nardus* are important aromatic grasses from the family Poaceae that share several botanical characteristics but differ in chemical composition, biological activity, and practical use. Both species are perennial clump-forming grasses with fibrous roots, long narrow leaves, aromatic tissues, and essential oil-producing structures. *Cymbopogon citratus* is generally distinguished by its broader whitish stem base and distinct lemon-like aroma, whereas *Cymbopogon nardus* is characterized by a more slender reddish to purplish stem and a stronger citronella-like fragrance. Although these morphological traits are useful for preliminary identification, chemical profiling is necessary for more precise species differentiation. The major distinction between the two species is their essential oil composition, *Cymbopogon citratus* is dominated by citral, particularly geranial and neral, which supports its antimicrobial, antifungal, antioxidant, anti-inflammatory, culinary, and medicinal uses, while *Cymbopogon nardus* contains higher levels of citronellal, citronellol, geraniol, and related volatile compounds, making it more suitable for repellent, antifungal, cosmetic, fragrance, and aromatherapy applications. Therefore, although both species have broad biological and economic value, their dominant chemical constituents determine their specific functions and industrial uses.

Extraction technique is an important factor in determining essential oil yield, chemical quality, and biological activity. Steam distillation and hydrodistillation are still widely used because they are practical for isolating volatile compounds, while improved techniques such as microwave-assisted hydrodistillation, ultrasound pretreatment, and ohmic-heated hydrodistillation can increase efficiency, shorten extraction time, and help preserve heat-sensitive compounds. Agriculturally and environmentally, *Cymbopogon citratus* and *Cymbopogon nardus* are multifunctional crops because they can be harvested repeatedly, produce valuable biomass and essential oils, and respond to nutrient, water, light, and planting-system management. *Cymbopogon nardus* has strong potential for botanical pest control and productive use of marginal land, whereas *Cymbopogon citratus* is more relevant for phytoremediation and wastewater treatment under controlled conditions. Although both species belong to the same genus, they have distinct characteristics and applications. *Cymbopogon citratus* is mainly linked to citral-based uses in food, medicine, antimicrobial products, and antioxidant formulations, while *Cymbopogon nardus* is more closely associated with citronellal-, citronellol-, and geraniol-based applications in repellents, antifungal products, fragrances, and cosmetics. Therefore, accurate taxonomy, proper cultivation, suitable extraction

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methods, chemical analysis, and safety evaluation are essential to optimize both species for pharmaceutical, food, cosmetic, agricultural, and environmental applications.

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