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(REVIEW ARTICLE)

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A brief review on the aromatic fusion of lemongrass (*Cymbopogon citratus*) in herbal air freshener formulations

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Abstract

Interest in plant-based alternatives has increased due to growing concerns about indoor air pollution and the negative health impacts of synthetic air fresheners. The possibility of lemongrass (Cymbopogon citrates) essential oil as a sustainable and natural ingredient for herbal air freshener formulations is examined in this paper. Chitral and other bioactive components, such as geraniol and monoterpenes, which have significant antibacterial, antioxidant, insect-repelling, and mood-enhancing qualities, are found in high concentrations in lemongrass oil. Its phytochemical composition, pharmacological actions, and variables affecting the quantity and quality of essential oils are all summarized in this paper. The efficiency, optimization factors, and preservation of volatile chemicals are highlighted in the discussion of several extraction methods, including steam distillation, hydro distillation, microwave-assisted hydro distillation, and supercritical fluid extraction. Improved aroma retention, microbiological stability, and efficient odor neutralization are demonstrated by the possible development of gel-based herbal air fresheners using natural polymers and controlled-release methods. Lemongrass oil's economic and industrial relevance in the aromatherapy, cosmetic, pharmaceutical, and domestic sectors is further strengthened by consumers' growing preference for environmentally friendly and chemical-free products. In order to improve performance and market feasibility, future research should concentrate on formulation standardization, stability assessment, safety profiling, and investigation of synergistic combinations. All things considered, lemongrass essential oil is a viable green substitute for long-term indoor air quality control.

Keywords: Lemongrass Essential Oil; Cymbopogon Citrates; Formulation of Herbal Air Fresheners; Extraction of Essential Oils; Antimicrobial Activity; And Sustainable Indoor Air Quality

1. Introduction

Growing environmental pollution and the excessive use of synthetic compounds have necessitated the development of ecologically friendly pest control and air purification methods. Conventional synthetic insecticides and air fresheners, despite their efficacy, frequently damage non-target species, cause insect resistance, and emit hazardous chemicals that pollute indoor air quality. Migraines, asthma, respiratory and neurological issues, and skin irritation are all possible health hazards. Many commercial air fresheners include harmful chemicals such as acetaldehyde, acetone, benzaldehyde, and limonene, which accumulate inside and harm human health and the environment. [1] [2]

In contrast, natural plant-based options, notably essential oils and herbal formulations, have shown good antibacterial, insecticidal, and air-purifying capabilities while being safe and biodegradable. Lemongrass (Cymbopogon flexuous) essential oil, which contains a high concentration of central (70–80%), has been shown to have powerful insecticidal and repellent properties against a variety of pests, including weevils, moths, and mosquitoes. Whiteflies, mosquitoes,

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and fire ants are among the insects that are safe to humans. Similarly, camphor, a significant bioactive component in rosemary (Rosmarinus officinalis) oil, has considerable toxicity and repellency against beetles, weevils, ants, and houseflies, making it an efficient natural bug deterrent.[3]

1.1. Some of the most important species of this genus are

- Cymbopogon flexuous Stapf. (East Indian lemongrass)
- Cymbopogon citrates DC Stapf. (West Indian lemongrass)
- Cymbopogon Nardus (L)
- Cymbopogon winteriness Jowitt (citronella)
- Cymbopogon martini Roxby. (palmaris)
- C. Nardus x C. Jarnac's (Amarosa hybrid) [5]

To improve their practicality and stability, herbal preparations such as incense sticks and air freshener gels containing lemongrass or camphor have been created, giving long-lasting Fragrance, antibacterial action, and pest management without dangerous leftovers. Recent research has also looked into the antifungal and air-cleansing properties of medicinal plant extracts such as Azedarach indica, Mentha piperita, and Aloe barbadense, confirming their ability to eliminate airborne fungi and clean indoor air in realistic household situations. Together, these innovations offer sustainable, nontoxic solutions to synthetic air fresheners and insecticides, contributing to healthier indoor environments and promoting environmentally friendly pest and air quality management. [4]

2. Taxonomy

2.1. Lemongrass [Cymbopogon citrates][8] [6]

Figure 1 *Cymbopogon citrates* [15]

- Kingdom - Plantae
- Division - Magnoliophyte
- Class - Liliopsid
- Order - Pales
- Family - Pinaceae
- Genus - *Cymbopogon*
- Species – *Cymbopogon citrus*
- Synonyms - Malabar Grass, Cochin Grass.

2.1.1. Use

- Mosquito repellent.
- Air freshener.
- Natural pesticidal activity.

3. Morphology

3.1. Lemongrass [Cymbopogon Citrates]

Lemongrass (Cymbopogon flexuous and C. citrates), as well as related plants including palmaris (C. martini) and citronella (C. Nardus, C. winteriness), are tufted perennial C_4 Grasses of the Pinaceae family, known for their fibrous roots, short rhizomatous stocks, and several stiff stems that produce linear, lanceolate leaves. Lemongrass leaves are normally 50 cm long and 1–1.5 cm broad, with tubular sheaths that create pseudo stems. They, together with floral tops, serve as the main locations of essential oil (EO) creation. Essential oils contain several bioactive chemicals such as central, geraniol, geranyl acetate, citronellol, citronellal, and linalool, with content, quality, and perfume varying both within and across species. Cymbopogon species exhibit substantial intra- and interspecific variance in morphology, with lemongrass propagating by seeds, slips, or rhizome-derived suckers that create thick groups. Early harvesting frequently limits the flowering of lemongrass in cultivation. These chemicals have a wide range of applications, including antibacterial, antifungal, antiviral, insecticidal, antiparasitic, and antiprotozoal activities, as well as use in food, cosmetics, perfumery, medicines, and insect-repellent formulations. [7] [8]

4. Geographical Distribution and Cultivation

4.1. Lemongrass (*Cymbopogon citratus*)

Lemongrass and other Cymbopogon species are native to Asia's tropical and subtropical zones, with significant production occurring in India, notably Kerala, Assam, Maharashtra, and Uttar Pradesh, as well as other nations such as China, Australia, Brazil, Mexico, Dominica, Haiti, Madagascar, and portions of Asia. India is the greatest producer, providing around 1,000 tonnes of lemongrass oil per year approximately 90% of worldwide exports primarily through the port of Cochin, giving it the title of Local name: Cochin grass. Wild lemongrass (C. citratus) is used to produce West Indian oil, but C. flexuosus is the primary source of East Indian oil. Other Cymbopogon species, including C. martinii, C. nardus, C. pendulus, C. ambiguus, C. bombycinus, C. obtectus, C. refractus, and C. schoenanthus, are farmed or naturally distributed across Asia, Southeast Asia, and Australia, with selection and breeding for differences in essential oil composition and fragrance. These plants thrive in well-drained soils with full sun or light shade, showing adaptability to a wide range of agro-climatic zones, and are prized for their essential oils, fragrances, and other qualities. Cosmetics, medicines, and traditional medicinal uses.[7] [8]

4.2. Lemongrass Geographical Distribution

Figure 2 Lemongrass Geographical Distribution [17]

5. Phytochemical Constituent

5.1. Lemongrass (Cymbopogon Citrates)

5.1.1. Major Compounds:

Citrates like geraniol and nerolidol are commonly found in many Cymbopogon plants, comprising approximately 75-88% of their essential oils. Carries out tasks such as emitting citrus scent, inhibiting bacteria growth, eliminating odors, preventing infections, and reducing inflammation.[5][7][9]

Geraniol is abundant in species like C. martini, C. Nardus, and specific varieties; it enhances aroma, possesses antibacterial properties, and combats fungal infections. Citrus oils like limonene can be found in numerous plant varieties. The score is five against twenty-seven. In C. sheathes, 3%; this percentage aids in enhancing antibacterial properties alongside interacting positively with additional components.[5][7][8]

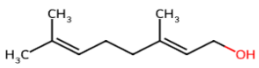
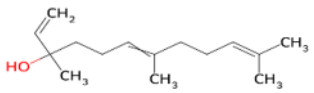
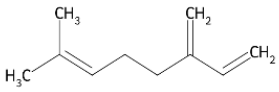
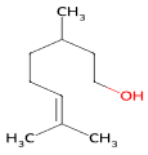
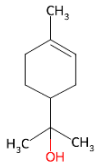
Beta-myrcene is an insignificant monoterpenoid compound; it influences fluidity and boosts comprehensive biological efficacy when used together. Citronellol is primarily found in species like Citrus wintering and Citrus nodosa (~27%). It exhibits both antifungal and larvicidal effects. [5][7][8][9]

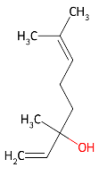
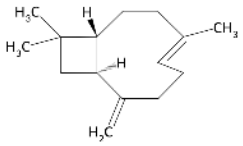
5.1.2. Minor Compounds

Alpha-terpineol boosts biological activity; it is present in various plants such as C. schizanthus and C. ambos. Linalool: Contributes to aroma and antimicrobial effects. β-Caryophyllene: Supports antimicrobial and synergistic effects. [5][7][8][9]

Additional lesser-known compounds such as tannins, flavonoids, saponins, alkaloids, sterols, and sugars exhibit antibacterial, anti-fungal properties, and pain-relieving effects.[9]

Table 1: Minor Compounds

Sr.no	Plant Species	Compound Name	Type	Pharmacological Activities	Plant Part Used	References
1.	Lemongrass (Cymbopogon citratus)	Geraniol 	Major	Antibacterial, antifungal, aromatic enhancer	Leaves	[5][7][8][9]
2.	Lemongrass (Cymbopogon citratus)	Nerolidol 	Major	Citrus scent, antimicrobial, anti-inflammatory	Leaves	[5][7][9]
3.	Lemongrass (Cymbopogon citratus)	Beta – Myrcene 	Major	Enhances membrane fluidity, synergistic biological effects	Leaves	[5][7][8]
4.	Lemongrass (Cymbopogon citratus)	Citronellol 	Major	Antifungal, larvicidal, aromatic	Leaves	[5][7][8][9]
5.	Lemongrass (Cymbopogon citratus)	Alpha – Terpineol 	Minor	Enhances antimicrobial and biological activity	Leaves	[5][7][8][9]

6.	Lemongrass (Cymbopogon citratus)	Linalool 	Minor	Aroma compound, antimicrobial	Leaves	[5][7][8][9]
7.	Lemongrass (Cymbopogon citratus)	Beta – Caryophyllene 	Minor	Antimicrobial, synergistic with other oils	Leaves	[5][7][8][9]
8.	Lemongrass (Cymbopogon citratus)	Tannins, flavonoid, saponins, alkaloids, sterols, sugars	Minor	Antibacterial, antifungal, analgesic	Leaves	[9]

5.2. Factors Influencing Oil Yield and Quality

Table 2: Factors Influencing Oil Yield and Quality

Plant	Influencing Factors	Main Observations	Reference
Lemongrass (*Cymbopogon citrates*)	1. Harvest time	First crop after 4–6 months; later every 2–3 months; affects yield and aldehyde content.	[5][7][8][9]
	2. Plant age	Older plants give higher biomass and oil concentration.	[5][7][8][9]
	3. Cultivation and environment	Soil, temperature, humidity, season, and genotype affect oil purity and composition.	[5][7][8][9]
	4. Plant part used	Leaves (~5% of dry matter) are main source.	[5][7][8][9]
	5. Distillation method	Solvent choice influences oil composition and bioactivity.	[5][7][8][9]

6. Pharmacological And Aromatherapeutic Properties

6.1. Lemongrass (Cymbopogon Citrates)

6.1.1. Antimicrobial Activity

Cymbopogon species, especially C. citrates and C. flexuous, show a wide range of antimicrobial effects against various types of bacteria and fungi. This includes Gram-positive bacteria like Staphylococcus aureus, Bacillus subtilis, and B. cereus, Gram-negative bacteria like Escherichia coli, Klebsiella pneumoniae, and Pseudomonas aeruginosa, fungi such as Candida albicans, Aspergillus Niger, and Fusarium exospore, dermatophytes like Trichophyton and Microspore, and yeasts such as Saccharomyces cerevisiae. [5][7][8][9]10] The mechanisms include damaging the microbial cell membranes, affecting mitochondria, causing ion leakage of calcium, potassium, and magnesium, blocking enzyme activity, interfering with metabolic processes, preventing biofilm formation, and reducing aflatoxin production.[5][8] These effects are mostly caused by the bioactive substances central, geraniol, limonene, flavonoids, and tannins. These oils are beneficial in food preservation, pharmaceuticals, and cosmetics, and they can increase the efficacy of traditional antibiotics while providing a safer substitute for synthetic drugs.[7][8][10]

6.2. Insect Repellent Action

Cymbopogon essential oils have a natural insect-repelling effect. Certain species, such C. winterianus (citronella) and C. martinii, help keep mosquitoes away, particularly Anopheles sundaicus, and provide protection stored grains from pests

like Tribolium and Callosobruchus. [5][7][8][9][10] These oils influence insect growth through allelochemical activity. They are commonly used in soaps, candles, perfumes, and repellents. Their effectiveness is similar to chemical repellents, but they are less toxic.[9]

6.3. Antioxidant Potential

Cymbopogon oils and extracts, particularly those from C. schoenanthus and C. citratus, have strong antioxidant properties. They neutralize free radicals, reduce oxidative stress, and protect DNA and cellular structures. The presence of polyphenols, flavonoids, tannins, and phenolic acids contributes to anti-mutagenic, anti-inflammatory, gastro-protective, and cytoprotective effects, which may also support anticancer properties and overall cellular health. .[5][9][10]

6.4. Mood-Enhancing and Neuroprotective Effects

Lemongrass essential oil and its main components, such as citral and geraniol, have effects that reduce anxiety, relieve pain, improve neurobehavioral functions, prevent seizures, and lower stress. These properties support their use in aromatherapy and treatments related to the central nervous system. .[5][7][8][10] They may enhance cognitive function, spatial memory, and mood by influencing neurotransmitters and retinoic acid synthesis.[7] Traditionally, they are consumed as teas or decoctions to achieve calming, analgesic, and anti-inflammatory effects.[8]

6.5. Additional Pharmacological Activities

- Anti-inflammatory and Analgesic: These oils help reduce inflammation and relieve pain by inhibiting inflammatory mediators and providing peripheral pain relief.
- Anticancer: They can induce programmed cell death and prevent the growth of tumors.
- Anti-diabetic and Lipid-lowering: These oils help lower fasting and post-meal blood sugar levels, reduce cholesterol, triglycerides, and low-density lipoprotein (LDL), while increasing high-density lipoprotein (HDL) levels.[9]
- Anti-malarial, Anti-protozoan, Anti-diarrheal: These oils have broad therapeutic effects, attributed to their bioactive constituents, which are effective against malaria, protozoan infections, and diarrhea.[10]

7. Extraction Of Lemongrass Oil

7.1. Steam Distillation (Preferred Method) [11]

The most popular and recommended method for extracting essential oil from lemongrass.

- Procedure: The process involves passing steam through the plant material to evaporate the oil, which is subsequently condensed and segregated.

7.1.1. Benefits

- Steam flow and Quality can be easily controlled.
- Thermal degradation risk is low (<100 °C)
- Ideal for materials with high boiling points and fresh lemongrass.

7.1.2. Drawbacks

- Needs expert maintenance and operation.

7.1.3. Optimization Factors

- Particle size: Larger particles (4–20 mm) result in higher yields.
- Temperature: The yield of oil increases with temperature (10–50 °C).
- Distillation time: Extended times (30–120 min) increase yield.
- Yield reported: 0.51–0.84%

7.2. Hydro distillation (HD) [11][12]

- Principle: Extraction of volatile oils by co-distillation of plant material immersed in water.
- Procedure: Plant material boiled in water; steam carries volatile oil to the condenser, which is then separated.
- Advantages: Conventional, simple setup.

7.2.1. Disadvantages

- Longer extraction times result in higher energy use.
- Thermal deterioration and smells from overheating are risks.

7.2.2. Optimization Factors

- Particle size: Heat transfer is enhanced by uniformly crushed samples.
- Temperature: ~100 °C guarantees decomposition-free volatilization.
- Duration: Persisted until no additional oil was extracted.
- Yield: 0.98 %

7.3. Microwave-Assisted Hydro distillation (MAHD):[11][13]

Hydro distillation and microwaves are combined in this modern hybrid process for quicker and more effective extraction.

Procedure: The method involves using a modified microwave oven (600 W, 2 h, 3 bar) to distill 500 mL of deionized water and 30 g of dried lemongrass. Increases oil release by encouraging cell wall breakdown.

7.3.1. Advantages

- Shorter extraction times and less energy usage.
- Improved oil quality and increased production.
- Controllable parameters and consistent heating.

7.3.2. Optimization Factors

- Microwave power: 250–600 W of microwave power is ideal for both quality and efficiency.
- Duration: 90 minutes to 2 hours yields the most production without deterioration.
- Ratio of water-to-plant: 8 :1.
- Pressure/Airflow: Vapor transport is enhanced by moderate pressure/airflow (3 bar).
- Pre-drying: Chitral is preserved and photodegradation is avoided by semi-dark drying (10–15 days).
- Yield Reported: 1.46 %

7.4. Solvent Extraction:[12]

- Principle: Organic solvents (n-hexane, ethanol) dissolve essential oils from dried lemongrass leaves.

7.4.1. Procedure

- 130 g dried lemongrass soaked in 600 mL n-hexane for 24 h → liquid–liquid separation with ethanol → evaporation at 78 °C.

7.4.2. Advantages

- High oil yield (~4.5 %) (Alhassan et al., 2018).
- Effective for dried samples.

7.4.3. Disadvantages

- Risk of solvent residue contamination.
- Requires solvent recovery and safety control.

7.4.4. Optimization Factors

- Particle size: Crushed samples improve solvent penetration.
- Temperature: 78 °C ensures solvent evaporation without decomposition.
- Duration: 24 hr. soaking ensures complete solubilization.

7.5. Effleurage Method [12]

- Principle: Uses fats/oils (e.g., olive oil) to absorb essential oils from the plant.

- Procedure: Olive oil and pounded lemongrass are combined for 24 hours at room temperature before ethanol is extracted and evaporated at 78 °C.

7.5.1. Optimization Factors

- Particle size: The exposed surface area is increased by pounding.
- Temperature: Absorption without volatilization is encouraged by mild heating.
- Duration: Complete dispersal is ensured by standing for 24 hours.
- Yield: Determined gravimetrically

7.6. Other Emerging Extraction Techniques: [11]

- Ohmic-Assisted Hydro distillation (OHD): Improves heating efficiency and reduces extraction time.

7.6.1. Supercritical Fluid Extraction (SFE)

- Uses CO2 under supercritical conditions, usually with 10% hexane.
- Produces fresh aromatic, highly - purity oil
- Yield: ~0.65 %
- Ultrasound-Assisted Extraction (UAE): Enhances cell rupture via sound waves (20 kHz–2 MHz).
- Subcritical Water Extraction / Solvent-Free Microwave Extraction (SFME):
- Reduces the use of solvent.
- Maintain the composition and natural scent.

8. Optimization Factors Affecting Lemongrass Oil Yield:[11][12][13]

Table 3: Optimization Factors Affecting Lemongrass Oil Yield

Sr .no	Extraction Method	Reported Yield (%)	Conditions
1.	Steam Distillation	0.51–0.84	Yield increases with particle size (4–20 mm), time (30–120 min), temperature (10–50 °C)
2.	Hydro distillation (HD)	0.98	Long process, high energy use
3.	Microwave-Assisted Hydro distillation (MAHD)	1.46	250 W, 8:1 water: plant ratio, 90 min
4.	Supercritical CO_2 Extraction (SFE)	0.65	CO_2 + 10% hexane improves yield and compound diversity
5.	Solvent Extraction	4.5	High yield but solvent residue risk

9. Formulation Of Herbal Odo nil [2]

9.1. Base Material

Herbal camphor substitute: The primary active element in the study was lemongrass essential oil (Cymbopogon citrates).It has antibacterial properties and a natural aroma.

Instead of using artificial or carrageenan-based gels as the foundation, agar-agar (2%) was utilized. It is safe to use and provides natural gel strength.

9.2. Binders

- Natural gums (1%) contributed to the mixture's cohesiveness and smooth smoothness.
- Additionally, 1% sodium chloride (NaCl) was added as a binder to improve the gel's ability to maintain its structure.

9.3. Additives

- Lemongrass oil (1–5%) was the main source of the scent and active ingredients.
- Sodium benzoate (0.5%) was used as a natural preservative to stop harmful bacteria from growing.
- Ethylene glycol (1.5%) kept the product moist and made it easier to spread.
- Polysorbate 20 (1%) helped mix oil and water evenly.
- Aquest (88–92%) was the main liquid used to dissolve other ingredients and help them spread.
- Natural dyes can be added to make the product look better.

9.4. Molding / Form

- After blending and stirring, the mixture was cooled in containers to produce a solid or semi-solid gel block or cone. This resembles the form of common air fresheners, such as Odo nil.

9.5. Evaluation Parameters:[2]

Table 4: Evaluation Parameters

Sr.no	Parameters	Observation / Results
1.	Fragrance Intensity (Hedonic Test)	5% oil formulation (F5) most preferred; very fragrant and long – lasting.
2.	Release Rate	Gradual scent release; maintained freshness for several weeks
3.	Microbial Stability	No Bacterial or Fungal growth observed during testing.
4.	pH Stability	Neutral pH maintained (7.01-7.51); suitable for home use.
5.	Macroscopic Stability	No change in shape, mixing, or colour at 40° C storage conditions.

9.6. Mechanism of action in odor neutralization [2]

- Chemical Neutralization: β-pinene, nerolidol, isoneral, and squalene are among the compounds found in lemongrass oil. These react with odors in the air, such as those caused by ammonia or sulfur, and aid in their removal.
- Aromatic Release Mechanism: Ethylene glycol, agar, and gum base regulate the rate at which the aroma is released. As a result, the aroma is released into the air gradually.
- Camphor-like Volatilization Effect: Lemongrass oils behave like natural camphor. They gradually release the fragrance, maintaining its freshness without making it overpowering.
- Microbial Inhibition: Lemongrass contains natural compounds that inhibit the growth of bacteria, including nerolidol and β-pinene. This aids in preventing odors brought on by harmful microorganisms decomposing organic items.
- Psychological / Environmental Impact: The continuous release of lemongrass aroma improves moods, purifies the air, and even repels insects like mosquitoes. This has two benefits: It keeps odors under control and makes the area feel cleaner and cozier.

9.7. Market Potential (Global and Indian)

9.7.1. Lemongrass (Cymbopogon Citrates) [15][16][17]

Table Market Potential of Lemongrass

Parameters	Indian Market Potential	Global Market Potential
Production Scale	Produces ~1000 tonnes of lemongrass oil annually; major producer globally.	World production also ~1000 tonnes; cultivated across ~16,000 ha worldwide.
Cultivation Area	~4000 ha under cultivation across states including Kerala, Karnataka, UP, Assam, Jharkhand, etc.	Global area ~16,000 ha, with major producers including India, Guatemala, China, Mexico, Bangladesh.

Export Share and Position	India is largest global exporter, exporting 75–80% of its production to 75–80 countries.	Strong, rising demand from USA, Europe, Asia-Pacific; essential oil valued for perfumery, cosmetics, foods, pharmaceuticals.
Export Growth (Long-term)	Export quantity grew from 80.28 thousand kg (1997–02) to 2552.42 thousand kg (2017–20). Value increased from ₹413.65 lakh to ₹30874.49 lakh. CAGR: 16.13% (qty) and 28.04% (value).	Global demand has risen sharply, especially post-COVID due to disinfection and aromatherapy markets. Global lemongrass essential-oil market valued USD 38.02 million (2022) expected to reach USD 81.23 million by 2030.
Recent Two-Decade Growth	Over last 20 years (2003–23), CGR: 16.08% (qty) and 25.20% (value), showing robust and sustained market performance. Variability stable (instability index moderate).	Global demand expanding due to natural product preference, clean-label foods, aromatherapy and pharmaceuticals. CAGR globally driven by FandB (35%), cosmetics/ aromatherapy (29%), household (16%), pharma (15%).
Major Export Destinations	USA (41%), Canada, France, Germany, Spain, UK, Australia, China, Singapore — together ~81% of exports.	Demand concentrated in USA, Western Europe, Japan, Brazil, South Africa, Singapore, Spain, Switzerland.
Domestic Consumption Trend	Domestic demand increasing steadily due to aromatherapy, food flavoring, pharma uses; also used in Indian aroma industry.	Global consumption rising due to switching to natural disinfectants, organic cosmetics, essential-oil-based therapeutics.
Economic Role	High profitability for farmers on marginal land; yields ₹0.40–1.30 lakh/ha profit; drought-tolerant and low input. Generates rural employment.	Attractive crop for small producers in tropical countries due to steady global demand; used in food, beverages, perfumery, pharmaceuticals.
Drivers of Market Potential	High central-rich chemotypes developed by CSIR-CIMAP	-
India's Aroma Mission boosted output	-	-
Strong export growth and large global market presence	Rising global interest in aromatherapy	-
Natural preservative and antimicrobial market growth	-	-
Organic and natural products in food, cosmetic sectors	-	-
Post-pandemic sanitization and essential-oil demand boom	-	-
Overall Market Outlook	Strong, expanding, export-dominant; stable supply chain and increasing cultivation area; India emerging as global market leader.	Fast-growing, demand-driven market with projected doubling by 2030; essential oils market showing major upward trend.

9.8. Future Prospects

9.9. Lemongrass (*Cymbopogon citratus*): [11][14]

9.9.1. Increasing Demand for Natural Products

Both articles emphasize growing consumer concerns regarding the use of synthetic preservatives, fragrances, and antibiotics. This indicates a strong future demand for:

- Natural antimicrobial preservatives in food industries
- Herbal cosmetics and aromatherapy formulations
- Organic household products

Since lemongrass oil possesses broad antimicrobial, antifungal, antioxidant, anti-inflammatory, and insecticidal activities, it will continue to replace synthetic chemicals in many sectors.

9.10. Large Scope for Green Extraction Technologies

It shows advanced, sustainable extraction techniques such as

- Supercritical Fluid Extraction (SFE)
- Microwave-Assisted Hydro-distillation (MAHD)
- Solvent-Free Microwave Extraction (SFME)
- Ultrasound-Assisted Extraction (UAE)

9.11. Future research is expected to focus on

- Improving extraction yield
- Reducing energy consumption
- Enhancing central purity
- Industrial-scale adoption of green technologies

These allow production of high-quality, residue-free essential oils suitable for pharmaceuticals and food applications.

9.12. Novel Pharmaceutical Formulations

9.12.1. Lemongrass has reported

- antimicrobial, antifungal, antimalarial,
- anti-mutagenic, hypoglycemic, anti-inflammatory,
- neuroprotective and cardioprotective properties.

9.12.2. Future areas include

- Standardized herbal formulations, nano emulsions for improved penetration, and controlled-release gels, ointments, and patches are examples of future areas.
- Combination treatment for pathogens that are resistant to multiple drugs (MDR) .
- The primary bioactive compound, central, might also be used as a lead molecule in the search for novel drugs.

9.12.3. Agricultural and Veterinary Applications

With strong insect-repellent and antifungal properties, lemongrass can be developed into

- Eco-friendly pesticides.
- Natural livestock disinfectants.
- Organic fungicides to protect crops.
- Feed additives to promote poultry gut health

The global trend toward pesticide-free agriculture is consistent with this.

9.12.4. Expanding Cosmetic and Personal-Care Sector

Future product development includes the following because of its aroma, antioxidant, and antibacterial properties:

- Herbal acne creams and natural deodorants.
- Anti-dandruff tonics and scalp treatments.
- Organic lotions, shampoos, and soaps.

Although lemongrass oil is already used in perfumery, demand is predicted to increase as customers favor plant perfumes free of artificial allergens.

9.12.5. Food Industry Applications

Lemongrass oil can be used in the following ways in light of growing concerns about chemical food preservatives:

- Natural food preservatives.
- Antimicrobial edible coatings.
- Flavoring compounds for beverages.
- Herbal infusions rich in antioxidants.
- It has a benefit for clean-label food products due to its potent aromatic and antibacterial qualities.

9.12.6. Commercial and Industrial Value

Both reviews emphasize how widely used lemongrass oil is in

- Aromatherapy.
- Perfume production.
- Detergents and cleaning supplies.
- Nutraceuticals and Pharmaceuticals.

9.12.7. Prospects for the future include

- Cultivating high-central types.
- Exporting essential oils internationally.
- Developing standardized, ISO-quality oils.

Lemongrass is therefore economically significant for developing markets.

9.13. Biotechnology and Genetic Improvement

- Enhancing citral content through plant breeding, tissue-culture-based mass propagation, genetic alteration for better oil composition, and metabolic pathway engineering for increased yield are some possible areas for future research.
- These developments have the potential to greatly increase business output.

10. Conclusion

The essential oil of lemongrass (Cymbopogon citrates) has received a lot of interest as a sustainable and natural substitute for the artificial ingredients included in traditional air refreshing products. The plant's potent antibacterial, antioxidant, insect-repelling, and aromatherapeutic qualities are attributed to a variety of bioactive components, including central, geraniol, and other monoterpenes. Because of these qualities, lemongrass oil can be used in a variety of household, medicinal, cosmetic, and aromatherapy products.

The yield, purity, and quality of the essential oil are determined by a variety of extraction procedures, such as steam distillation, hydro distillation, microwave-assisted extraction, and solvent-based approaches. The production of effective, eco-friendly goods is further aided by developments in green extraction technologies and formulation techniques. Additionally, lemongrass oil's commercial and industrial significance in both local and international markets has risen drastically due to consumers' growing preference for natural and chemical-free products.

Overall, the scientific data that is now available shows how promising lemongrass essential oil is as a natural remedy for controlling odors and purifying indoor air. Future research should concentrate on formulation standardization,

stability studies, safety assessment, and controlled-release systems to enhance product performance and commercial feasibility. In order to achieve improved fragrance diffusion, antimicrobial action, and extended air-freshening activity, future research will develop and assess a herbal air freshener formulation using lemongrass essential oil incorporated into a camphor-based matrix.

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