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Essential Oils from Medicinal and Aromatic Plants as a Natural Arsenal for Antimicrobial Therapies: A Review

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A B S T R A C T

Medicinal and aromatic plants have been integral to traditional healthcare systems for centuries, offering a vast reservoir of bioactive compounds with therapeutic relevance. Among these, essential oils (EOs) have gained significant attention due to their broad-spectrum pharmacological properties and relatively low toxicity compared to synthetic drugs. Essential oils are volatile, aromatic extracts primarily obtained through steam distillation and they consist of a diverse range of phytochemicals such as monoterpenes, sesquiterpenes, oxygenated terpenes and phenolic compounds. These constituents are largely responsible for the notable antimicrobial, antioxidant, antidiabetic, antiviral, anticancer and aromatherapeutic properties of essential oils. Their natural origin, chemical diversity and multifaceted biological activities make them promising candidates for the development of alternative therapeutic agents and novel drug delivery systems. This review compiles and evaluates existing literature concerning the chemical composition, biological activities and medicinal applications of essential oils derived from various plant sources, highlighting their potential role in modern pharmacology and integrative medicine.

Introduction

Medicinal and aromatic plants are a valuable source of diverse bioactive secondary metabolites that offer a wide range of pharmacological properties. These natural compounds are increasingly utilized in the development of innovative therapeutic agents due to their safety, efficacy and broad-spectrum biological activities. India with its unique climatic and geographical conditions, harbors a rich diversity of medicinal flora, many of which produce essential oils (EOs) with distinctive chemical profiles and therapeutic potentials compared to similar species found in other regions.

Several aromatic plant species have been identified as prolific sources of essential oils, which are complex mixtures of volatile and aromatic compounds, including mono-, sesqui- and di-terpenes, phenolic constituents, sulfur-containing molecules and phenylpropanoids (El-Said *et al.,* 2021). These chemical constituents are largely responsible for the biological activities attributed to essential oils, particularly their notable antimicrobial properties.

EOs are gaining prominence as promising alternatives to conventional antibiotics, especially in the face of growing antimicrobial resistance. Their multifaceted modes of action—such as targeting microbial membranes, disrupting enzyme systems and interfering with microbial signaling—make them effective against multi-drug resistant pathogens (Soliman *et al.,* 2017; Oliva *et al.,* 2018). Additionally, essential oils and their constituents are widely applied across industries, including perfumery, cosmetics, pharmaceuticals, aromatherapy, dentistry, agriculture, food preservation and natural healthcare products, contributing to their expanding global market (Bakkali *et al.,* 2008).

Given the broad applications and therapeutic efficacy of essential oils, this review aims to explore their chemical nature, extraction techniques and biological properties, with particular emphasis on their antioxidant, antibacterial and antifungal activities, as well as profiling key aromatic plants known for EO production.

Nature and Biosynthesis of Essential Oils

Essential oils (EOs) are volatile, aromatic compounds synthesized through the secondary metabolism of aromatic plants. Termed "essential" because they embody the plant's characteristic fragrance and therapeutic attributes, EOs are intricate mixtures of bioactive constituents derived from various plant parts. These plant parts include seeds (e.g., caraway, cumin, coriander), leaves (e.g., mint, thyme, sageh, rosemary, oregano, basil, celery, parsley), fruits (e.g., anise, fennel, lemon), flowers (e.g., rose, rosemary), bark (e.g., cinnamon), buds or cloves (e.g., clove, garlic) and rhizomes (e.g., ginger).

The biosynthesis of essential oils occurs within the cytoplasm and plastids via multiple biochemical pathways, including the mevalonic acid (MVA), malonic acid and methyl-D-erythritol phosphate (MEP) pathways. Once synthesized, these volatile compounds are stored in specific anatomical structures such as glandular trichomes, secretory cavities, resin ducts and epidermal cells (Sharifi-Rad *et al.,* 2017). The aroma, color and chemical profile of EOs are influenced by the plant's species, geographic origin, climatic conditions and the developmental stage at harvest. Most essential oils are colorless to pale yellow, although some, such as those from blue chamomile and European valerian, exhibit distinctive hues.

In ecological terms, essential oils serve crucial protective functions—repelling herbivores, inhibiting microbial pathogens and attracting pollinators to aid reproduction (Sharifi-Rad *et al.,* 2017). These biological roles are largely attributed to their diverse phytochemical composition. Furthermore, environmental variables such as soil type, humidity, temperature and elevation can greatly affect the yield and composition of essential oils (Swamy *et al.,* 2015; Arumugam *et al.,* 2016). As such, understanding the biochemical and ecological factors influencing EO production is key to harnessing their full therapeutic and commercial potential.

Chemical Composition and Diversity of Essential Oils

Essential oils (EOs) are intricate mixtures of volatile organic compounds, primarily comprising two major classes: terpenes and phenylpropanoids, which are responsible for their aroma, flavor and diverse biological properties. In most essential oils, terpenes and terpenoids are dominant, while in some species, phenylpropanoids contribute significantly to their chemical profile and therapeutic effects (Zuzarte and Salgueiro, 2015; Sharifi-Rad *et al.,* 2017).

The biosynthesis of these compounds occurs via distinct metabolic pathways: monoterpenes and diterpene**s** are produced through the methylerythritol phosphate (MEP) pathway**,** sesquiterpenes through the mevalonate (MVA) pathway and phenylpropenes through the shikimic acid pathway (Zuzarte and Salgueiro, 2015). The chemical composition of EOs varies due to the presence of a wide array of secondary metabolites, including aldehydes, ketones, esters, alcohols and phenylpropanoids, which contribute to the specific characteristics of each oil (Sharifi-Rad *et al.,* 2017).

Terpenes are categorized based on the number of isoprene units they contain, such as monoterpenes, sesquiterpenes and diterpenes. Examples of common monoterpenes include p-cymene, limonene, sabinene, β-myrcene and γ-terpinene (Sharma *et al.,* 2017). Enzymatic modifications result in terpenoids, such as menthol, carvacrol, α-terpineol, geraniol and thymol, which exhibit enhanced structural diversity and biological activity (Gyawali and Ibrahim, 2014).

Although often present in smaller quantities, phenylpropanoids like eugenol, isoeugenol, cinnamaldehyde and safrole significantly contribute to the antimicrobial and antioxidant properties of EOs (Hyldgaard *et al.,* 2012).

The concentration and stereochemistry of these bioactive compounds can be influenced by factors such as plant species, geographical origin, harvest time, drying methods and distillation techniques, all of which affect the final EO profile (Swamy *et al.,* 2015; Arumugam *et al.,* 2016).

Most essential oils contain between 20 and 100 different compounds, although their distinct biological activities and aroma are typically attributed to just two or three major components, often present at concentrations between 20–70% (Chouhan *et al.,* 2017).

For instance, *Origanum* EO is dominated by carvacrol (30%) and thymol (27%), *Coriandrum* EO by linalool (68%), *Cinnamomum* EO by 1,8-cineole (50%) and *Mentha* EO by menthol (59%) and menthone (19%) (Bakkali *et al.,* 2008). Similarly, *Lavandula pubescens* oil contains carvacrol (55.7%) and methyl carvacrol (13.4%), while α-pinene and δ-3-carene are dominant in *Juniperus procera* (El-Said *et al.,* 2021).

Analytical tools such as Gas Chromatography–Mass Spectrometry (GC–MS) are widely used to characterize essential oil components. The GC component separates volatile compounds and the MS identifies them based on their unique fragmentation patterns, enabling accurate structural identification (Zuzarte and Salgueiro, 2015).

Extraction of Essential Oils

The analysis of essential oils (EOs) generally involves two key steps: the extraction or distillation of the oil, which usually takes several hours, followed by chemical analysis, which requires only a few minutes.

The method of extraction plays a critical role in determining the yield, quality and chemical composition of the essential oils (Butnariu and Sarac, 2018). Hydro-distillation using a Clevenger apparatus is the standard technique for EO extraction at the laboratory scale, as it efficiently recovers volatile aromatic compounds from plant tissues. In industrial practices, steam distillation is widely preferred for its scalability and ability to maintain oil purity and consistency (Sadeh *et al.,* 2019).

Solvent extraction, while effective and commonly used in industrial settings, is generally unsuitable for food and pharmaceutical applications due to the potential toxicity of residual solvents. To address this concern and improve extraction efficiency, various green technologies have been introduced. These include microwave-assisted extraction (MAE), ultrasound-assisted extraction (UAE) and ohmic hydro-distillation, which offer improved sustainability, reduced processing time and preservation of thermolabile constituents (Taban *et al.,* 2018; Butnariu and Sarac, 2018).

The extraction technique also affects the profile of bioactive compounds in the resulting oil. Oils derived through steam distillation typically retain volatile compounds, whereas solvent-based methods may include a broader spectrum of both volatile and non-volatile constituents. Therefore, the selection of an appropriate extraction method should be based on the plant's nature and the intended use of the oil (Butnariu and Sarac, 2018).

To ensure consistency in quality, the extraction process should be standardized across parameters such as plant part selection, harvest season and drying method. Fresh flowers should be used immediately for EO extraction, while leaves, seeds and other plant parts can be processed either fresh or after partial drying, depending on the compound stability and intended end-use (Butnariu and Sarac, 2018).

Biological Activities of Essential Oils

Since ancient times, aromatic herbs have been used not only as flavoring agents in the food industry but also as curative and preservative agents. The therapeutic effects of these plants are primarily attributed to their essential oils (EOs), which possess a wide array of biological properties. While major compounds (those present in higher concentrations) are considered key contributors, evidence suggests that the synergistic actions of various minor constituents also play a significant role in the bioactivity of EOs (Raut and Karuppayil, 2014).

EOs have been extensively employed in pharmaceutical applications, particularly in aromatherapy and as enhancers of drug palatability. Several traditional medicine systems across the globe have adopted EOs to manage a range of health conditions. For instance, *Eucalyptus* oil is used to alleviate bronchitis and coughs, *Sage* and *Clove* oils are recognized for their antibacterial effects and *Peppermint* and *Anise* oils serve as carminatives and respiratory aids (Swamy and Sinniah, 2015; Swamy *et al.,* 2016).

Essential Oils as Antioxidants

Essential oils have been widely reported as potent natural antioxidants, largely due to their safety and effectiveness compared to synthetic antioxidants such as butylated hydroxyanisole (BHA) and butylated hydroxytoluene (BHT), which are associated with potential health risks (Lanigan and Yamarik, 2002). An ideal antioxidant neutralizes free radicals by donating an electron, rendering the radicals less reactive and less damaging to cellular components (Firuzi *et al.,* 2011).

In vitro chemical assays such as DPPH (2,2-diphenyl-1-picrylhydrazyl) and $ABTS^{+}$ (2,2′-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid)) are commonly employed to evaluate the antioxidant activities of EOs. These tests involve stable free radicals that undergo decolorization upon interaction with antioxidant compounds. In the DPPH assay, antioxidants reduce the purple DPPH radical to a colourless form, with the degree of decolorization (measured at 519 nm via UV spectrophotometry) correlating to the antioxidant strength of the sample (Liang and Kitts, 2014).

Oxidative stress, resulting from excessive reactive oxygen species (ROS) and free radicals, contributes to numerous chronic diseases including cancer, diabetes, atherosclerosis, Alzheimer's disease and aging (Edris, 2007). Natural antioxidants such as those found in EOs help mitigate these conditions by scavenging excess radicals and protecting cellular components (Miguel, 2010).

Several studies have highlighted the antioxidant activities of EOs derived from aromatic species such as *Origanum*, *Tagetes*, *Bacopa*, *Thymus*, *Satureja*, *Mentha*, *Salvia*, *Curcuma*, *Achillea*, *Melaleuca* and *Ocimum*.

Among them, $ABTS^{+}$ scavenging activity often surpasses that of DPPH. Similarly, strong antioxidant capabilities have been observed in *Petroselinum*, *Coriandrum*, *Cuminum* and various *Allium* species. *Clove* oil has been reported to exhibit the highest radical-scavenging potential, followed by *Cinnamon*, *Nutmeg*, *Basil*, *Oregano* and *Thyme*. Key constituents like thymol (in *Thymus* spp.) and carvacrol (in *Origanum* spp.) have also shown superior antioxidant efficacy (Miguel, 2010).

Essential Oils as Antibacterial Agents

The escalating prevalence of antibiotic resistance—largely driven by overuse of conventional antimicrobials—poses a critical challenge to infectious disease management. Plant-derived bioactives, particularly essential oils (EOs), have demonstrated potent antibacterial efficacy against both Gram-positive and Gram-negative bacteria, offering a promising alternative for antimicrobial therapy and food preservation (Edris, 2007; Lang & Buchbauer, 2012).

EOs' antibacterial effectiveness is influenced by the presence and concentration of bioactive constituents such as phenylpropanoids, terpenoids, alcohols, aldehydes, ketones and esters. These compounds exert multi-targeted mechanisms of action—primarily involving hydrophobic interactions with bacterial membrane lipids that disrupt membrane integrity, impair nutrient uptake and destabilize electron transport and biosynthetic pathways, ultimately causing cell death (Petretto *et al.,* 2013; Bhavaniramya *et al.,* 2019).

Following membrane disruption, EO actives may penetrate into bacterial cells and inhibit protein synthesis or damage nucleic acids and polysaccharides (Bhavaniramya *et al.,* 2019). Oils from thyme, cinnamon, oregano, clove, lemongrass, peppermint, rosemary, bay and tea tree have shown strong bactericidal activities. For example, clove oil and oregano oil demonstrate inhibition at low concentrations (~0.04–0.05 %), while bay oil is active at ~0.02 % (Carson *et al.,* 2006; Bhavaniramya *et al.,* 2019).

Significant efficacy has also been reported against challenging pathogens such as methicillin-resistant *Staphylococcus aureus* (MRSA), where tea tree, lemon myrtle and garlic oils were notably effective (Carson *et al.,* 2006).

Essential oils from plants like tamarind, black cumin, nutmeg, garlic, onion and pomegranate seeds exhibit activity against *Salmonella enteritidis* and *Listeria monocytogenes* (Mota *et al.,* 2015). Although wild fennel fruit oils from Portugal displayed only mild effects against *S. enteritidis*, *E. coli*, *Pseudomonas aeruginosa* and *Proteus mirabilis* (Mota *et al.,* 2015).

Key individual constituents—such as eugenol from clove, carvacrol from oregano and terpinen-4-ol from tea tree oil—often outperform their whole oil mixtures in antibacterial potency. Phenylpropanoids like cinnamaldehyde, isoeugenol and safrole also contribute to activity (Carson *et al.,* 2006; Bhavaniramya *et al.,* 2019).

Microscopy and in vitro studies provide mechanistic insights: cumin oil causes membrane permeability defects in *Listeria innocua* and *E. coli*, leading to leakage and cell death; *Trachyspermum copticum* oil induces pore formation and lysis in *E. coli*; *Artemisia argyi* oil increases *S. aureus* membrane permeability, causing protein and potassium efflux; *Citrus changshan-huyou* oil and carvacrol trigger cell surface damage and fragmentation in *L. monocytogenes* (Behbahani *et al.,* 2019; Huang *et al.,* 2019; Xiang *et al.,* 2018; Guo *et al.,* 2019; Churklam *et al.,* 2020).

Essential Oils as Antifungal Agents

A wide variety of essential oils from aromatic plants have exhibited strong antifungal activity against pathogenic fungi, particularly *Candida* species. For instance, essential oils from *Foeniculum vulgare* (fennel), *Coriandrum sativum* (coriander) and *Pimpinella anisum* (anise) inhibited *Candida albicans* at concentrations around 1%, 0.5% and 0.25%, respectively (Nazzaro *et al.,* 2017). Similarly, oils from geranium, Japanese mint, cinnamon, clove, ginger grass and lemongrass (0.01–0.15%) effectively inhibited *C. albicans* (Nazzaro *et al.,* 2017). Oils derived from *Lavandula multifida* and *Cymbopogon* species also showed pronounced antifungal effects (Viuda-Martos *et al*., 2008).

Notable bioactive molecules, such as eugenol (a phenylpropanoid) and β-bisabolol (a sesquiterpene alcohol), demonstrated significant antifungal activity against dermatophytes and their spores (Pragadheesh *et al.,* 2013). Lemongrass oil, at minimal concentrations (0.006–0.03%), suppressed *Aspergillus flavus* growth and aflatoxin production. Additionally, citrus oils from lemon, mandarin, grapefruit and orange (at <1%) inhibited various *Aspergillus* and *Penicillium* species (Viuda-Martos *et al*., 2008).

In treating drug-resistant *C. albicans* biofilms, certain essential oils and their constituents inhibit ergosterol synthesis and disrupt signaling pathways related to hyphal formation (Raut *et al*., 2013). Key compounds—citral, citronellol, geraniol and geranyl acetate—have been found to arrest *C. albicans* cell cycle at the S-phase, thereby impeding fungal growth (Zore *et al*., 2011). Other terpenoid phenols, including carvacrol, eugenol and thymol, impair *Saccharomyces cerevisiae* viability by disrupting calcium and proton ion homeostasis (Rao *et al*., 2010).

The underlying mechanism of these antifungal agents involves induction of calcium stress and inhibition of the TOR (target of rapamycin) pathway, as shown in yeast models. This leads to altered gene expression, disrupted metabolic function and fungal cell death (Rao *et al*., 2010).

These findings underscore the potent antifungal potential of essential oils and their constituents. Various bioactive essential oils, their major compounds, target microorganisms, effective concentrations, detailed comparison of MIC values and mechanisms of action is presented in Table 1.

Different Important Medicinal Plants Producing Essential Oils

Medicinal herbs have played a significant role in traditional healthcare systems, particularly across African and Asian civilizations, for thousands of years.

Over recent decades, there has been a marked global resurgence in the acceptance and utilization of natural therapies. According to the World Health Organization (WHO), approximately 85% of the global population, equating to nearly four billion people, rely on herbal remedies as an alternative or supplement to conventional medicine (WHO, 2019). Moreover, nearly 25% of modern pharmaceutical drugs are either directly derived from or inspired by compounds found in medicinal plants (Jugreet *et al.,* 2020).

Essential oils (EOs) derived from medicinal and aromatic plants (MAPs) exhibit a diverse array of bioactive properties and are used extensively in pharmaceuticals, cosmetics, aromatherapy and food industries. The rising interest in the therapeutic potential of EOs has encouraged researchers and cultivators to focus on their production and commercial utilization (Swamy and Sinniah, 2016).

These oils are predominantly sourced from plants that thrive in warm and tropical climates, with species from families such as Lamiaceae, Myrtaceae, Rutaceae, Apiaceae, Asteraceae, Alliaceae and Poaceae being particularly prolific (Jugreet *et al.,* 2020).

Table.1 Bioactive Essential Oils: Major Compounds, Target Microorganisms, Effective Concentrations and Mechanisms of Action

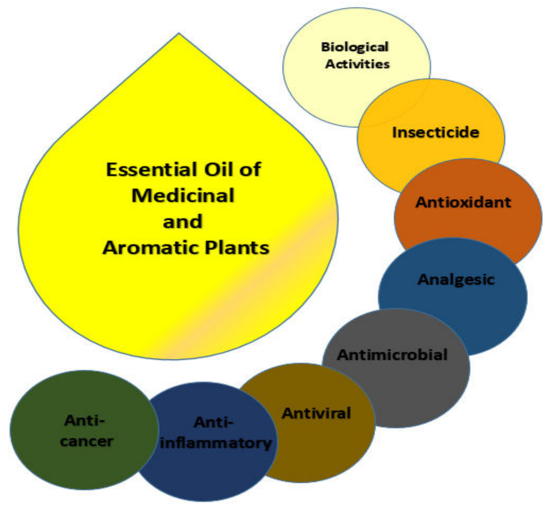
Essential Oil (Botanical Name)	Major Active Compounds	Target Microorganisms	Effective Concentration (MIC)	Mechanism of Action	Reference (DOI)
Lemongrass (*Cymbopogon citratus*)	Citral	*Candida albicans*, *Aspergillus flavus*, yeasts	0.006–0.03%	Disrupts membrane integrity; inhibits aflatoxin biosynthesis	10.1016/j.foodcont.2007.12.003
Clove (*Syzygium aromaticum*)	Eugenol	*C. albicans*, *Staphylococcus aureus*	0.04–0.06%	Membrane disruption, ergosterol inhibition	10.1016/j.phytochem.2012.04.016
Thyme (*Thymus vulgaris*)	Thymol, Carvacrol	*Escherichia coli*, *S. aureus*	0.05%	Increases membrane permeability; protein denaturation	10.1016/j.lwt.2005.03.015
Oregano (*Origanum vulgare*)	Carvacrol	*S. aureus*, *C. albicans*	0.05%	Disrupts cell membrane, ATP synthesis inhibition	10.1016/j.fm.2007.01.010
Tea Tree (*Melaleuca alternifolia*)	Terpinen-4-ol	MRSA, *Candida spp.*	0.125%	Respiratory inhibition, DNA and cell cycle disruption	10.1128/AAC.01200-06
Cinnamon (*Cinnamomum zeylanicum*)	Cinnamaldehyde	*C. albicans*, *S. aureus*, dermatophytes	0.02–0.1%	Lipid interference, enzyme inhibition, membrane disintegration	10.1016/j.indcrop.2013.06.019
Geranium (*Pelargonium graveolens*)	Geraniol, Citronellol	*C. albicans*	~0.03%	Inhibits hyphal morphogenesis; blocks S phase in cell cycle	10.1016/j.phymed.2011.04.004
Lavandula multifida	Linalool, Camphor	*C. albicans*	~0.5%	Membrane destruction; ergosterol inhibition	10.1016/j.phytochem.2012.04.016
Camphor tree (*Cinnamomum camphora*)	1,8-Cineole, Camphor	Dermatophytes	~0.1%	Destroys spore walls; blocks germination	10.1016/j.indcrop.2013.06.019
Citrus oils (*Citrus spp.*: Lemon, Orange, etc.)	Limonene, Linalool	*Aspergillus*, *Penicillium* spp.	< 1%	Inhibits conidia germination and fungal sporulation	10.1016/j.foodcont.2008.01.003
Japanese Mint (*Mentha arvensis*)	Menthol	*C. albicans*	0.01–0.15%	Alters fungal enzyme activities; disrupts	10.1016/j.fct.2010.01.043

				membrane potential	
Ginger Grass (*Cymbopogon martinii*)	Geraniol, Linalool	*C. albicans*	0.01–0.15%	Antifungal by disrupting membrane and energy metabolism	10.1016/j.foodcont.2008.01.003
Eucalyptus (*Eucalyptus globulus*)	Citral	*C. albicans*	Not specified	Arrests cell cycle in S phase	10.1016/j.phymed.2011.04.004
Foeniculum vulgare (Fennel)	Trans-anethole, Fenchone	*C. albicans*	1%	Alters membrane integrity	10.1016/j.arabjc.2011.01.017
Anise (*Pimpinella anisum*)	Anethole	*C. albicans*	0.25%	Inhibits fungal growth; impacts ergosterol synthesis	10.1016/j.phymed.2012.03.008

Table.2 Selected Medicinal Plants Producing Essential Oils, Their Bioactive Components and Applications

Plant Species	Family	Major Bioactive Compounds	Part Used	Key Applications
***Ocimum basilicum* (Basil)**	Lamiaceae	Linalool, Methyl chavicol	Leaves	Antibacterial, antioxidant, food flavoring
***Mentha arvensis* (Maize mint)**	Lamiaceae	Menthol, Menthone	Leaves	Antiseptic, cooling agent, toothpaste, pharma
***Cymbopogon citratus* (Lemongrass)**	Poaceae	Citral, Geraniol, Myrcene	Leaves	Antifungal, anti-inflammatory, insect repellent
***Cinnamomum camphora* (Camphor)**	Lauraceae	Camphor, 1,8-Cineole, Safrole	Bark, wood	Anti-inflammatory, rubefacient, antimicrobial
***Syzygium aromaticum* (Clove)**	Myrtaceae	Eugenol, β-Caryophyllene	Flower buds	Antiseptic, dental applications, antioxidant
***Citrus limon* (Lemon)**	Rutaceae	Limonene, β-Pinene, Citral	Peel	Antimicrobial, food preservative, cleaning agent
***Citrus sinensis* (Sweet Orange)**	Rutaceae	Limonene, Myrcene, Linalool	Peel	Antioxidant, aromatherapy, beverage flavoring
Eucalyptus globulus	Myrtaceae	1,8-Cineole (Eucalyptol), α-Pinene	Leaves	Respiratory treatments, antiseptic, insect repellent
***Pogostemon cablin* (Patchouli)**	Lamiaceae	Patchoulol, Norpatchoulenol	Leaves	Fixative in perfumes, antifungal, skin applications
***Cymbopogon nardus* (Citronella)**	Poaceae	Citronellal, Geraniol, Limonene	Leaves	Mosquito repellent, antifungal, aromatherapy

Figure.1 Different biological effects of EOs



Out of approximately 3,000 identified essential oils across various plant genera, only about 300 are of significant commercial importance. Commonly used essential oils with medicinal value include those from *Ocimum basilicum* (basil), *Mentha arvensis* (maize mint), *Cymbopogon citratus* (lemongrass), *Cinnamomum camphora* (camphor), *Syzygium aromaticum* (clove), *Eucalyptus globulus* (eucalyptus), *Pogostemon cablin* (patchouli) and several citrus species such as *Citrus limon* (lemon) and *Citrus sinensis* (sweet orange).

These oils contain key phytoconstituents like linalool, menthol, citral, eugenol, limonene and 1, 8-cineole, which contribute to their wide-ranging pharmacological activities (Swamy and Sinniah, 2016; Jugreet *et al.,* 2020).

Essential oils (EOs), as natural plant-derived products, have garnered significant attention due to their multifaceted applications in traditional medicine and modern therapeutic systems worldwide.

This review highlights the diverse nature of essential oils, their beneficial biological properties, active constituents and the medicinal and aromatic plants (MAPs) that serve as their primary sources.

The findings summarized here aim to stimulate further interest among researchers exploring novel, effective and natural antimicrobial agents—particularly in the face of rising antimicrobial resistance. Moreover, the therapeutic versatility of EOs, including their role in alleviating oxidative stress-related disorders, supports their potential as complementary or alternative interventions in human and agricultural health.

This review also emphasizes the various mechanisms of action by which EOs exert antimicrobial and pesticidal effects. Such understanding could pave the way for innovative applications in essential oil-based therapies and sustainable agriculture. However, to translate these promising bioactivities into practical applications, further in-depth studies—especially clinical trials and field evaluations—are necessary. These efforts will help facilitate the development of standardized, safe and effective EO-based formulations for future use in medicine, food safety and eco-friendly farming systems.

Future Outlook

The growing body of evidence on the multifunctional properties of essential oils underscores their potential as eco-friendly alternatives to synthetic agrochemicals and pharmaceutical agents. However, several challenges remain in translating laboratory findings into real-world applications. Future research should prioritize:

- **Standardization of EO compositions** to ensure consistency across batches and sources.
- **Comprehensive toxicological and pharmacokinetic studies** to establish safety profiles for human, animal and environmental health.

- **Advanced formulation strategies**, such as nanoemulsions and encapsulation techniques, to enhance the stability, solubility and bioavailability of essential oils.
- **Field-scale trials** in diverse agro-ecological zones to validate their efficacy as biopesticides, biofungicides, or biostimulants.
- **Integration of EO applications in integrated pest management (IPM)** and sustainable agricultural practices.

Interdisciplinary collaboration among botanists, chemists, pharmacologists, agronomists and policy-makers will be crucial to fully unlock the therapeutic and agricultural value of essential oils and position them as a sustainable solution for global challenges in health and food security.

Author Contributions

Dr Snigdharani Dash: Conceived the original idea, gather the resources, analysed the data, writing- review and editing.

Data Availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical Approval Not applicable.

Consent to Participate Not applicable.

Consent to Publish Not applicable.

Conflict of Interest The authors declare no competing interests.

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