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Evaluation of the Antimicrobial Potential of Essential Oils from Traditional Indian Medicinal Herbs: Eucalyptus, Curcuma, Zingiber, and Citrus

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ABSTRACT
The rapid escalation of multidrug-resistant (MDR) pathogens has critically compromised the efficacy of conventional antibiotics, driving the imperative to explore novel, plant-derived bioactive compounds. This study systematically evaluates the in vitro antimicrobial and antifungal potential of essential oils extracted from four therapeutically significant medicinal plants: Eucalyptus globulus (Eucalyptus), Curcuma longa (Turmeric), Zingiber officinale (Ginger), and Citrus limon (Lemon). The extraction of volatile oils was executed via hydro distillation utilizing a Clevenger-type apparatus. The antimicrobial efficacy of the obtained extracts was subsequently evaluated using the agar well diffusion method against a selected panel of pathogenic strains, including Escherichia coli, Pseudomonas aeruginosa, and the fungal strain Rhizopus. Antimicrobial potency was quantitatively determined by measuring the respective zones of inhibition (ZOI).The experimental outcomes revealed significant, differential susceptibility profiles among the tested micro-organisms. Eucalyptus globulus and Zingiber officinale essential oils demonstrated robust antimicrobial activity, characterized by pronounced zones of inhibition, whereas Curcuma longa and Citrus limon exhibited moderate inhibitory efficacy. Furthermore, a comparative analysis indicated that Gram-positive bacteria displayed greater sensitivity to the treatments than Gram-negative strains. These findings collectively suggest that these essential oils possess potent bioactive constituents and hold significant potential as natural, sustainable antimicrobial agents, offering promising avenues for the development of novel phytopharmaceuticals to combat resistant microbial strains.

Keywords: Essential oils, Antimicrobial activity, Medicinal herbs, Hydro-distillation, Eucalyptus, Ginger, Turmeric

1. Introduction

Since ancient times, medicinal plants have functioned as the primary foundation of traditional health care systems. This historical reliance is deeply rooted in the Indian subcontinent, where traditional practices like Ayurveda, Unani, and Siddha continue to play a vital role in public health.

The therapeutic value of these botanical resources lies in their diverse array of bioactive secondary metabolites.Thes naturally occurring compounds are responsible for a wide spectrum of pharmacological effects, most notably demonstrating potential microbial, antioxidant, anti-inflammatory, and anticancer activities(Cowan,1999).Themodernerahaswitnessedanotabletransitiontowardstheuseofplant-derivednatural products, primarily as a response to the escalating adverse effects and inherent constraints of synthetic medications. Botanical sources are gaining prominence not only for their therapeutic efficacy but also because theyoffer a safer, environmentally sustainable, and more affordable approach to managing various clinical conditions (Rates, 2001). The biological functionality of medicinal plants is fundamentally driven by their diverse profiles of secondary metabolites, including alkaloids, flavonoids, terpenoids, and various phenolic constituents. Within this chemical framework, essential oils have emerged as particularly significant due to their robust antimicrobial properties and broad-spectrum efficacy against pathogenic microorganisms (Bakkali et al., 2008).

1.1 Eucalyptus globules

Eucalyptus is extensively recognized for its potent antiseptic and antimicrobial characteristics. The therapeutic profile of its essential oil is primarily attributed to its high concentration of 1 ,8-cineole (eucalyptol). This bioactive monoterpene is the principal constituent responsible for the plant's robust inhibitory action against a diverse range of bacterial and fungal pathogens (Sadlon & Lamson, 2010).

1.2 Zingiber officinale (Ginger)

Zingiber officinale, commonly known as ginger, is a pharmacologically significant rhizome prized forits extensive antimicrobial capabilities. The essential oil derived from this plant is a complex matrix of bioactive constituents, notably gingerols, shogaols, and zingiberene. These specific phytochemicals are the primary drivers of the oil's biological efficacy, providing a synergistic defense against various bacterial strains and fungal isolates (Singh et al., 2008).

1.3 Turmeric (Curcuma longa)

The therapeutic application of turmeric in ethnomedicine is largely attributed to curcumin's anti-inflammatory and antimicrobial profile; however, as highlighted by (Gupta et al., 2013), its biological efficacy is frequently compromised by its poor aqueous solubility.

1.4 Lemon (Citrus limon)

Owing to its high limonene content, the essential oil derived from Citrus limon demonstrates significant antioxidant and antimicrobial activity. Consequently, it has become a staple ingredient in cosmetic formulations and food stabilization techniques (Fisher & Phillips, 2006)

2. Materials and Methods

The experimental investigations for the current study, titled "Evaluation of Antimicrobial Potential of Essential Oils Isolated from Traditional Indian Medicinal Herbs: Eucalyptus, Haldi,GingerandLemon,"wereconductedintheresearchlaboratoriesofthe Department of Biotechnology/Microbiology during the academic session 2025-2026.Themethodological framework comprised the extraction of essential oils from the selected plant matrices, formulation ofstable oil emulsions, systematic antimicrobial screening, and subsequent statistical validation of the empirical data. The study was strategically designed to assess and compare the inhibitoryefficacyofthe isolated essential oils against a panel of pathogenic bacterial and fungal strains. This evaluation was executed utilizing the standardized agar well diffusion assay, followed by the determination of the Minimum Inhibitory Concentration (MIC) for each active extract.

Fresh plant materials were procured from local herbal markets and formally authenticated based on their distinct morphological and taxonomic characteristics

2.1 Collection of Plant Material

 Eucalyptus globulus	 Zingiber officinale
 Curcuma longa	 Citrus limon

2.2 Preparation of Plant Material

The collected plant samples were prepared for extraction by first reducing their size using sterile scissors and a grinder. Specifically, the eucalyptus leaves were finely chopped, while the turmeric and ginger rhizomes were peeled and sliced into smaller pieces. The lemon peels were carefully separated from the fruit. Once prepared, all the plant materials were transferred to airtight containers and stored appropriately until the extraction process began.

2.3 Extraction of Essential Oils

For each extraction, 200-300g of fresh plant material was placed into a round-bottom flask, and sufficient amount of distilled water was added to ensure complete submersion. The flask was then connected to the Clevenger-type apparatus and heated continuously for 3-4 hours (Bose et al., 2013). During this process, the steam-volatile compounds vaporized and were subsequently condensed. There distillate separated into two distinct phases an essential oil layer and an aqueous layer. The essential oil was carefully recovered from the top of the condensate using a micropipette. To remove any trace of residual moisture, the collected oil was treated with anhydrous sodium sulfate. Finally, the extracted oils were transferred into amber-colored glass bottles and stored at 4°C to prevent degradation until further analysis.

Eucalyptus globulus Essential Oil   Zingiber officinale Essential Oil


Curcuma longa Essential Oil Citrus limon Essential

Preparation of Essential Oil Emulsions

Given the hydrophobic nature of essential oils, their integration into aqueous media was achieved by preparing emulsions using Tween-20 or Tween-80 as emulsifying agents.

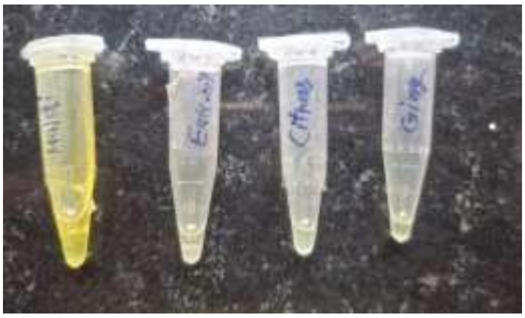
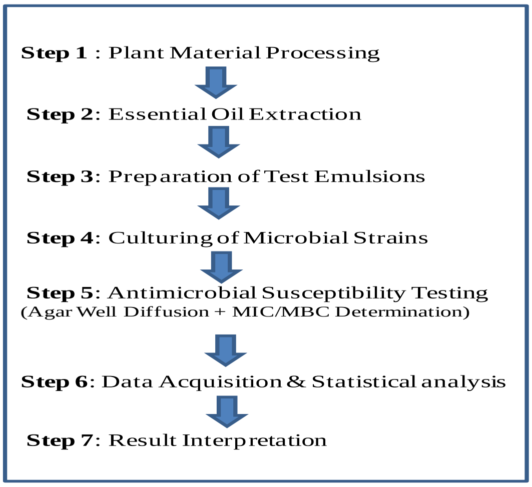


Figure 1:- Different Oil Emulsion

2.4 Experimental Procedure

To investigate the effect of different concentrations, essential oil emulsions were prepared at 25%, 50%, 75%, and 100% (v/v) ratios. A measured quantity of Tween-20 was added to the essential oil to facilitate proper emulsification and enhance solubility. Subsequently, distilled water was added to the mixture to reach the required final volume. Each preparation was then vortexed for 20-30 seconds to ensure a stable and homogeneous emulsion. To maintain experimental accuracy and prevent phase separation, fresh emulsions were prepared immediately before each individual experiment.

2.5 Flow of chart of Experimental work



3 RESULTS

The antibacterial activity of the selected essential oils against E. coli was evaluated by measuring the zone of inhibition at different concentrations. Among the tested oils, Curcuma longa (turmeric) exhibited the highest inhibition zone (1.8 mm) at 100 µL, indicating comparatively stronger antibacterial activity. All essential oils demonstrated inhibitory effects against E. coli, with activity generally increasing at higher concentrations (Table 1). The antibacterial activity of essential oils against Pseudomonas aeruginosa was assessed using the zone of inhibition method. Curcuma longa demonstrated the highest inhibitory effect, producing a maximum zone of inhibition of 1.9 mm at 75 µL and 100 µL concentrations. The findings suggest that all tested essential oils possess varying degrees of antibacterial activity against P. aeruginosa (Table 2).

For Plate/Image (Antibacterial Assay)

The agar well diffusion assay showed clear zones of inhibition around wells containing the essential oils, indicating antibacterial activity against the tested bacterial strains. Variations in inhibition zones were observed among different oils and concentrations, reflecting differences in their antimicrobial efficacy. The results support the potential use of these essential oils as natural antibacterial agents.

Table 1: Antibacterial Activity against E. coli

Sr. No	Essential Oils	NAM	Standard antibiotic (mm)	Essential Oil Con. 25µL	Essential Oil Con. 50µL	Essential Oil Con. 75µL	Essential Oil Con. 100µL
1	Eucalyptus	E. coli	2.20 mm	1.25 mm	1.20 mm	1.3 mm	1.60 mm
2	Lemon	E. coli	2.35 mm	1.10 mm	1.45 mm	1.4 mm	1.55 mm
3	Haldi	E. coli	2.50 mm	1.20 mm	1.40 mm	1.6 mm	1.80 mm
4	Ginger	E. coli	2.20 mm	1.50 mm	1.40 mm	1.6 mm	1.50 mm

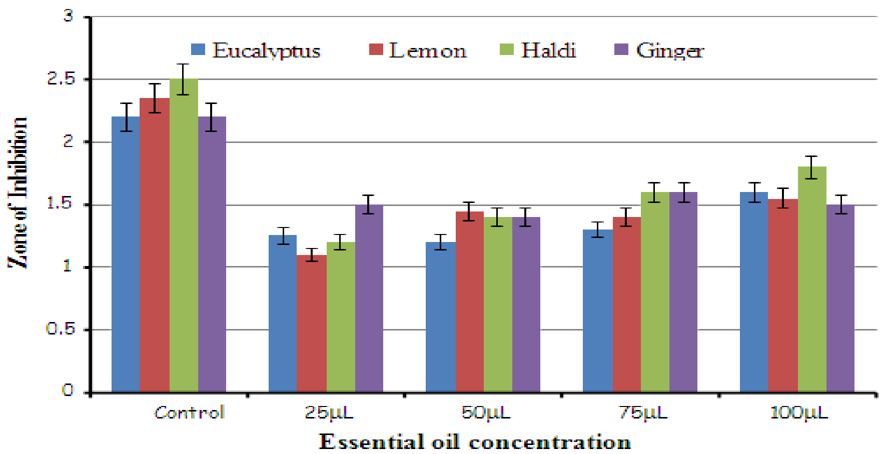


Fig 2:- Graph shows the activity of different essential oil on E. coli

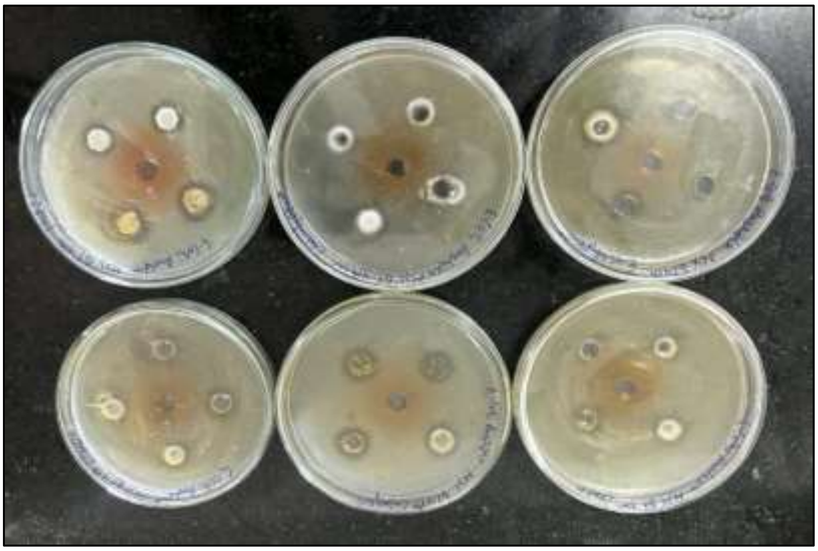


Fig 3 Antibacterial activity of essential oils against Pseudomonas aeruginosa

Table 2: Table shows the antibacterial activity against Pseudomonas

Sr. No.	**Essential Oils**	**NAM**	**Standard antibiotic (mm)**	**Essential oil conc. 25µL**	**Essential oil conc. 50µL**	**Essential oil conc. 75µL**	**Essential oil conc. 100µL**
1	Eucalyptus globules	Pseudomonas	2.5 mm	1.10 mm	1.25 mm	1.5 mm	1.55 mm
2	Citrus Limon	Pseudomonas	2.0 mm	1.35 mm	1.45 mm	1.55 mm	1.45 mm
3	Curcuma longa	Pseudomonas	1 .9 mm	1.50 mm	1.70 mm	1.90 mm	1.90 mm
4	Zingiber officinale	Pseudomonas	2.3 mm	1.40 mm	1.80 mm	1.50 mm	1.50 mm

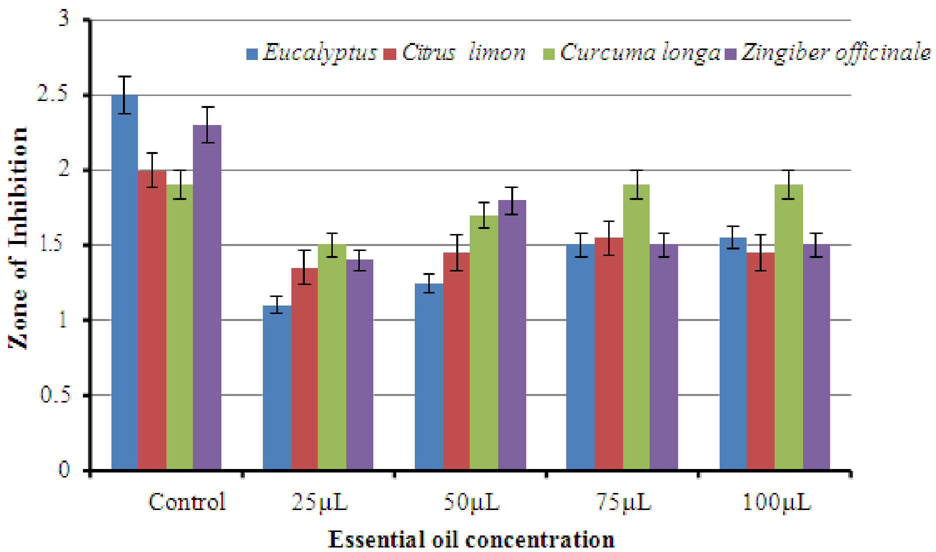


Fig 4:- Graph shows the activity of different essential oil on Pseudomonas

Table:3 Antifungal activity against Rhizopus

Sr. No.	Essential Oils	SDA	Standard Antibiotic (mm)	Essential oil conc. 25µL	Essential oil conc. 50µL	Essential oil conc. 75µL	Essential oil conc. 100µL
1	Curcuma longa	Rhizopus	2.5 mm	1 .5 mm	1 .3 mm	2.1 mm	2.2 mm
2	Zingiber officinale	Rhizopus	2.2 mm	1 .3 mm	1 .5 mm	1 .8 mm	2.0 mm
3	Citrus limon	Rhizopus	1 .5 mm	1 .1 mm	1 .4 mm	1 .5 mm	2.0 mm
4	Eucalyptus globulus	Rhizopus	2.0 mm	1 .0 mm	1 .3 mm	1 .7 mm	1 .8 mm

4. Discussion

The study revealed significant antimicrobial activity of all tested essential oils (Table 1, 2 and 3). Lemon oil exhibited the strongest antimicrobial effect, likely due to the presence of limonene and citrul. Eucalyptus oil showed substantial antibacterial activity attributed to eucalyptol. Ginger and Turmeric oils demonstrated moderate inhibitory effects, which may be linked to gingerols and turmerones, respectively (Fig2; 3 and 4).

The antimicrobial action of essential oils is primarily associated with disruption of microbial cell membranes, leakage of intracellular contents, and inhibition of metabolic pathways. The results support previous findings regarding the therapeutic potential of medicinal plant essential oils.

5. Conclusion

The present investigation evaluated the antimicrobial efficacy of essential oils derived from selected traditional Indian medicinal herbs, namely eucalyptus (Eucalyptus globulus), turmeric (Curcuma longa), ginger (Zingiber officinale), and lemon (Citrus limon). The findings demonstrate that these oils exhibit significant inhibitory potential against the tested microbial strains, including Escherichia coli, Pseudomonas aeruginosa, and Rhizopus species. Experimental data indicate that the observed antimicrobial activity is concentration-dependent and is fundamentally influenced by the specific phytochemical composition of each essential oil. Consequently, these results support the potential application of these plant-derived oils as natural antimicrobial agents.

Among the essential oils evaluated, eucalyptus and lemon demonstrated potent antibacterial efficacy, whereas ginger and turmeric oils exhibited effective antifungal properties alongside moderate antibacterial activity. The observed antimicrobial action is likely attributable to the presence of bioactive compounds, such as eucalyptol, curcumin, gingerol, and limonene, as well as other phenolic constituents, which function by disrupting microbial cell membranes and inhibiting microbial growth."

This study confirms that essential oils extracted from medicinal plants provide a viable, eco-friendly alternative to synthetic antimicrobial agents. These oils hold significant potential for diverse applications within the pharmaceutical, food preservation, cosmetic, and healthcare sectors. Ultimately, these findings validate the traditional medicinal significance of these herbs and demonstrate that plant-derived essential oils warrant further investigation for the development of effective, natural antimicrobial formulations.

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