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Essential Oil-Based Microemulsions In Antimicrobial Applications: A Natural Approach

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Abstract: The growing resistance to conventional antimicrobials has accelerated the demand for safer, eco-friendly alternatives. Essential oil-based microemulsions (EO-MEs) have emerged as promising carriers for antimicrobial applications, offering improved solubility, stability, and penetration. This review outlines recent advancements in extraction techniques for essential oils, the principles and formulations of microemulsions, and their efficacy against various microbial strains. Emphasis is placed on Citrus-based essential oils, particularly lemon (Citrus limon), which exhibit broad-spectrum antimicrobial activity. The paper also discusses evaluation strategies, stability considerations, and the future scope of EO-MEs in therapeutic and industrial domains.

Key Words : Essential oils, Microemulsions, Antimicrobial activity, Lemon oil

I. INTRODUCTION

The global rise in antimicrobial resistance (AMR) has posed one of the most significant threats to public health in the 21st century. The overuse and misuse of synthetic antibiotics have led to the emergence of resistant microbial strains that no longer respond to conventional treatments. Consequently, there is an urgent need to explore alternative strategies that are effective, safe, and environmentally sustainable. Among the various natural options explored, essential oils (EOs) have attracted considerable attention due to their wide range of biological activities, particularly their antimicrobial potential [1].

EOs are volatile, aromatic compounds extracted from various parts of plants including leaves, fruits, seeds, flowers, roots, and bark. Comprising terpenes, alcohols, esters, aldehydes, phenols, and ketones, EOs exhibit remarkable pharmacological effects such as antimicrobial, antioxidant, antiviral, anti-inflammatory, and wound-healing properties [2,3]. The inherent bioactivity of these compounds, particularly in combating bacterial and fungal infections, offers an eco-friendly and biodegradable alternative to synthetic chemicals. However, the direct application of essential oils in pharmaceutical or cosmetic formulations faces several limitations. These include low aqueous solubility, high volatility, photodegradation, and instability upon exposure to air or light [3].

To address these limitations, microemulsions (MEs) have emerged as promising vehicles for EO delivery. MEs are clear, thermodynamically stable, and isotropic mixtures of oil, water, surfactant, and often a co-surfactant. The droplet size of MEs typically ranges between 10–100 nm, which significantly enhances surface area, improves membrane penetration, and facilitates controlled drug release. These features are particularly advantageous when formulating topical or spray-based antimicrobial products [2,3].

The integration of essential oils into microemulsion systems has led to the development of novel formulations with enhanced antimicrobial activity, superior shelf life, and improved skin permeability. Several essential oils—including those from tea tree, rosemary, clove, basil, peppermint, and especially citrus fruits—have been incorporated into MEs for applications in wound healing, personal care, disinfection, and food preservation. Among citrus oils, lemon (Citrus limon) peel oil has emerged as a particularly potent antimicrobial agent. Rich in D-limonene, a monocyclic monoterpene hydrocarbon, lemon oil demonstrates strong antibacterial and antifungal effects against a wide spectrum of pathogens [4,5].

Recent research, including that by Chakraborty et al., has shown that lemon oil-based microemulsions can be effectively developed using biocompatible surfactants like Tween 80 and co-surfactants like PEG 400. Such systems offer stable, alcohol-free formulations suitable for skin application or surface disinfection. These microemulsions exhibit favorable physicochemical properties such as appropriate pH, low viscosity, and low surface tension, which are ideal for topical usage.

II. SOURCES AND COMPOSITION OF ESSENTIAL OILS

EOs are secondary metabolites synthesized by aromatic plants as part of their defense mechanism against pathogens and herbivores. Their chemical composition depends on plant species, geographical origin, extraction method, and the part of the plant used. For instance, citrus essential oils derived from peels are predominantly composed of limonene, a compound with proven antimicrobial and antioxidant activity [4].
Lemon essential oil, specifically, contains a high concentration of monoterpenes such as D-limonene (60–75%), β-pinene, and γ-terpinene. These constituents contribute to both antimicrobial and anti-inflammatory effects [4,5]. Other essential oils commonly studied for antimicrobial applications include tea tree oil (Melaleuca alternifolia), which contains terpinen-4-ol, and clove oil (Syzygium aromaticum), which is rich in eugenol [2,3]. The bioactivity of these oils, particularly in low concentrations, makes them attractive candidates for inclusion in drug delivery systems.

III. EXTRACTION TECHNIQUES AND YIELD OPTIMIZATION

Multiple extraction techniques are employed to isolate essential oils. The most common ones include hydro-distillation, steam distillation, cold pressing, and solvent extraction. Hydro-distillation, particularly via a Clevenger apparatus, is widely used due to its efficiency in preserving heat-sensitive volatile compounds [6,7]. Zeleke et al. demonstrated the successful extraction of limonene-rich oils from citrus peels using hydro-distillation, validating it as a preferred method for quality retention [6].
While Soxhlet extraction yields more oil quantitatively, it often degrades thermolabile compounds, resulting in lower-quality oils [6,7]. Cold pressing, though gentle, is restricted to peel-based oils like those from citrus fruits. GC-MS (Gas Chromatography–Mass Spectrometry) analysis is often used post-extraction to confirm oil composition and purity.

IV. MICROEMULSION SYSTEMS FOR EO DELIVERY

Microemulsions are composed of oil, water, surfactant, and co-surfactant. Surfactants reduce interfacial tension between oil and water, while co-surfactants increase fluidity at the interface, promoting nano-sized droplet formation [2,10]. Commonly used surfactants in EO-MEs include non-ionic surfactants like Tween 80 and Span 20. Co-surfactants such as PEG 400 or ethanol are added to improve formulation stability [10].
Formation methods include phase titration, where components are mixed systematically to generate transparent and thermodynamically stable systems. Pseudo-ternary phase diagrams aid in visualizing the compositional ranges yielding microemulsions [15,16]. A well-defined microemulsion region suggests greater formulation robustness.

V. MECHANISM OF ANTIMICROBIAL ACTION OF EO-MES

The antimicrobial action of essential oils is multifaceted. EO constituents such as limonene, eugenol, and carvacrol disrupt microbial cell membranes, increase permeability, and lead to leakage of cellular contents. When incorporated into microemulsions, their delivery is enhanced by nanoscale droplet size and increased contact with microbial surfaces [4,5].
The surfactants used in EO-MEs may themselves possess mild antimicrobial activity and can facilitate EO diffusion into bacterial membranes. This synergistic interaction improves overall efficacy and may help in overcoming microbial resistance [2,10].

VI. IN-VITRO EVALUATION METHODS

In-vitro evaluation of EO-MEs involves determining antimicrobial susceptibility using standard microbiological assays. Disk diffusion and agar well diffusion are simple, qualitative methods, whereas broth microdilution provides quantitative data like minimum inhibitory concentration (MIC) and minimum bactericidal concentration (MBC) [12].
For example, Malik and Upadhyay tested rosemary and tea tree oil microemulsions against bacterial strains using the agar well diffusion method and observed significant zones of inhibition, confirming potent

antimicrobial action [2]. Bhavsar et al. similarly reported improved efficacy of basil oil MEs against sinusitis pathogens [10].

VII. STABILITY AND PHYSICOCHEMICAL EVALUATION

Ensuring formulation stability is critical. Parameters like pH, viscosity, surface tension, and phase separation are commonly assessed. Stable pH values between 4.5–6.5 ensure compatibility with skin and mucosa. Viscosity influences application, while surface tension affects spreadability. Low surface tension (~33–35 dyne/cm) promotes rapid distribution on surfaces [14].

Chakraborty et al. evaluated 27 formulations of lemon oil MEs using Tween 80 and PEG 400. The most stable formulations had Smix ratios of 2:1 and showed desirable properties: pH 5–6, viscosity ~5.5 cP, and surface tension ~34 dyne/cm. Only a few formulations underwent phase separation after 60 days, indicating overall stability.

VIII. CASE STUDY: LEMON PEEL EO MICROEMULSIONS BY CHAKRABORTY ET AL.

In a recent study, lemon peel essential oil was extracted using hydro-distillation and formulated into 27 different microemulsions using varying ratios of oil, Smix (Tween 80 and PEG 400), and water. These were evaluated through pseudo-ternary phase diagrams, pH, viscosity, surface tension, and phase separation tests. Most of the formulations exhibited good transparency, citrus aroma, and remained stable over 60 days. The pH ranged between 4.3 and 6.5, viscosity between 5.3–6.6 cP, and surface tension ~34–35 dyne/cm. Only six out of 27 showed phase separation. These findings validate the potential of such EO-MEs as natural antimicrobial formulations suitable for spray-based delivery.

IX. APPLICATIONS AND FUTURE PERSPECTIVES

EO-MEs offer applications across pharmaceuticals, cosmeceuticals, food preservation, and agriculture. In pharmaceuticals, they can be used in wound healing sprays, antiseptics, and topical anti-acne or antifungal treatments. In food, EO-MEs may serve as preservative sprays or coatings to extend shelf life and reduce microbial spoilage [3,4,5].

Future advancements should focus on enhancing encapsulation stability, developing sustained-release versions, and conducting clinical trials to confirm efficacy. The use of nanocarriers and liposomal systems may further improve bioavailability. Regulatory standardization and scalability of production remain critical for widespread adoption.

X. CONCLUSION

Essential oil-based microemulsions represent a sustainable, effective, and biocompatible approach to address microbial resistance and product stability. Lemon peel essential oil, rich in D-limonene, exhibits broad-spectrum activity and has shown promising results in stable microemulsion systems. With continued research and clinical validation, EO-MEs can play a vital role in future natural antimicrobial product development.

REFERENCES

1. Yadav V, Jadhav P, Kanase K, Bodhe A, Dombe S. Preparation and evaluation of microemulsion containing antihypertensive drug. Int J Appl Pharm. 2018;10(5):138. https://doi.org/10.22159/ijap.2018v10i5.27415
2. Malik P, Upadhyay P. Formulation and evaluation of tea tree/rosemary essential oil-based microemulsion for antimicrobial activity. Biosci Biotech Res Asia. 2023;20(1):229–239. https://doi.org/10.13005/bbra/3084
3. Thakur D, Kaur G, Puri A, Nanda R. Therapeutic potential of essential oil-based microemulsions: Reviewing state-of-the-art. Curr Drug Deliv. 2021;18(9):1218–1233. https://doi.org/10.2174/1567201818666210217161240
4. Kačániová M, Čmiková N, Vukovic NL, et al. Citrus limon essential oil: chemical composition and selected biological properties focusing on the antimicrobial (in vitro, in situ), antibiofilm, insecticidal activity and preservative effect against Salmonella enterica inoculated in carrot. Plants. 2024;13(4):524. https://doi.org/10.3390/plants13040524
5. Oliveira JJ, Passos EMD, Alves SM, et al. Microemulsion of essential oil of Citrus aurantium var. dulcis for control of Aleurocanthus woglumi and evaluation of selectivity against Aschersonia

aleyrodis and Ceraeochrysa cornuta. Crop Prot. 2024;106586. https://doi.org/10.1016/j.cropro.2024.106586

6. Zeleke ZZ. Extraction of essential oil from lemon and orange peel by Clevenger apparatus: Comparative GC_MS analysis of chemical composition. Ann Biotechnol. 2022. Available from: http://meddocsonline.org/
7. Sikdar D. Extraction of citrus oil from lemon (Citrus limon) peels by steam distillation and its characterizations. Int J Tech Res Appl. 2017;5(2):29–33. Available from: https://www.ijtra.com
8. Bhavsar J, Goswami JR, Patel T, Chauhan S. Revolutionizing sinusitis relief: microemulsion-based nasal spray – formulation, evaluation, and optimization. Int J Creat Res Thoughts. 2023;11(9). Available from: https://www.ijcrt.org
9. Ahire K, Gorle AP. An overview on methods of preparation and characterization of nano-emulsion. World J Pharm Pharm Sci. 2021;10(8):897–908. https://doi.org/10.20959/wjpps20218-19575
10. Azmy RM, Gohary EGEE, Mahmoud DM, et al. Assessment of larvicidal activity of nano emulsion from Citrus sinensis essential oil on Culex pipiens L. (Diptera: Culicidae). Egypt J Aquat Biol Fish. 2019;23(3):61–67. https://doi.org/10.21608/ejabf.2019.35100
11. Berkman M, Güleç K. Pseudo ternary phase diagrams: A practical approach for the area and centroid calculation of stable microemulsion regions. Istanbul Univ J Pharm. 2021;51(1):42–49. https://doi.org/10.26650/istanbuljpharm.2020.0090
12. Syed HK, Peh KK. Identification of phases of various oil, surfactant/co-surfactants and water system by ternary phase diagram. Indian J Pharm Sci. 2014;71(2):301–309. https://pubmed.ncbi.nlm.nih.gov/25272651