Solvent-Engineered Extraction of Ziziphus Mauritiana Essential Oils as Functional Antimicrobial Additives for Antimicrobial Coatings and Packaging Systems

By

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Source KOREAN JOURNAL OF CHEMICAL ENGINEERING

View Journal Impact

Volume: 43 Issue: 10 Page: 2721-2733

DOI: 10.1007/s11814-026-00730-2

Published AUG 2026

Early Access MAY 2026

Indexed 2026-05-14

Document Type Article

Jump to Enriched Cited References

Abstract Bio-derived antimicrobial additives are gaining significant attention for functional polymer materials, including antimicrobial coatings, packaging films, and surface-engineered composites. In such macromolecular systems, the extraction chemistry is a critical factor as it governs the molecular functionality, polarity balance, and subsequent compatibility with polymer matrices. This study demonstrates a solvent-controlled Soxhlet extraction strategy using mixed hexane-ethanol systems (4:6, 6:4, and 7:3 ratios) to tailor the chemical characteristics of Ziziphus mauritiana essential oils for materials-oriented applications. A hexane-ethanol ratio of 6:4 produced a markedly enhanced oil yield of 39.8%, attrib-uted to optimized solvent-matrix interactions enabling the simultaneous recovery of nonpolar lipid components and polar oxygenated compounds. FT-IR analysis revealed a balanced distribution of functional groups, indicating strong potential for intermolecular interactions relevant to polymer compatibility and dispersion stability. Gas chromatography-mass spec-trometry (GC-MS) analysis identified the presence of major plant-derived constituents such as phytol, squalene, fatty acid ethyl esters, and minor oxygenated terpenoids. Scanning electron microscopy (SEM) and optical microscopy provided mechanistic insights into mass transport, revealing solvent-dependent disruption of the plant matrix that facilitates the release of active species. The optimized bio-additive exhibited superior antibacterial activity against both Gram-positive and Gram-negative bacteria, alongside concentration-dependent antifungal performance. These findings highlight the role of solvent engineering as a