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

Korean Journal of Chemical Engineering • Article • 2026 •
DOI: 10.1007/s11814-026-00730-2

Zohdi, Nabiil Ahmadi Mohd [a]; Ali, Fathilah [a]; Azle, Wan Muhammad Arief Wan [a]; Rezal, Muhammad Nasrul Hakimi Muhammad [a]; Nizam, Muhammad Alif Ziqri Ahmad [a]; +9 authors

[a] Department of Chemical Engineering and Sustainability, International Islamic University Malaysia, Kuala Lumpur, Malaysia

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%, attributed 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 spectrometry (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 robust materials design strategy for tailoring bio-derived additives, supporting their integration into sustainable and high-performance antimicrobial polymer systems.

Author keywords

Antimicrobial polymer materials; Bio-derived functional additives; Solvent polarity; Soxhlet extraction

Indexed keywords

Engineering controlled terms

Additives; Bacteria; Coatings; Dispersions; Ethanol; Films; Hexane; Macromolecules; Mass spectrometry; Molecular biology; Molecular polarity; Packaging; Packaging machines; Packaging materials; Solvent extraction; Solvents

Engineering uncontrolled terms

Antimicrobial additives; Antimicrobial polymer material; Antimicrobial polymers; Bio-derived functional additive; Functional additives; Functionals; Mauritiana; Polymer materials; Solvent polarity; Soxhlet extraction

Engineering main heading

Gas chromatography; Scanning electron microscopy

Funding details

Details about financial support for research, including funding sources and grant numbers as provided in academic publications.

Funding sponsor	Funding number	Acronym
Suchon National University Global University Project Fund (2025)	2025-G056	

Funding text

This research was supported by Suchon National University Global University Project Fund (2025). (Grant number: 2025-G056).

Corresponding authors

Corresponding author	F. Ali
Affiliation	Department of Chemical Engineering and Sustainability, International Islamic University Malaysia, Kuala Lumpur, Malaysia
Email address	fathilah@iium.edu.my
Corresponding author	M.P. Kim
Affiliation	Department of Chemical Engineering, Sunchon National University, Jeollanam-Do, Suncheon-Si, South Korea
Email address	mspkim@scnu.ac.kr