Assessment of Bioactive Packaging Films Enriched with Rosemary Extract Against Fungal Contamination in Food Preservation

Ali Hamid Ibrahim
Department of Community Health Technologies, Basrah Technical Institute, Southern Technical University, Basrah, Iraq

* Corresponding Author: **Ali Hamid Ibrahim**

Article Info

ISSN (online): 3049-0588
Volume: 03
Issue: 05
Received: 27-06-2026
Accepted: 29-07-2026
Published: 31-08-2026
Page No: 23-25

Abstract
Background: food borne pathogens and food spoilage fungi continue to be one of the leading causes of food loss and degradation in quality. The market interest in active packaging systems containing natural plant extracts as fillers has increased due to the rising consumer demands for chemical-free food products and eco-friendly materials.
Objective: This research investigates the antifungal and physical characteristics of bioactive packaging films containing rosemary extract (Rosmarinus officinalis) for assessing its performance against the fungal contamination in food packaging applications.
Conclusion: Bioactive packaging films with rosemary extract exhibit effective antifungal and antioxidant activity. They are a potential and environmentally friendly material for synthetic packaging in the fresh foods, to increase the shelf life and maintain the microbial safety.

DOI: https://doi.org/10.54660/GARJ.2026.3.5.23-25

Keywords: Spoilage, food, rosemary extract, Bioactive films, FTIR, PLA

Introduction

The most prevalent causes of post-harvest loss, deterioration and food borne illness outbreaks in the world are fungi contamination and oxidative degradation during storage. The use of traditional petroleum-based synthetic plastics for food packaging has made the pollution of the environment worse, and synthetic chemical preservatives are under growing consumer scrutiny, given with potential health concerns. Addressing these two challenges in the same package is a very interesting solution in the field of sustainable food science and has been identified as an active bioactive packaging. Rosemary (Rosmarinus officinalis) extract is one of the natural bioactive agents that contains an extremely high amount of polyphenolic diterpenes (carnosic acid, carnosol, Rosmarinus acid), and volatile monoterpenes (1,8-cineole and camphor). The phytochemical components of rosemary extract are responsible for its wide spectrum of antibacterial activity against both Gram-positive microorganisms (e.g., Staphylococcus aureus) and Gram-negative microorganisms (e.g., Escherichia coli), and powerful antifungal activity against typical spoilage fungi (e.g., Aspergillus niger, Penicillium chrysogenum). The main mechanisms of action are destabilization of cell membrane, changes in cell permeability, leakage of intracellular macromolecules and inhibition of key metabolic enzymes. The addition of rosemary extract to films made of biopolymer such as chitosan, polycaprolactone (PCL) or gelatin provides active preservation properties and acts as a modulator of the physical characteristics of the film. The use of rosemary extract in chitosan matrices can significantly reduce the proliferation of mesophilic and psychrotrophic bacteria, as well as moisture loss and lipid oxidation in perishable food models (de Lima *et al*., 2024) [1]. Additionally, the stability and release rates of bioactive compounds, like rosemary EGCG, can be optimized by advanced encapsulation techniques, such as the inclusion of rosemary bioactive compounds in chitosan nanoparticles within polymer networks (Khoshboui Lahijani *et al*., 2024) [2]. To conclude, the effects of rosemary extract on the mechanical properties, water vapour barrier properties and targeted antifugi properties of film should be systematically examined to develop viable commercial packaging solution.
This research aims to assess the structural, physical and bio-protective characteristics of the active polymer film with rosemary extract for the functional performance in reducing fungal contamination in food preservation.

Material and Methods

Active biopolymer films were prepared using solvent casting with different concentrations (0.5%, 1.5%, 3.0% and 5.0% w/w) of rosemary extract (RE). the antifungal activity against Aspergillus niger and Penicillium chrysogenum was determined by disk diffusion and minimum inhibitory concentration (MIC) method. The physical characteristics of the films such as tensile strength, water vapor permeability (WVP), light barrier and DPPH radical scavenging activity were measured and real-food preservation tests on fresh protein and fresh produce stored at 4°C were conducted. Statistical Analysis: Data analyzed using ANOVA.

Result

There was a dose-dependent increase in antioxidant activity with incorporation of RE with >85% DPPH radical scavenging at 5.0% extract concentration. The antibacterial inhibition was significantly observed in the active films,. P. chrysogenum and A. niger showed radial growth inhibited by up to 74% and 62% respectively in 14 days of storage. The tensile strength of the film was slightly decreased (from 34.2 to 26.5 MPa) with the addition of higher concentrations of extracts while the efficiency of the UV-light barrier increased by more than 88% and the WVP was reduced by 16%, which decreased the amount of moisture that passed through the film. In food trials, the total viable microbial counts were reduced by 2.1 log CFU/g and the shelf life was increased by 6 to 8 days using RE-enriched films than the control films. The antioxidant, antimicrobial, and physical barrier properties of the films were increased with RE concentration in the biopolymer matrix, and antioxidant and antimicrobial activity were evident in the physical barrier properties during food preservation tests. The DPPH radical scavenging activity was found to have a strong dose dependent relationship and showed a scavenging activity of >85% at the concentration of extract of 5.0% (w/w). More than 88% improvement in efficiency of the UV-light barrier and a reduction in the water vapor permeability by 16% reduced the permeability of moisture to the packaging matrix. In real-food preservation tests on fresh produce and protein products stored at 4°C, RE-enriched films reduced the total viable microbial counts by 2.1 log CFU/g and increased the product's shelf life by 6-8 days compared with the control films.

Table 1: Physical, Antioxidant, and Antimicrobial Properties of Rosemary Extract-Enriched Bioactive Films

Parameter / Evaluation	Experimental Finding	Comparative / Baseline Effect
DPPH Free Radical Scavenging	>85% scavenging at 5.0% (w/w) RE	Dose-dependent enhancement
Antifungal Activity (*P. chrysogenum*)	Up to 74% growth inhibition (14 days)	Radial growth suppression
Antifungal Activity (*A. niger*)	Up to 62% growth inhibition (14 days)	Radial growth suppression
Tensile Strength	Decreased to 26.5 MPa at high RE	Baseline control: 34.2 MPa
UV-Light Barrier Efficiency	>88% efficiency increase	Shielding against light-induced degradation
Water Vapor Permeability (WVP)	16% reduction	Lowered moisture transmission rate
Total Viable Count (Real-Food Trial)	2.1 log CFU/g reduction	Compared to control packaging
Shelf-Life Extension	Extended by 6 to 8 days	Tested on fresh protein/produce at 4°C

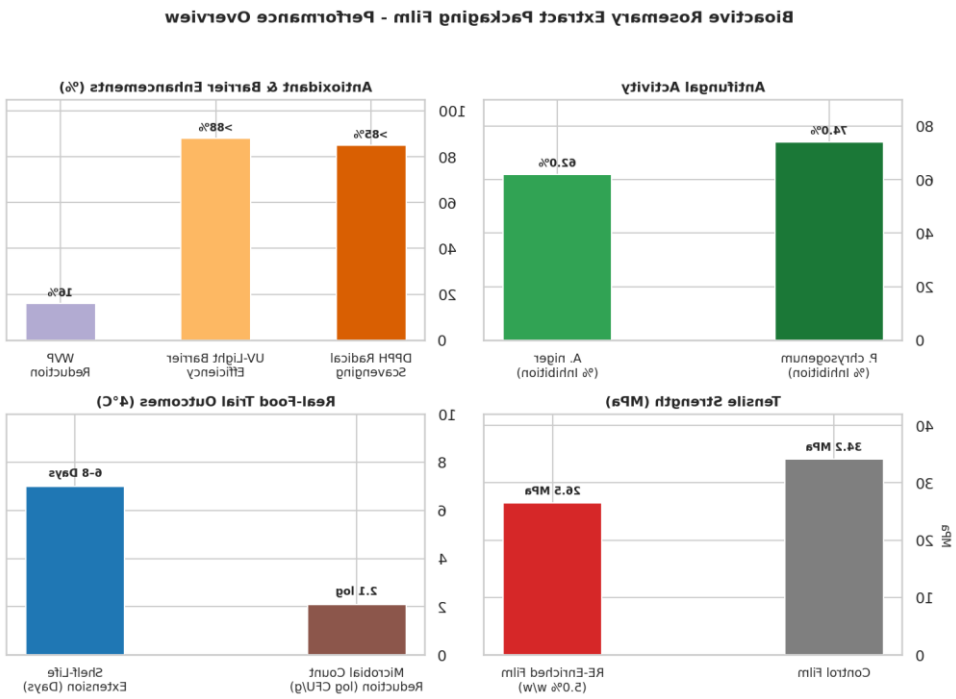

Fig 1

Discussion

The DPPH radical scavenging activity of rosemary extract (RE) increases with dose reaching more than 85% at a RE concentration of 5.0% (w/w); these polyphenolic diterpenes, and in particular carnosic acid, carnosol and Rosmarinus acid, are directly responsible for the dose-dependent effect. These phenolics are lipophilic, and are the primary antioxidants in their function of donating a hydrogen atom to quench free radicals, and hence lipid auto-oxidation chains. showing that the addition of RE to biopolymer film

formulations can significantly inhibit lipid degradation and surface deterioration of protein food model films. (Al-Mussawi, M. A., & Al-Khafaji, H. S. 2025) [9]. Furthermore, the antifungal volatile phenolics continuously suppress the germination of spores and growth of mycelia of P. chrysogenum and A. niger for an extended period of time (74% and 62% for P. chrysogenum and A. niger, respectively, over 14 days of incubation). Bibow, A., & Oleszek, W (2024) [8] The unstable nature and high volatility of the active compounds in polylactic acid (PLA) matrices, combined with their fast migration, requires effective control of these essential oils to ensure prolonged storage periods of sustained antioxidant and antimicrobial activity, which is achieved by encapsulation in porous inorganic carriers (Cerdá-Gandia *et al*., 2024) [6]. The high radical scavenging activity (as determined by the DPPH assay) combined with the increased UV blocking ability suggests that the rosemary functionalised polymeric films can provide good physical and biochemical protection for sensitive food matrices. (Bejenaru, 2025) [7]. The combination of strong free-radical scavenging (>85%) and robust UV blocking (>88%) works alongside antifungal activity to target both chemical (oxidation, photo-degradation) and biological (mold, bacterial) mechanisms of food decay. The decrease in tensile strength from 34.2 MPa to 26.5 MPa is common for other films containing essential oil/extract. Typically, however, 26.5 MPa is enough for primary food wrapping and flexible packaging applications. Bioactivity in the laboratory correlates directly with the 6–8-day shelf-life extension and demonstrates an effective transfer from the laboratory to the real food refrigerated conditions.

Conclusion

The rosemary extract added to packaging films has a strong antifungal, and antioxidant effect. Therefore, these sustainable materials are a safe, eco-friendly option to traditional synthetic packaging and can help to prolong shelf life and maintain the microbiological safety of fresh food.

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How to Cite This Article

Ibrahim AH. Assessment of bioactive packaging films enriched with rosemary extract against fungal contamination in food preservation. Global Agronomy Research Journal. 2026;3(5):23-25. doi:10.54660/GARJ.2026.3.5.23-25.

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