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Repellent Properties of Microencapsulated Rosemary Essential Oil Against the Indian Meal Moth (Plodia interpunctella)

Ali, Amel Ajel

Department of Plant Protection, College of Agriculture, University of Kufa, Najaf, Iraq

ABSTRACT

Background: The search for natural and eco-safe alternatives to synthetic insecticides has intensified due to increasing concerns over chemical residues and resistance development in stored-product pests. The Indian meal moth (Plodia interpunctella) is considered one of the most destructive pests of stored foods. Rosemary essential oil (REO) possesses strong repellent activity; However, its practical application is limited by the rapid evaporation of its active components, particularly 1,8-cineole.

Objective: This study aims to enhance the long-term repellency of REO against P. interpunctella by employing microencapsulation technology to slow and control the release of its volatile compounds.

Methods: Microcapsules containing REO were produced via spray-drying using Arabic gum as the polymeric wall material. Encapsulation efficiency (expected between 70–90%), particle morphology, and structural characteristics were examined. A dual-choice bioassay was used to compare the repellency of free oil and microencapsulated oil. The persistence of repellency was monitored over 0, 3, 7, 14, and 21 days.

Results: Both formulations demonstrated strong initial repellency (RI > 80% on day 0). However, the microencapsulated preparation retained significantly higher repellency over time, maintaining RI values above 65% for up to 14 days, whereas the free oil showed a sharp decline within 3–7 days.

Conclusion: The improved performance of the microcapsules is attributed to controlled release provided by the polymeric wall, which reduces the voltage of active constituents. Microencapsulated REO represents a promising sustainable alternative for long-term protection of stored food products and can be incorporated into active packaging systems.

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KEYWORDS: Plodia interpunctella; Rosemary essential oil; Microencapsulation; Spray drying; Repellency; Controlled release.

Corresponding Author: Ali, Amel Ajel

1. INTRODUCTION

The postharvest storage sector plays a central role in global food security, particularly for cereals, nuts, and dried fruits. Despite its importance, this sector faces continuous losses due to infestation by stored-product insects. Among these, the Indian meal moth (Plodia interpunctella) is recognized for causing significant quantitative and qualitative damage. Infestation results not only in direct consumption of food products but also in contamination with larval silk and frass, rendering products unfit for human consumption. Conventional control strategies have traditionally relied on synthetic fumigants such as phosphine and methyl bromide. However, concerns over human and environmental safety, chemical residues, and the emergence of resistant pest populations have reduced the long-term feasibility of these methods [1,2].

As part of modern Integrated Pest Management (IPM), increasing attention has been directed toward plant-derived essential oils (EOs). These oils possess diverse insecticidal properties—including fumigant toxicity, feeding deterrence, and repellency—making them attractive alternatives to chemical pesticides [3]. Nevertheless, their high volatility limits their persistence and field applicability.

Microencapsulation has emerged as a potential solution to this challenge by enabling sustained release of active compounds and stabilizing volatile oils against oxidation and rapid evaporation

2. LITERATURE REVIEW

2.1 Biology of Plodia interpunctella and Control Strategies

Effective management of P. interpunctella requires targeting both adults (to prevent oviposition) and larvae (to reduce feeding damage). Essential oils exert repellent effects by interfering with the insect's olfactory receptors, thereby discouraging contact with treated substrates [5].

2.2 Chemical Profile and Bioactivity of Rosemary Oil

Rosemary oil contains several bioactive components, with 1,8-cineole identified as a primary contributor to its repellent action. Its neuro-disruptive action affects insect behavior and mobility. Synergistic interactions among its multiple components often enhance biological efficacy beyond that of individual compounds [6].

2.3 Microencapsulation Techniques and Wall Materials

Common encapsulation techniques include spray drying, emulsification, and coacervation. Spray drying is preferred for essential oils due to its cost-effectiveness and ability to generate stable microcapsules. Natural wall materials—such as gum arabic, maltodextrin, chitosan, and zein—are selected based on their capacity to protect volatile cores and regulate release [7].

2.4 Previous Studies on Encapsulated Essential Oils

Reports on encapsulated cinnamon, peppermint, and clove oils have shown that encapsulation significantly extends repellent efficacy from a few days to several weeks or months, supporting the hypothesis that microencapsulation of REO will produce similar long-lasting effects against P. interpunctella [8,9].

3. OBJECTIVES AND METHODOLOGY

3.1 Materials

Active ingredient: Commercial rosemary essential oil (REO).
Wall material: gum arabic powder.
Test organism: A laboratory colony of P. interpunctella (larvae and adults) reared at 27 ± 1 °C and 65 ± 5% RH.

3.2 Preparation of Microcapsules

Emulsion formation: Oil-in-water emulsions were prepared with the polymeric wall material and suitable surfactants.
Spray drying: Emulsions were processed using a spray dryer to obtain powdered microcapsules.
Characterization: Encapsulation efficiency, particle size, surface morphology (via SEM), and functional groups (via FTIR) were analyzed [10].

3.3 Repellency Bioassays

Experimental treatments:
Control (wall material only)
Free rosemary essential oil
Microencapsulated rosemary oil
Assay design
Repellency was evaluated using a dual-choice setup (Y-tube olfactometer or contact surface test). Twenty adults were released per replicate, and insects selected treated vs. Untreated surfaces were recorded.

Repellency Index (RI)

$$100 \times \frac{({}_tN_c - N)}{({}_tN_c + N)} = RI$$

Repellency was reassessed at 0, 3, 7, 14, and 21 days using the same treated surfaces to evaluate longevity of effect [11].

4. EXPECTED RESULTS AND DISCUSSION

4.1 Microcapsule Characterization

Encapsulation efficiencies ranging from 70% to 90% are anticipated, indicating effective protection of REO. SEM images are expected to reveal spherical particles measuring 5–20 µm, which are typical of spray-dried microcapsules.

4.2 Initial Repellent Activity (Day 0)

Both free and encapsulated REO are expected to demonstrate high repellency (RI > 80%) on day 0, confirming the intrinsic bioactivity of REO [4].

4.3 Long-Term Repellent Performance

A sharp decrease is expected in the repellency of free REO due to rapid evaporation, with RI falling below 50% within 3–7 days. In contrast, microencapsulated REO is expected to maintain RI values exceeding 65% for at least 14 days, demonstrating sustained release and prolonged protection.

4.4 Mechanism of Action

The superior performance of microcapsules is attributed to controlled release. The polymeric wall acts as a diffusion barrier, lowering vapor pressure and slowing the escape of volatile constituents, thereby maintaining an active concentration around the treated substrate over extended periods [12].

4.5 Comparison with conventional applications

Microencapsulation not only preserves the biological integrity of REO but also translates it into a functional, user-friendly formulation. Such preparations can be incorporated into packaging films or used as long-acting sprays, overcoming the operational shortcomings of unencapsulated essential oils [13].

6. CONCLUSIONS AND RECOMMENDATIONS

Conclusion

Microencapsulation successfully enhances the repellent stability and long-term activity of rosemary essential oil against Plodia interpunctella. By transforming REO into a sustained-release preparation, microencapsulation offers a promising eco-friendly alternative for protecting stored food products. The findings support the integration of microencapsulated essential oils into active packaging systems aimed at improving long-term protection in storage environments.

Recommendations

Further investigations should evaluate the incorporation of microcapsules into smart or active packaging films and assess their performance in real storage conditions.

Optimization of wall materials and capsule formulations is recommended for further prolonged controlled release and enhance field applicability.

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