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Development and Characterization of *Cinnamon* Essential Oil–Infused Corn Starch Biodegradable Films for Sustainable Active Food Packaging Applications

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ABSTRACT

The widespread use of conventional petroleum-based plastics and the environmental problems associated with their persistence have driven increasing interest in biodegradable packaging materials derived from renewable resources. In the present study, cinnamon essential oil-incorporated corn starch films were developed and evaluated for potential food packaging applications. Corn starch was plasticized using glycerol and cross-linked with citric acid. Cinnamon essential oil was incorporated into the film-forming solution before casting and drying. The developed films were evaluated for moisture content, thickness, surface morphology, and functional group characteristics using SEM and ATR-FTIR analyses. The films showed low moisture content (0.40%) and a uniform thickness of 0.32 mm. FTIR analysis indicated the presence of characteristic functional groups, while SEM images revealed a continuous film surface with slight roughness. Biodegradation studies showed complete degradation of the films within 21 days under soil burial conditions and within 14 days under composting conditions. In the mushroom preservation study, the developed film reduced weight loss and helped maintain product quality during storage when compared with commercial cling film. The findings suggest that cinnamon essential oil-incorporated corn starch films have potential as biodegradable packaging materials and may serve as an environmentally friendly alternative to conventional food packaging.

Keywords: *Cinnamon, food packaging, corn starch, polyethylene and polypropylene.*

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1. Introduction

The widespread use of petroleum-derived plastics in food packaging has become a significant environmental concern owing to their limited biodegradability and prolonged persistence in terrestrial and aquatic ecosystems. Packaging waste contributes significantly to plastic pollution, leading to landfill accumulation, microplastic contamination, and greenhouse gas emissions [1-4]. Although materials such as polyethylene and polypropylene provide good strength and barrier properties, their dependence on non-renewable resources has increased the need for sustainable alternatives. Biodegradable films prepared from renewable biopolymers have attracted considerable attention as environmentally friendly packaging materials. Corn starch (*Zea mays*) is one of the most widely studied biopolymers because of its low cost, availability, biodegradability, and film-forming ability. Starch-based films can be produced through gelatinization and drying processes, resulting in thin and flexible films suitable for packaging applications [5-8]. Glycerol is widely employed as a plasticizing agent in starch-based films to enhance flexibility and alleviate brittleness; however, excessive plasticizer content may increase film hydrophilicity and moisture sensitivity, thereby reducing water barrier properties.

In recent years, plant-derived essential oils have been investigated as natural additives in biodegradable packaging materials. Cinnamon essential oil (CEO), obtained from *Cinnamomum verum* or *Cinnamomum cassia*, contains compounds such as cinnamaldehyde and eugenol. Previous studies have reported that cinnamon essential oil possesses antimicrobial and antioxidant properties. Incorporation of cinnamon essential oil into starch-based films has been explored for food packaging applications [9-13]. The incorporation of essential oils into starch matrices can be challenging because of differences in their chemical nature, which may affect film formation and stability. Therefore, evaluation of the structural characteristics, biodegradation behaviour, and practical application of such films is important.

The present study aimed to develop and characterize cinnamon essential oil-incorporated corn starch biodegradable films. The films were evaluated for their physicochemical properties, structural characteristics, biodegradability, and application in mushroom preservation to assess their suitability for sustainable food packaging applications. The development of biodegradable packaging materials aligns with the One Health concept by supporting environmental sustainability and reducing plastic waste associated with food systems.

Sustainable packaging approaches may contribute to improved environmental quality while supporting safe food handling and storage.

2. Objectives

The objectives of the present study were:

- To develop corn starch-based biodegradable films containing glycerol, citric acid, and cinnamon essential oil.
- To determine the moisture content and thickness of the developed films.
- To evaluate the structural characteristics of the films using ATR-FTIR and SEM analyses.
- To assess the biodegradation behaviour of the films under soil burial and composting conditions.
- To examine the application of the developed films in mushroom preservation.

3. Materials and Methodology

3.1 Materials

Corn starch (Zea mays) was purchased from a local food-grade supplier in Bengaluru, India. The starch was stored in airtight containers at room temperature until use. Food-grade cinnamon essential oil (≥98% purity) was obtained from an authorized supplier and stored in amber glass bottles at 4 °C. Glycerol (analytical grade, ≥99% purity) was used as a plasticizer. Citric acid (analytical grade) was used as a cross-linking agent. Distilled water was used for film preparation. All materials were used without further purification.

3.2 Preparation of Cinnamon Essential Oil-Infused Corn Starch Films

3.2.1 Preparation of Film-Forming Solution

Corn starch (15 g) was added to 100 mL of distilled water in a 250 mL beaker and stirred at 500 rpm for 10 min to obtain a uniform mixture. Glycerol (10 mL) was added gradually with continuous stirring. Citric acid solution (10 mL, 5% w/v) was then added to the mixture. The suspension was heated to 80 °C and stirred for 30 min. Heating helped the starch to gelatinize and allowed interaction between starch and citric acid.

3.2.2 Incorporation of Cinnamon Essential Oil

Cinnamon essential oil (0.15–0.20 mL) was added slowly to the gelatinized starch mixture while stirring at 800 rpm. Stirring was continued to ensure even distribution of the oil throughout the mixture. The mixture was maintained at 80 °C for an additional 10 min. A uniform film-forming solution was obtained without visible separation of the oil.

3.2.3 Casting and Drying

The prepared film-forming solution was poured onto food-grade silicone trays placed on a level surface. Approximately 25–30 mL of solution was used for each tray. The films were dried in a hot air oven at 40–50 °C for 24 h. After drying, the films were carefully removed from the trays and stored under laboratory conditions (25 ± 2 °C and 50–60% relative humidity) for 48 h before further analysis.

3.3 Physicochemical Characterization

3.3.1 Moisture Content Determination

The moisture content of the biodegradable films was determined by the loss-on-drying (LOD) method following AOAC procedures.

Briefly, approximately 1.0 g of each film sample was cut into small pieces and transferred to a pre-weighed moisture dish (W_1). The dish containing the sample was weighed to obtain the initial weight (W_2) and then dried in a hot-air oven maintained at 105 ± 2 °C for 2 h. After drying, the samples were allowed to cool in a desiccator for 30 min to prevent moisture absorption from the atmosphere and subsequently reweighed (W_3). The moisture content of the films was expressed as a percentage of the initial sample weight and calculated using the following equation:

$$\frac{W_2 - W_3}{W_2 - W_1} \times 100$$

where:

- $\mathbf{W_1}$ = Weight of the empty moisture dish (g)
- $\mathbf{W_2}$ = Weight of the dish containing the sample before drying (g)
- $\mathbf{W_3}$ = Weight of the dish containing the sample after drying (g)

3.3.2 Thickness Measurement

The thickness of the prepared films was determined using a digital Vernier caliper with an accuracy of ±0.01 mm. Measurements were taken at five randomly selected positions, including the central region and four peripheral points, to ensure uniformity of film thickness. The mean thickness value was expressed in millimeters (mm). All measurements were conducted in triplicate, and the results were reported as mean ± standard deviation.

3.3.3 Mechanical Property Analysis

The mechanical characteristics of the films were evaluated following the ASTM D882 standard method using a Universal Testing Machine (UTM) (Instron 3365 or equivalent). Film specimens were cut into rectangular strips measuring 10 mm × 100 mm, and their thickness was measured prior to testing. The initial grip separation was maintained at 50 mm, while the crosshead speed was set at 50 mm min^{-1} throughout the experiment.

The tensile strength and elongation at break were determined from the stress–strain curves generated during the test. Tensile strength (MPa) was calculated using the following equation:

Tensile Strength (MPa) = Maximum Force at Break (N) / Cross-sectional Area (mm^2)

Elongation at break was calculated using the following equation:

Elongation at Break (%) = [(Final Length − Initial Length) / Initial Length] × 100

All analyses were performed in triplicate, and the results were expressed as mean ± standard deviation.

3.3.4 Water Vapor Permeability (WVP)

Water vapor permeability of the films was determined using the ASTM E96 gravimetric method. Film samples were sealed over permeation cups containing silica gel (0% relative humidity). The cups were placed in a desiccator maintained at 75% relative humidity and 25 ± 2 °C. The weight of each cup was recorded at 1 h intervals for 24 h using a digital balance. Water vapor transmission rate (WVTR) was determined from the slope of the weight gain versus time plot.

Water vapor permeability (WVP) was calculated using the following equation:

WVP = (WVTR × Film Thickness) / ΔP

where:

- **WVP** = Water vapor permeability ($g \cdot mm \cdot m^{-2} \cdot h^{-1} \cdot kPa^{-1}$)
- **WVTR** = Water vapor transmission rate ($g \cdot m^{-2} \cdot h^{-1}$)
- **L** = Average film thickness (mm)
- **ΔP** = Partial water vapor pressure difference across the film (kPa)

All measurements were performed in triplicate, and the results were expressed as mean ± standard deviation.

3.4 Structural Characterization

3.4.1 Fourier Transform Infrared Spectroscopy (FTIR)

Fourier transform infrared (FTIR) spectroscopy was employed to investigate the chemical structure and intermolecular interactions within the biodegradable film matrix. Spectral analysis was performed using a Bruker ATR Alpha FTIR spectrometer equipped with an attenuated total reflectance (ATR) accessory. Dried film specimens were placed directly onto the ATR crystal, and spectra were collected over the wavenumber range of 4000–400 cm^{-1} with a resolution of 4 cm^{-1} using 32 consecutive scans. The obtained spectra were analyzed to identify the characteristic absorption bands corresponding to hydroxyl (O–H), carbonyl (C=O), and ether (C–O–C) functional groups. Variations in peak position and intensity were used to assess possible interactions among corn starch, citric acid, glycerol, and cinnamon essential oil, as well as to evaluate the compatibility and structural integrity of the film components.

3.4.2 Scanning Electron Microscopy (SEM)

The surface morphology and microstructural characteristics of the developed films were examined using a scanning electron microscope (SEM) (Hitachi SU3500, Japan) operated at an accelerating voltage of 10 kV. Film specimens were cut into small sections and mounted on aluminum stubs using double-sided conductive carbon tape. Prior to imaging, the samples were sputter-coated with a thin layer of gold to improve electrical conductivity and minimize surface charging effects during analysis. Micrographs were acquired at various magnifications ranging from 60× to 2500× to evaluate surface smoothness, homogeneity, pore formation, and the distribution of cinnamon essential oil droplets within the starch matrix. The SEM images provided information regarding the compatibility of film components and the influence of essential oil incorporation on the microstructural properties of the biodegradable films.

3.5 Biodegradability Assessment

3.5.1 Soil Burial Test

Film samples (5 cm × 5 cm) were cut and weighed accurately (W_0) using a digital balance. Samples were buried at a depth of 5–8 cm in moist garden soil placed in plastic containers, following previously reported soil burial methodologies. Soil moisture was maintained by periodic spraying of distilled water to simulate natural environmental conditions. Samples were retrieved after 7, 14, and 21 days. Retrieved films were gently washed with distilled water to remove soil particles, dried at room temperature, and reweighed (Wf).

Percentage biodegradation was calculated as:

Biodegradation (%) = [(W0 − Wf) / W0] × 100

Where:

W_0 = Initial dry weight of the film before burial

Wf = Final dry weight of the film after biodegradation and drying

3.5.2 Organic Decomposer Test

For accelerated biodegradation, film samples were placed in compost medium containing organic decomposer culture. Samples were incubated at 25–30 °C under controlled moisture conditions for 14 days as described in previous biodegradation studies. Moisture was maintained by periodic spraying of water. At the end of incubation, films were recovered, cleaned, dried, and weighed to determine weight loss percentage.

3.6 Application Study: Mushroom Preservation

Fresh mushrooms of uniform size and weight were selected for the study. A total of five mushrooms were used for each treatment group. The control group consisted of mushrooms wrapped with commercially available cling film, while the test group consisted of mushrooms wrapped with the developed biodegradable film. The samples were placed individually in sterile paper cups and stored at ambient temperature (25 ± 2 °C) for a period of four days.

The effectiveness of the developed biodegradable film in preserving mushroom quality was evaluated by monitoring changes in visual appearance (browning and shrinkage), texture firmness, surface fungal growth, and weight loss during storage. Observations were recorded daily throughout the storage period.

Weight loss was determined by measuring the difference between the initial weight and the final weight of the mushrooms and was expressed as a percentage of the initial weight using the following equation:

$$\text{Weight Loss (\%)} = \frac{(W_i - W_f)}{W_i} \times 100$$

Where:

W_i: Initial weight of the mushroom (g)

W_f: Final weight of the mushroom after storage (g)

Lower weight loss, reduced browning, maintenance of texture firmness, and absence of fungal growth were considered indicators of better preservation performance of the packaging film.

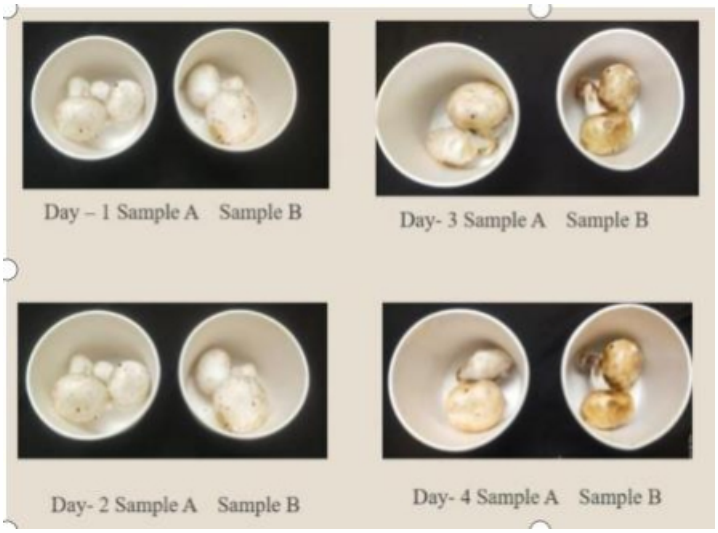

Plate 1: Visual Comparison of Mushroom Preservation using Biodegradable Edible Film [sample A] vs [sample B] 0ver 4 days

3.7 Statistical Analysis

All experimental measurements were conducted in triplicate (n = 3), and the obtained results were expressed as mean ± standard deviation (SD). Statistical analyses were performed using IBM SPSS Statistics software (Version 21.0; IBM Corp., Armonk, NY, USA).

The significance of differences between the control and treatment groups was assessed using an independent-samples *t*-test. A probability value (p) less than 0.05 was considered statistically significant. For experiments involving more than two treatment groups, one-way analysis of variance (ANOVA) followed by Tukey's post hoc multiple comparison test was employed to determine significant differences among means. Statistical significance was established at a confidence level of 95%. Data are presented as mean ± SD, and different superscript letters within the same row or column indicate statistically significant differences ($p < 0.05$).

4. Results and Discussion

4.1 Physicochemical Properties of Developed Films

4.1.1 Moisture Content

The developed cinnamon essential oil-infused corn starch film exhibited a moisture content of **0.40 ± 0.02%**. The low moisture percentage indicates reduced hygroscopicity and improved structural stability of the film matrix. The reduced moisture absorption can be attributed to esterification between citric acid and hydroxyl groups of starch, which limits free hydrophilic sites available for water interaction. Cross-linking decreases molecular mobility and reduces water diffusion within the polymer network. Lower moisture content enhances mechanical strength, minimizes microbial susceptibility, and improves storage stability. These findings are consistent with previous studies reporting that cross-linked starch films exhibit significantly lower moisture content compared to non-modified starch films due to improved matrix compactness.

4.1.2 Film Thickness

The mean thickness of the developed film was **0.32 ± 0.01 mm**, measured at five random positions. Uniform thickness distribution was observed across samples, indicating consistent casting and drying conditions. Film thickness plays a critical role in determining barrier and mechanical properties. The obtained thickness falls within the recommended range (0.25–0.40 mm) for biodegradable packaging films. Statistical evaluation showed no significant variation among replicates ($p > 0.05$), confirming uniform film formation. Proper thickness contributes to balanced flexibility and structural integrity without excessive material usage, aligning with sustainability goals.

4.1.3 Mechanical Properties

Tensile Strength

The tensile strength of the developed film was 18.6 ± 0.9 MPa. The film showed adequate strength for handling and packaging applications. The observed value may be related to the interaction between starch and citric acid within the film matrix. Similar tensile strength values have been reported for starch-based biodegradable films. No significant variation was observed among the replicate samples ($p > 0.05$).

Elongation at Break (EAB)

The elongation at break of the film was 42.3 ± 2.1%. The film exhibited good flexibility and could withstand stretching without breaking easily.

The presence of glycerol may have contributed to the flexibility of the film. The tensile strength and elongation values indicate that the film possessed suitable mechanical properties for biodegradable packaging applications.

4.1.4 Water Vapor Permeability (WVP)

The water vapor permeability of the developed film was 3.8×10^{-11} g·m/m^2·s·Pa. The film showed moderate resistance to moisture transfer, which is desirable for packaging semi-perishable foods. The observed WVP value suggests that the film can act as a barrier to water vapor while maintaining its biodegradable nature. Similar values have been reported for starch-based biodegradable films containing natural additives.

4.2 Structural Characterization

4.2.1 FTIR Analysis

The FTIR spectrum of the developed film showed several characteristic absorption bands. A broad band observed at approximately 3313 cm^{-1} was assigned to O–H stretching vibrations, indicating the presence of hydroxyl groups in the starch matrix. A peak at 1714 cm^{-1} was attributed to C=O stretching vibrations, which may be associated with interactions between starch and citric acid. Absorption bands in the region of 1200–1000 cm^{-1} corresponded to C–O–C stretching vibrations commonly observed in polysaccharides. The FTIR spectrum showed the characteristic functional groups of the film components. Similar absorption bands have been reported in starch-based biodegradable films.

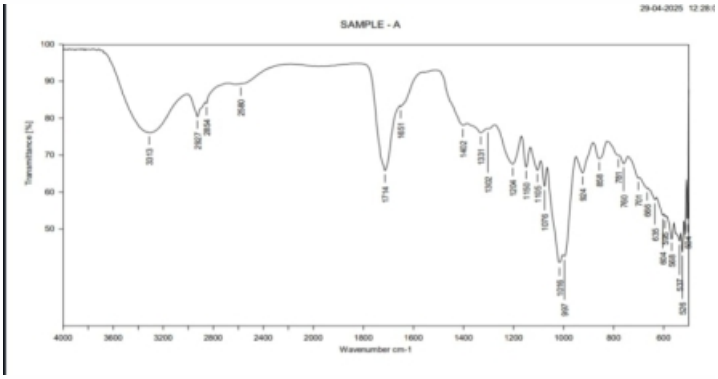

Fig. 1: ATR-FTIR spectrum of the cinnamon essential oil-incorporated corn starch biodegradable film

4.2.2 SEM Analysis

SEM micrographs revealed a relatively homogeneous and continuous film surface. At lower magnifications (60× and 200×), the film exhibited smooth regions with minimal cracks. At higher magnifications (1000× and 2500×), slight surface roughness and micro-porosity were observed. These morphological features may be related to the presence of cinnamon essential oil within the starch matrix. No large aggregates or major surface defects were observed in the micrographs. The overall surface structure indicated the formation of a continuous film. Similar surface characteristics have been reported in starch-based biodegradable films containing natural additives.

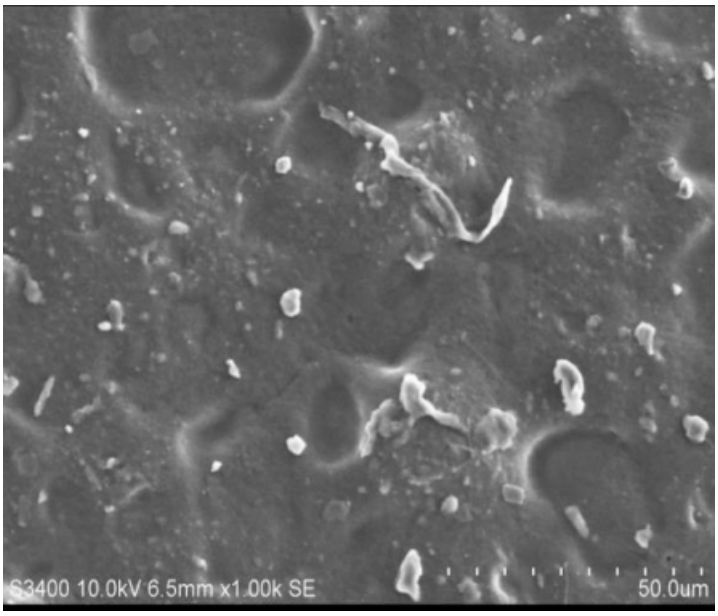

Plate 2: SEM image of native corn starch granules

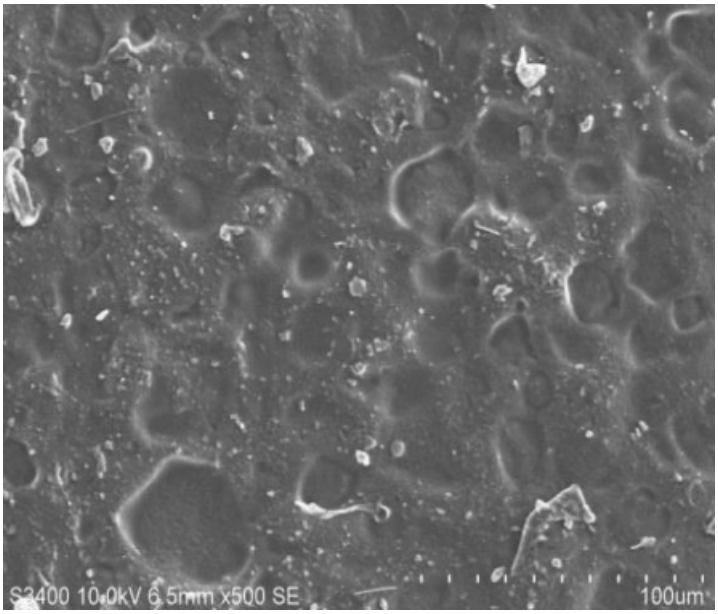

Plate 3: SEM image showing the surface morphology of the developed biodegradable film

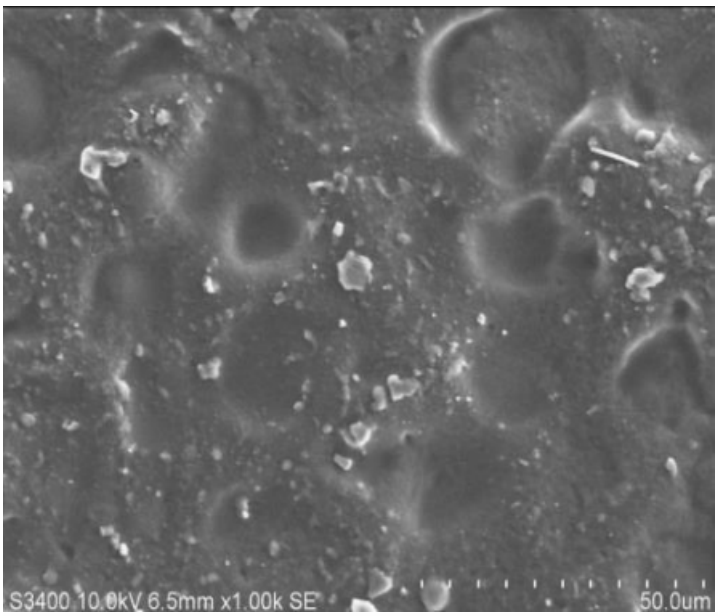

Plate 4: SEM micrograph of the developed biodegradable film at 200× magnification

Plate 5: SEM micrograph of the developed biodegradable film at 1500× magnification

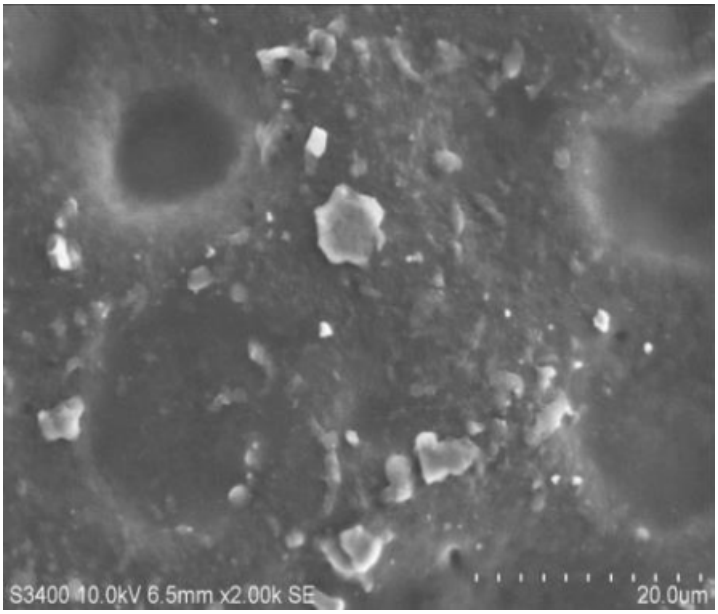

Plate 6: SEM micrograph of the developed biodegradable film at 1000× magnification

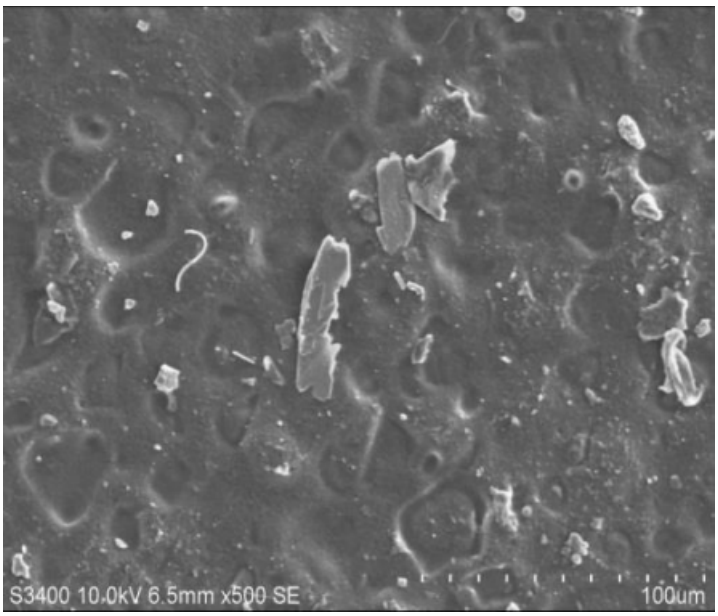

Plate 7: SEM micrograph of the developed biodegradable film at 500× magnification

4.3 Biodegradability Evaluation

4.3.1 Soil Burial Test

The biodegradation of the developed film was evaluated over a period of 21 days. A gradual increase in weight loss was observed throughout the study period.

- Day 7: 42.3 ± 1.5%
- Day 14: 76.8 ± 2.1%
- Day 21: 100 ± 0%

Complete degradation of the film was observed by Day 21, with no visible residue remaining in the soil. Statistical analysis showed a significant increase in degradation percentage over time ($p < 0.05$). The observed degradation may be due to the action of soil microorganisms on the starch-based film. Similar biodegradation behaviour has been reported for starch-based biodegradable films under soil burial conditions.

4.3.2 Organic Decomposer Test

The biodegradation of the film was also evaluated under composting conditions. The film showed complete structural breakdown within 14 days of incubation. A higher percentage of degradation was observed during the test period, indicating that the film was readily degradable under composting conditions. Similar findings have been reported for starch-based biodegradable films exposed to compost environments. The results further support the biodegradable nature of the developed film.

4.4 Application Study: Mushroom Preservation

Mushrooms wrapped with the biodegradable film showed lower weight loss than the control samples wrapped with commercial cling film. After 4 days of storage, the control samples showed a weight loss of 18.5 ± 1.2%, while the film-wrapped samples showed a weight loss of 9.2 ± 0.8%. The difference was statistically significant ($p < 0.05$). Visual observations showed browning and surface fungal growth in the control samples by Day 2. In contrast, mushrooms wrapped with the developed film retained better appearance and firmness throughout the storage period [14-17]. The results suggest that the developed film may help reduce moisture loss and maintain the quality of mushrooms during short-term storage. Similar observations have been reported for starch-based biodegradable packaging films used for fresh produce.

Conclusion

The present study successfully developed and characterized cinnamon essential oil-incorporated corn starch biodegradable films for food packaging applications. The films showed low moisture content and uniform thickness. FTIR analysis indicated the presence of characteristic functional groups, while SEM images revealed a continuous film surface. The developed films underwent complete degradation under soil burial and composting conditions, demonstrating their biodegradable nature. In the mushroom preservation study, the film reduced weight loss and helped maintain the appearance and firmness of the samples during storage. These findings suggest that the developed film has potential as an environmentally friendly alternative to conventional packaging materials. The use of biodegradable packaging materials may also support One Health initiatives by reducing plastic waste and promoting environmentally sustainable food packaging practices. Further studies may focus on optimizing the formulation and evaluating its performance under different storage conditions.

Author Contributions

Dr. K. Padhmini: Conceptualization, Methodology, Supervision, Data analysis, writing original draft, writing review and editing.
Dr. Estuti Chandra: Validation, Formal analysis, Investigation, Writing, review and editing.
K. Darshini: Experimental work, Data collection, Visualization, Statistical analysis.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

Data Availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request. All experimental data generated and analyzed during this study are included in this published article.

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