RESEARCH ARTICLE

International Journal of Civil, Environmental and Agricultural Engineering

DOI: 10.34256/ijceae2614

Muskmelon Peel Extract-Reinforced Chitosan/Gelatin/Starch Composite Films for Biodegradable Food-Packaging Applications

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Received: 26-01-2026, Revised: 28-04-2026, Accepted: 07-05-2026, Published: 19-05-2026

Abstract: Petroleum-derived food-packaging materials provide useful mechanical and barrier performance but create persistent end-of-life waste. This study reports the preparation of biodegradable composite films based on chitosan, gelatin, starch, glycerol and muskmelon peel extract (MPE). Chitosan was obtained from mud-crab shell waste through deproteinisation, demineralisation, decolourisation and deacetylation. Muskmelon peel was dried, milled and extracted using an aqueous ethanol system. Composite film-forming solutions containing 0%, 10% and 30% MPE were prepared by solution casting. Fourier-transform infrared spectroscopy was used to examine the functional groups of the extracted chitosan, and macroscopic film formation was assessed after drying and conditioning. The extracted material exhibited the characteristic broad hydroxyl/amino absorption region and amide-associated bands expected for chitosan. Continuous self-supporting films were obtained at the tested MPE concentrations, with visible formulation-dependent differences in colour and appearance. These observations demonstrate the feasibility of incorporating muskmelon peel-derived components into a chitosan/gelatin/starch matrix. However, tensile strength, elongation, water-vapour permeability, antioxidant capacity, antimicrobial activity, migration safety, biodegradation and food shelf-life performance were not quantitatively evaluated in the present work. The films should therefore be considered preliminary laboratory prototypes rather than validated food-contact packaging. Future studies should establish composition-property relationships and verify safety and preservation performance using standardised methods.

Keywords: Active Packaging, Biodegradable Film, Chitosan, Fruit-Peel Valorisation, Muskmelon Peel Extract, Solution Casting.

1. Introduction

Food packaging protects products against physical damage, moisture transfer, oxygen, light, odours and microbial contamination during distribution and storage. Petroleum-derived polymers remain dominant because they are inexpensive, lightweight and readily processed; however, their persistence after disposal has intensified interest in renewable and biodegradable packaging systems [1, 2]. Biopolymers including polysaccharides, proteins and their blends can form edible or biodegradable films, although their moisture sensitivity and comparatively weak mechanical performance often restrict direct substitution for conventional plastics [3, 4].

Chitosan is produced by partial deacetylation of chitin obtained principally from crustacean-processing residues. Its biodegradability, film-forming ability, cationic character and reported antimicrobial functionality make it an extensively investigated packaging polymer [5-8]. Nevertheless, neat chitosan films are generally hydrophilic and may require blending, plasticisation or reinforcement to improve flexibility, water resistance and mechanical integrity [7, 8]. Gelatin and starch can contribute complementary film-forming properties, whereas glycerol is commonly used to reduce brittleness by increasing polymer-chain mobility [9]. Active packaging extends the role of a package beyond passive containment by incorporating components that can interact with the packaged food or its headspace. Plant-derived phenolics, essential oils and agro-industrial extracts have consequently been introduced into chitosan-based matrices to provide antioxidant or antimicrobial functionality [10-13]. Fruit-peel residues are particularly attractive because they are generated in large quantities and may contain phenolic compounds, pigments and other bioactive constituents. Their utilisation can therefore connect packaging development with waste valorisation and circular-bioeconomy objectives [12-14]. Muskmelon (Cucumis melo L.) peel is an underused processing residue. Although fruit-peel extracts have been incorporated into several biopolymer systems, evidence specific to muskmelon-peel-containing chitosan/gelatin/starch films remains limited. The present work therefore aimed to: (i) extract chitosan from mud-crab shell waste; (ii) prepare an ethanolic-aqueous muskmelon peel extract; (iii) fabricate composite films containing 0%, 10% and 30% MPE by solution casting; and (iv) provide preliminary chemical and macroscopic characterisation. Because no validated mechanical, barrier, antimicrobial, antioxidant, migration or shelf-life dataset was available, the study does not claim commercial packaging performance.

2. Materials and Methods

2.1 Raw-Material Collection And Preparation

Mud-crab shells were obtained from a local seafood market. Residual tissue and adhering contaminants were removed by repeated washing. The shells were dried to constant mass and ground to obtain a uniform powder. Muskmelon peels were collected separately, washed with distilled water, cut into small pieces, dried at 50 °C for 24 h and milled before extraction.

2.2 Extraction of Chitosan from Crab-Shell Waste

Chitosan extraction was adapted from the conventional chemical sequence reported for crustacean shells [5, 6, 15]. Process conditions are reported as used in the laboratory protocol; future work should document reagent grade, replicate number, solid yield and degree of deacetylation.

Deproteinisation: Ground shell powder was treated with 2.0% (w/v) KOH at a solid-to-liquid ratio of 1:20 (w/v), stirred for 2 h at 90 °C and allowed to stand for 24 h. The solid fraction was filtered and washed with water until approximately neutral pH.

Demineralisation: The deproteinised material was treated with dilute hydrochloric acid at a solid-to-liquid ratio of 1:20 (w/v) to remove calcium carbonate and other mineral constituents. The solid was filtered, washed to approximately neutral pH and dried at 60 °C for 24 h. The acid concentration and treatment time should be reported explicitly in subsequent reproducibility studies.

Decolourisation: The recovered chitin was contacted with acetone for 10 min, air-dried for 2 h, washed thoroughly and oven-dried at 60 °C for 24 h.

Deacetylation: Chitin was treated with 40% (w/w) aqueous NaOH at a chitin-to-solution ratio of 1:15 (w/v) for 2 h at 105 °C. The product was filtered, washed with deionised water to approximately pH 7 and dried at 60 °C for 24 h to obtain chitosan [5].

2.3 Preparation of Muskmelon Peel Extract

Dried muskmelon peel powder was mixed with an ethanol-water extraction medium at a solid-to-solvent ratio of 1:10 (w/v). The suspension was agitated at 150 rpm and 35 °C for 24 h, filtered through Whatman filter paper, centrifuged and concentrated by solvent evaporation. The resulting MPE was stored at 4 °C until film preparation. For full reproducibility, the exact ethanol-to-water ratio, centrifugation conditions and extraction yield should be recorded in future experiments.

2.4 Preparation of Composite Films

Films were prepared by solution casting. Chitosan (1.5 g) was dissolved in 50 mL of 1% (v/v) acetic acid. A separate starch dispersion (2.0 g in water) and a gelatin solution were prepared at 60 °C. The chitosan, starch and gelatin phases were combined and maintained at 80 °C with mixing. Glycerol was added as a plasticiser at 30% of the total polymer dry mass. After cooling the chitosan/gelatin/starch (CGS) mixture to approximately 35 °C, MPE was incorporated at 0%, 10% or 30% relative to the selected formulation basis. Each mixture was homogenised for 45 min, cast into Petri dishes, dried at 40 °C and conditioned in a desiccator at approximately 50% relative humidity. Because gelatin mass, casting volume/area and MPE basis were not supplied in the source record, these variables must be specified before independent replication.

2.5 Preliminary Characterisation

Fourier-transform infrared (FTIR) spectroscopy was used to examine the principal functional groups in the extracted chitosan. Film formation, continuity, colour and visible homogeneity were assessed macroscopically after drying and conditioning. No quantitative tensile, barrier, antioxidant, antimicrobial, thermal, migration or biodegradation testing was reported; consequently, the present analysis is restricted to chemical identification and visual proof of film formation.

3. Results and Discussion

3.1 FTIR Characterisation of Extracted Chitosan

The FTIR spectrum of the extracted material is presented in Figure 1. The broad absorption region attributable to overlapping O-H and N-H stretching, together with amide- and saccharide-associated bands, is consistent with the functional-group profile generally reported for chitosan [5-8].

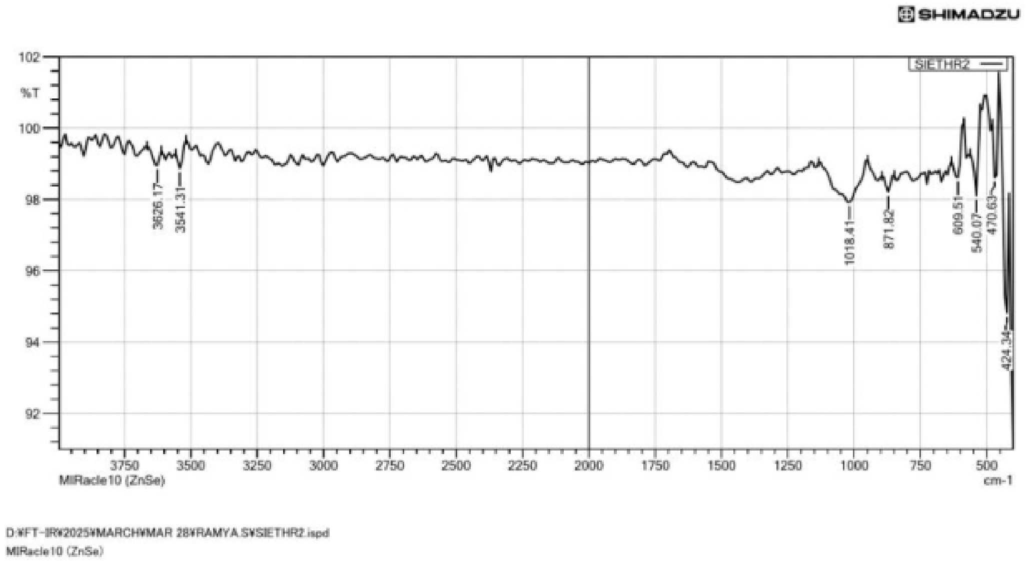

Figure 1. FTIR spectrum of chitosan extracted from mud-crab shell waste.

FTIR supports chemical identification but does not, by itself, establish purity, molecular mass or degree of deacetylation. Quantitative determination of the degree of deacetylation, ash content, moisture content and extraction yield is therefore required before comparing the material with commercial food-grade chitosan.

3.2 Formation and Macroscopic Appearance of CGS-MPE Films

Solution casting produced self-supporting CGS films with MPE contents of 0%, 10% and 30%. A representative film is shown in Figure 2. The visible colour and surface appearance varied with extract incorporation, indicating that MPE-derived constituents were retained in the dried matrix. The ability to peel an intact film from the casting surface provides preliminary evidence of matrix formation, but visual inspection cannot establish packaging suitability.

Figure 2. Representative chitosan/gelatin/starch film containing muskmelon peel extract prepared by solution casting.

The expected effects of plant extracts on biopolymer films are formulation dependent. Phenolic constituents may contribute antioxidant or antimicrobial activity, but they can also disrupt polymer-polymer interactions, alter film opacity and increase or decrease tensile and barrier properties depending on concentration and compatibility [10-14]. Therefore, statements that MPE improved mechanical strength, water-vapour resistance, antioxidant activity or antimicrobial effectiveness cannot be supported without corresponding measurements and statistical analysis.

3.3 Required Performance Evaluation

Table 1 summarises the minimum tests needed to progress from a laboratory film to a defensible food-packaging candidate. These measurements should be conducted using independent film batches and appropriate statistical analysis.

Table 1. Recommended validation tests for muskmelon-peel-reinforced chitosan composite films.

Performance domain	Recommended measurements	Purpose
Composition and structure	Degree of deacetylation, extract yield, total phenolic content, FTIR, thickness	Confirm material identity and batch consistency
Mechanical behaviour	Tensile strength, elongation at break, elastic modulus	Determine handling and package integrity
Barrier performance	Water-vapour permeability, oxygen permeability, moisture uptake, solubility	Assess protection against environmental transfer
Functional activity	DPPH/ABTS antioxidant assays; antimicrobial tests against relevant food microorganisms	Verify active-packaging function
Thermal and optical properties	DSC/TGA, opacity, colour and light transmittance	Define processing stability and product visibility
Food-contact safety	Overall/specific migration, residual solvents, allergen and cytotoxicity assessment	Establish safety and regulatory suitability
Application performance	Controlled food-storage trial with microbial, oxidation and sensory endpoints	Demonstrate shelf-life benefit
End-of-life behaviour	Standardised biodegradation or compostability testing	Substantiate environmental claims

3.4 Study Limitations

The study is limited by incomplete reporting of several formulation and extraction parameters, absence of replicate numbers, lack of quantitative film-property data and absence of statistical analysis. No food-contact migration assessment, antimicrobial challenge test, antioxidant assay, biodegradation experiment or packaged-food shelf-life trial was provided. The films must therefore not be described as safe, effective or shelf-life-extending food-packaging materials at this stage. The work establishes only preliminary feasibility of extracting chitosan and forming MPE-containing composite films.

4. Conclusion

Chitosan was extracted from mud-crab shell waste and combined with gelatin, starch, glycerol and muskmelon peel extract to prepare composite films by solution casting. FTIR observations were consistent with the expected functional groups of chitosan, and intact films were obtained at the investigated extract concentrations. The work demonstrates a preliminary route for simultaneously valorising crustacean-shell and fruit-peel residues. However, the available evidence is insufficient to claim improved mechanical strength, barrier performance, antimicrobial activity, antioxidant capacity, food safety, biodegradability under standard conditions or extension of food shelf life. Establishing these properties requires fully specified formulations, replicated experiments, standard test methods, statistical analysis and food-contact safety evaluation. Accordingly, the resulting materials should be regarded as early-stage biodegradable-film prototypes rather than publication-ready proof of a commercial active-packaging system.

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Funding: No funding was received for conducting this study.

Conflict of interest: The Author's have no conflicts of interest to declare that they are relevant to the content of this article.