

Research article

CHARACTERISATION OF CHITOSAN-STARCH FILM CONTAINING BANANA PEEL EXTRACT FOR POTENTIAL ACTIVE FOOD PACKAGING APPLICATIONS

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ABSTRACT

This study investigates the development of biodegradable composite films composed of chitosan-starch (CS) and banana peel extract (BPE) for food packaging applications. Films with varying BPE concentrations (0-2%) were analysed for physicochemical, mechanical and antimicrobial properties. Fourier Transform Spectroscopy (FTIR) confirmed enhanced intermolecular interactions due to polyphenolic compounds in the extract. Tensile strength increased from 28 MPa to 39 MPa, while elongation at break increased from 45% to 87%. Additionally, antibacterial activity against *E. coli* improved with increasing BPE concentration, with inhibition zones increasing from 1.00 cm to 1.70 cm showed increased *E. coli* inhibition with higher BPE levels. This study demonstrates the valorisation of banana peel waste as a multifunctional bioactive additive in chitosan-starch films, simultaneously enhancing mechanical, barrier and antimicrobial properties.

1.Introduction

Food preservation plays a critical role in extending the shelf life of food products, preventing spoilage, and ensuring food safety. With an estimated one-third of the world's food being wasted annually, effective preservation methods are crucial to reducing food loss and enhancing food security. However, conventional preservation techniques, such as refrigeration, freezing, and canning, while effective, often result in non-sustainable packaging materials that contribute to environmental pollution. The

growing demand for food packaging has led to an increase in the use of synthetic plastics, whose non-biodegradable nature poses long-term ecological risks (Mia, 2023).

To address these concerns, researchers have explored biodegradable packaging materials derived from renewable sources as a sustainable alternative to petroleum-based plastics. These biodegradable films not only reduce plastic waste but also offer functional properties suitable for food packaging applications. Among these, chitosan and starch emerged as

widely studied biopolymers due to their film-forming ability and biodegradability for composite films. More recently, BPE has gained attention for its richness in bioactive compounds, particularly phenolics, which can further enhance the functional and protective performance of biodegradable films (Evyang et al., 2022; Oyekunle et al., 2024; Razak et al., 2020).

Despite the potential of CS films infused with BPE for sustainable food packaging, further research is needed to fully understand their synergistic effects. While previous studies have highlighted the individual benefits of each material, very few studies report a comprehensive analysis of the structural, mechanical, optical, and antibacterial effects of varying BPE concentrations in biopolymer matrices. In particular, the combined influence of BPE on intermolecular interactions, water barrier behaviour, and microbial inhibition in CS-based films remains underexplored. Therefore, this study aims to investigate the antibacterial properties of CS films with BPE, exploring their potential as effective and environmentally friendly solutions for food preservation (Luchese et al., 2018; Priyadarshi & Rhim, 2020).

Recent studies have demonstrated the potential of natural plant extracts as active additives in biodegradable packaging films owing to their antimicrobial activities (Cazon et al., 2025). Although banana peel-derived components have been investigated in starch-based films, the concentration-dependent effects of banana peel extract within a chitosan–starch matrix remain insufficiently characterised, particularly regarding the relationship between spectral changes, mechanical response and antibacterial activity. Existing studies have generally focused on selected film properties or different polymer matrices, making direct comparison of these responses within a chitosan–starch system difficult (Ahmed et al., 2025).

Most previous studies focused on starch-based films or investigated only selected film properties. Comprehensive evaluation of the simultaneous effects of BPE on molecular

interactions, mechanical performance, water resistance and antimicrobial activity within chitosan–starch matrices is still limited. Therefore, this study investigates the effect of BPE concentration (0–2%) on the FTIR characteristics, tensile properties and antibacterial activity of chitosan–starch films against *E. coli*. The study seeks to determine how increasing BPE concentration is associated with changes in the physicochemical and functional properties of the composite films.

2. Material and Methods

2.1. Material

Dwarf Cavendish bananas from Pasar Borong Selangor were cleaned, dried and used for extraction. Chitosan powder served as the primary biopolymer, while corn starch formed the film matrix. Glycerol improved film flexibility, acetic acid solubilised chitosan, and ethanol extracted bioactive components from banana peel. Materials were chosen based on availability, cost-effectiveness, and suitability for food preservation. All measurements were conducted in triplicate ($n = 3$), and the results are reported as mean $\pm$ standard deviation.

2.2 Methods

2.2.1. Preparation of Banana Peel Powder

The ripe banana peel was cleaned, dried with absorbent paper and chopped into small pieces. About 100 g of peel was boiled in 500 mL of distilled water at 90°C for 1 hour to extract bioactive compounds. The peels were dried with tissue and oven-dried at (40–50) °C for 12–24 hours, then ground into a fine powder and stored in a sealed container.

2.2.2. Preparation of Banana Peel Extract

BPE of 0.5%, 1.0%, 1.5% and 2% were prepared by mixing the corresponding amounts of banana peel powder (0.5g, 1.0 g, 1.5 g and 2 g) with ethanol (100 mL). The mixtures were stirred for 24 hours at room temperature, then filtered using vacuum filtration. The liquid extracts were collected and stored in sealed containers for further use.

2.2.3. Preparation of Starch Solution

2 g of cornstarch were mixed with 100 mL of distilled water, followed by the addition of 0.5

mL of glycerol to the mixture. The solution was heated to 75°C and stirred at 750 rpm until the cornstarch was fully dissolved and the solution became clear. Once clear, stirring continued for an additional 30 minutes to ensure uniformity and consistency throughout the solution.

2.2.4. Preparation of Chitosan Solution

1.5 g of chitosan was added to 100 mL of distilled water, followed by 0.5 mL of acetic acid to facilitate the dissolution of the chitosan. The solution was stirred at 350 rpm at room temperature until the chitosan fully dissolved and the solution became clear. After dissolution, the solution was left undisturbed for 24 hours to allow complete settling.

2.2.5. Preparation of Biodegradable Film

Chitosan and starch solutions were mixed in a clean beaker and stirred for several minutes to ensure a uniform blend. Twenty millilitres of the mixed solution were transferred into a separate beaker, and BPE at varying concentrations (0%, 0.5%, 1.0%, 1.5% and 2%) was added. The mixture was stirred for several minutes to distribute the extract a thin layer of approximately 10 mL was poured into a clean Petri dish and spread evenly to ensure consistent film thickness. The Petri dish was placed in an oven set to 50°C and allowed to dry for 24 hours.

2.3. Preparation of Agar Plates

14 g of nutrient agar powder was weighed and mixed with 500 mL of distilled water in a clean container. The mixture was stirred thoroughly until the agar powder was fully dissolved. The solution was then transferred into a reagent bottle, sealed tightly and autoclaved at 121°C and 15 psi for 15–20 min and the medium was allowed to cool. In a sterile environment, 20 mL of the agar solution was poured into a sterile petri dish. The Petri dishes were sealed with parafilm to prevent contamination and stored in a refrigerator for at least 24 hours before use.

2.4. Preparation of Antimicrobial Analysis

The *Escherichia coli* (*E. coli*) culture tube was gently swirled to ensure the bacteria were transferred onto the prepared agar plate, and a spreader was used to evenly distribute the bacteria across the surface. Paper discs were

dipped into a solution of chitosan and starch with varying concentrations of BPE (0%, 0.5%, 1.0% and 1.5%). Paper discs were soaked in the film solution were placed carefully onto the inoculated agar plates, ensuring they were evenly spaced. The Petri dish was covered with a lid, sealed with parafilm to prevent contamination and placed in an incubator for 24 hours to allow for bacterial growth and observe any antimicrobial effects. They were incubated at 37°C and inhibition zones were measured using a digital caliper.

2.5. Fourier Transform Spectroscopy Analysis (FTIR)

Fourier Transform Spectroscopy Analysis (FTIR) was used to identify and analyse the chemical composition of a material by detecting its molecular vibrations. It provided information about the functional groups present in the chitosan, starch and BPE samples. The films were analysed using FTIR with a range of 400–4000 cm⁻¹ and a resolution of 4 cm⁻¹ (Medeiros Silva et al., 2020).

2.6. Tensile Strength Analysis

The tensile strength (TS), elongation at break (EB), and elastic modulus (EM) tests were conducted on all films using an Instron H50KT Tinius Olsen universal testing machine equipped with a tensile group probe. The film samples were cut into rectangular grips (3 cm x 7 cm) and positioned in the film-extension grips of the texture testing machine, following the standard test method outlined in ASTM B882-10: Standard Test Method for Tensile Properties of Thin Plastic Sheeting. The test was conducted at a crosshead speed of 10 mm/s. (Chandrasekar et al., 2023). The film samples were stretched until breaking. A microcomputer was used to log the stress-strain curves. Some studies have used amylases to measure tensile strength, with values ranging from approximately 4.43 to 31.20 MPa (Taweecat et al., 2021). The recommended range for tensile strength is 5 to 25 MPa, as this balance of strength and flexibility is required for biodegradable films (Tan et al., 2022). For each film, a minimum of three replicate tests were performed. The results

of tensile strength were expressed in MPa, and elongation at break was expressed in % (Saber et al., 2017).

2.7. Statistical Analysis

All experiments were performed in triplicate and results are presented as mean $\pm$ standard deviation. Statistical analysis was conducted using one-way analysis of variance (ANOVA) to evaluate the effect of banana peel extract concentration on film properties. Significant differences among means were determined using Tukey's post hoc test at a confidence level

of 95% ($p < 0.05$). Statistical analyses were performed using IBM SPSS Statistics software.

3. Results and Discussion

3.1. Fourier Transform Spectroscopy (FTIR)

Fourier transform infrared spectroscopy (FTIR) was used to evaluate the molecular interactions between CS with various concentrations of BPE extract. The spectra for pure CS films and composite films with 0.5%, 1.0%, 1.5% and 2.0% BP extract are shown in Fig. 1.

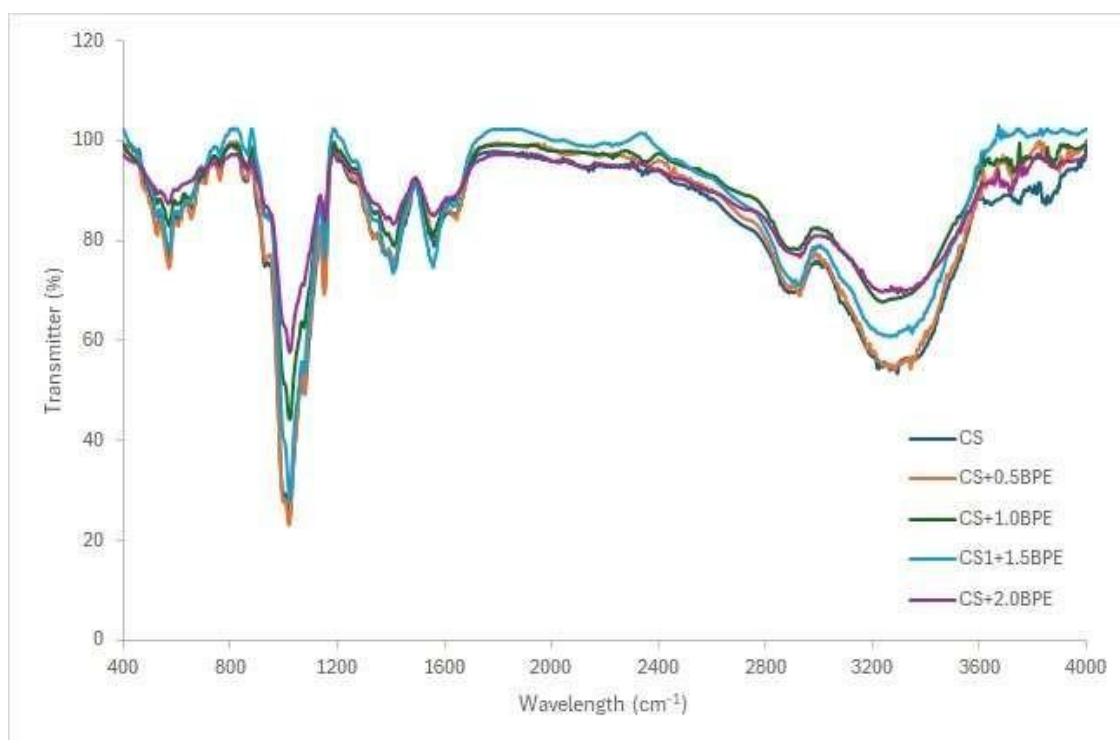


Figure 1. FTIR spectra of CS films with different BPE concentrations

The broad absorption band observed in the region of 3200-3400 cm^{-1} corresponded to the stretching vibrations of O-H and N-H functional groups. This band became broader and more intense with increasing BPE concentration, particularly at 1.5% and 2.0%, suggesting enhanced hydrogen bonding. Resulting from interactions between hydroxyl-rich phenolic compounds in the BPE and the CS matrix (Medeiros Silva et al., 2020).

The peak near 1640-1650 cm^{-1} , corresponding to C=O stretching (amide I) and possibly aromatic C=C stretching, also

increased in intensity with BPE addition. This indicates the presence and incorporation of polyphenolic and aromatic compounds from the BPE extract into the film matrix (Medeiros Silva et al., 2020). These observations are consistent with the findings of Medeiros Silva et al. (2020), who reported similar peak shifts and intensifications when incorporating plant extract into polysaccharide films.

In the region between 100-1150 cm^{-1} , associated with C-O and C-O-C stretching vibrations of polysaccharides, the spectra exhibited stronger absorbance with increasing

BPE concentration. This indicated that the natural polysaccharides in banana peel contribute to the film's structure, complementing the existing CS backbone. Minor but noticeable shifts were also observed in the fingerprint region ($600\text{-}900\text{ cm}^{-1}$), indicating subtle changes in the molecular structure resulting from BPE incorporation.

Overall, increasing the concentration of BPE from 0.5% to 2.0% resulted in more pronounced structural changes in the FTIR spectra. These changes indicate alterations in the vibrational environment of the composite matrix following

BPE incorporation, although the specific molecular interactions responsible cannot be conclusively identified from FTIR alone.

3.2. Tensile Strength

The mechanical performance of the BPE composite film was significantly influenced by the incorporation of BPE. As shown in Fig. 2, both tensile stress and strain exhibited non-linear trends across different BPE concentrations, indicating complex interactions between the extract and the biopolymer matrix.

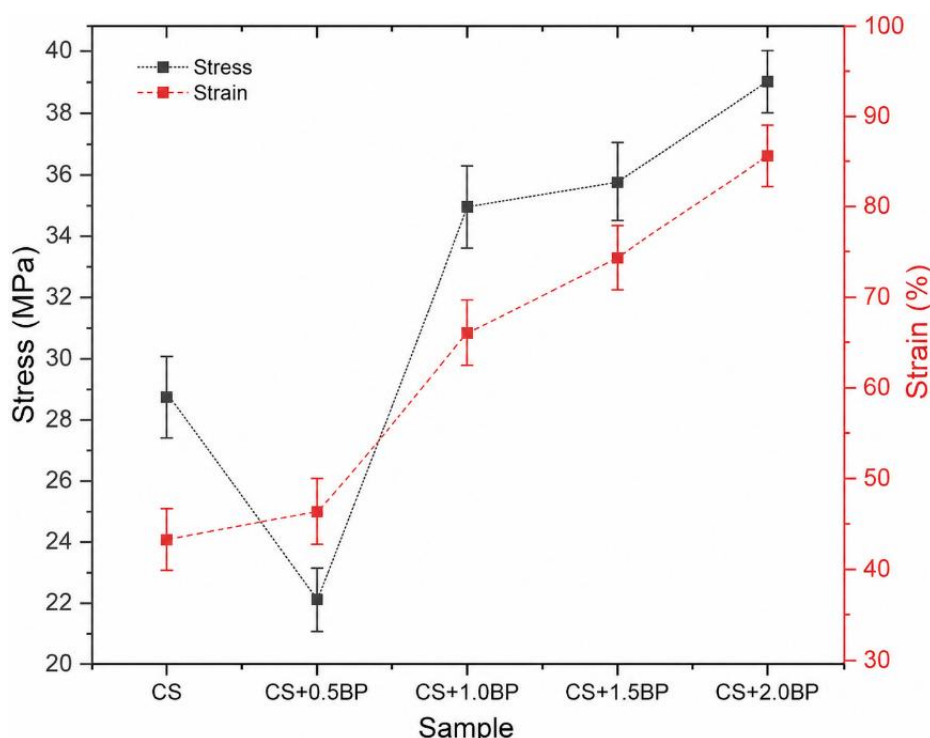


Figure 2. Tensile stress and strain of CS films with varying BPE concentrations.

At 0.5% BPE, a decrease in tensile stress was observed compared to the control film, likely due to the initial disruption of hydrogen bonding between chitosan by small molecules present in the extract. However, with increasing BPE concentration (1.0%-2.0 %), a consistent enhancement in both tensile strength and elongation at break was observed. The sample containing 2.0% BPE showed the highest mechanical performance, with a tensile stress of 39MPa and a strain of 87%, compared to 28MPa and 45% in control sample.

This dual improvement may be attributed to the polyphenolic and lignocellulosic composition of banana peel. Polyphenols such as tannins and flavonoids can form intermolecular hydrogen bonds or even weak cross-links with hydroxyl and amine groups in chitosan and starch, thereby reinforcing the matrix structure. Moreover, BPE contains plasticising components, such as sugars and organic acids, which may enhance chain mobility and flexibility at higher extract concentrations. Polyphenolic compounds

present in BPE may interact with hydroxyl groups of starch and amino groups of chitosan through hydrogen bonding, producing a denser polymer network that improves stress transfer and mechanical strength (Santhosh et al., 2024).

Additionally, the presence of insoluble lignocellulosic particles at higher extract levels may contribute to matrix reinforcement through a stress transfer mechanism, as seen in other natural fiber-reinforced biopolymers. These combined effects suggest that BPE serves both as a plasticizer and a reinforcing agent, depending on its concentration. Cellulose and hemicellulose particles present in banana peel may function as natural reinforcing fillers, improving load distribution within the matrix (Azriena et al., 2025).

These findings are consistent with earlier reports on the integration of natural plant-based extracts into biopolymer films, where improvements in mechanical strength and ductility were achieved due to enhanced intermolecular interactions and filler effects (Chandrasekar et al., 2023; Tan et al., 2022). The results highlight the potential of banana peel as a functional additive in sustainable packaging materials.

The incorporation of BPE affected both tensile strength and elongation at break, although the response was not linear across the tested concentrations. Tensile strength increased from 28 MPa for the control film to 39 MPa at 2% BPE. One-way ANOVA followed by Tukey's post hoc test indicated that the tensile strength differed significantly among BPE concentrations ($p < 0.05$), with the 2% BPE film exhibiting a significantly higher value than the control. Similar changes in mechanical properties have been reported for polysaccharide-based films containing plant-derived components. The observed improvement may be associated with changes in polymer-extract interactions and the presence of structural components in banana peel. However, because the present study did not independently quantify the phenolic, lignocellulosic or other extract constituents, these mechanisms should be considered possible explanations rather than directly demonstrated mechanisms.

The tensile strength obtained at 2% BPE was higher than values reported within the comparative range cited in previous studies, indicating that BPE incorporation can substantially modify the mechanical response of the chitosan-starch matrix. Nevertheless, suitability for a particular packaging application would require evaluation of additional properties and application-specific performance criteria.

3.3. Antibacterial Analysis

The antimicrobial activity increased with increasing BPE concentration, although the response was concentration-dependent (see Table 2 and Fig. 3). The inhibition zones of the control, 0.5% BPE and 1.0% BPE films were statistically comparable, as indicated by the same Tukey grouping ($p > 0.05$). In contrast, the 1.5% and 2.0% BPE films showed greater inhibition zones than the lower-concentration films ($p < 0.05$). The 2.0% BPE film produced the largest inhibition zone (1.70 ± 0.08 cm), indicating that a higher BPE concentration was associated with enhanced inhibition of *E. coli*.

The increasing inhibition-zone diameter with BPE concentration indicates that incorporation of BPE was associated with greater inhibitory activity against *E. coli* under the conditions tested. This effect may be related to antimicrobial constituents present in the extract, including phenolic compounds; however, the specific compounds responsible were not identified in the present study. Similar trends were reported by Taweechat et al. (2021).

Phenolic compounds alter membrane permeability, induce leakage of intracellular components and interfere with enzyme activity. Previous studies have proposed that phenolic and flavonoid compounds can inhibit bacterial growth through mechanisms involving membrane disruption and interference with cellular processes. These mechanisms may contribute to the observed inhibition in the present study, although they were not directly investigated. Flavonoids may additionally inhibit nucleic acid synthesis and energy metabolism, resulting in reduced bacterial growth.

This finding supports the potential use of CSBPE films in active food packaging to extend shelf life and improve food safety. However, the plateau at 0.5-1.0% suggests a threshold concentration below which the extract may not

be sufficiently active to inhibit microbial growth. The incorporation of BPE altered the functional properties of the CS films, with statistically significant differences observed for selected measured properties.

Table 2. Effect of BPE concentration on antimicrobial activity

Sample	Diameter of inhibition zone (cm)	Related FTIR observation
CS	1.00 ± 0.05^c	Baseline O-H and N-H stretch; no BPE functional groups
CS+0.5BPE	1.10 ± 0.04^c	Slight increase in O-H and C=O peaks
CS+1.0BPE	1.10 ± 0.06^c	Moderate increase in phenolic-
CS+1.5BPE	1.30 ± 0.07^b	Enhanced O-H/N-H and C=O stretch; signs of polyphenol presence
CS+2.0BPE	1.70 ± 0.08^a	Strongest O-H and C=O intensities; highest phenolic interaction

* Means with similar letters (a, b and c) are not significantly different among samples according to Tukey's test ($p < 0.05$) with 3 repetitions.

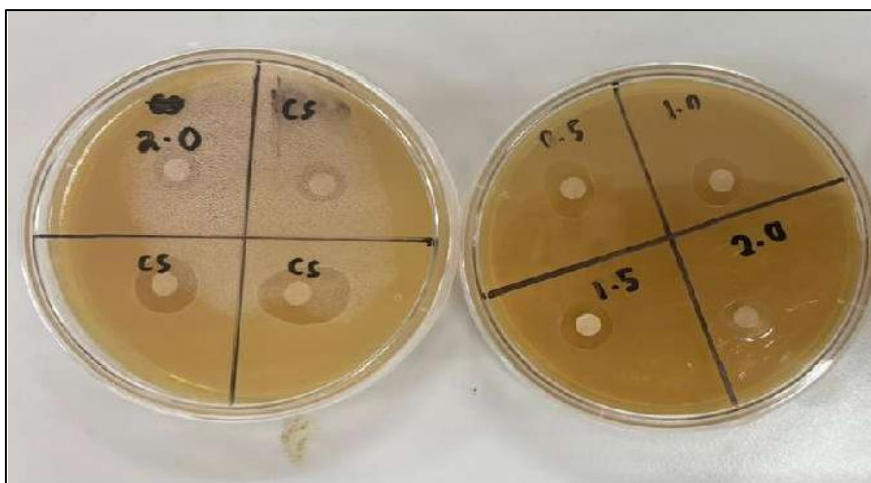


Figure 3. Antimicrobial Activity of CSBPE Films

4. Conclusion

The incorporation of banana peel extract altered the FTIR characteristics, mechanical properties and antibacterial response of chitosan–starch films. Increasing BPE concentration produced progressively more pronounced spectral changes, while the 2% BPE film exhibited the highest tensile stress and elongation at break among the formulations tested. Antibacterial activity against *E. coli* also increased at higher BPE concentrations, with the

largest inhibition zone observed for the 2% BPE film. These findings indicate that BPE incorporation can modify the physicochemical and antibacterial characteristics of chitosan–starch films. However, the specific molecular mechanisms responsible for these changes cannot be established solely from FTIR and tensile measurements. Further studies involving chemical profiling of BPE, barrier-property measurements and direct food-storage experiments are required before claims

regarding antioxidant functionality or food shelf-life extension can be established.

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