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Formulation and performance of edible biopolymer pouches: a novel delivery system for instant soup seasoning

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Plastic waste and pollution are on the rise, and ready-to-eat (RTE) foods such as instant noodle cups are a significant source of plastic pollution. In addition to external plastic coverings, internal plastics protect the seasonings for consumption. This study aimed to develop an edible and soluble packaging material to replace the internal seasoning packaging material using varied concentrations of chitosan, carboxymethyl cellulose (CMC), and inulin. Eight packaging films were developed from the combinations and evaluated for physical properties, mechanical properties, and protective qualities for instant noodle seasonings, as well as their effect on the final broth. The strongest mechanical properties were observed in S1.2 with a tensile strength of 6.42 MPa and an elongation at break of 35.77%, while the eight samples exhibited tensile strengths ranging from 0.74 to 9.96 MPa and elongations at break from 10.72 to 35.77%. The solubility varied between samples at all temperatures, and sample S1.1 showed the greatest difference in solubility cross temperature ranges, with an increase in solubility from 55% at 50 °C to nearly 80% at 90 °C. Other samples demonstrated higher total solubility, but smaller differences across temperature ranges. Upon application, the formulations showed different impacts on the pH, viscosity, or total soluble solids of the broth, with many showing no statistical difference on at least two parameters. Several of these formulations show great potential as edible and soluble packaging for seasonings and can provide an avenue for plastic reduction in a large product market.

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Sustainability spotlight

This study develops edible biopolymer spice pouches using chitosan, CMC, and inulin, materials derived from renewable sources. By replacing single-use plastic seasoning sachets, this innovation supports circularity in food packaging and aligns with UN Sustainable Development Goals 12 (Responsible Consumption & Production) and 14 (Life Below Water) by reducing packaging waste and its environmental impact.

1. Introduction

Global plastic pollution levels continue to rise drastically throughout the globe, and food systems are reported to account for approximately 15% of total plastic production.[1] This is exacerbated by the continued growth of RTE foods, including instant noodles, which reached demand levels of approximately 123 billion servings in 2024.[2] Instant noodle packaging typically includes external and internal seasoning packaging, which presents the potential to reduce plastic waste by altering the packaging solution for internal seasonings. Minimizing the consequences of food packaging requires innovative, sustainable solutions that retain similar physical and protective qualities of plastic materials.

Effective packaging requires good physical and mechanical properties that preserve food quality and protect it from the environment.[3] Bio-based packaging is a critical avenue of innovation that is non-toxic, biodegradable, and biocompatible.[4,5] Biopolymer packaging also has the advantage of processability and an abundance of environmental sources.[6] Additionally, biopolymers possess or can impart key bioactivities, including antimicrobial or antioxidant activities, while also improving delivery and sensory characteristics.

Polysaccharides, proteins, and lipid biopolymers all have potential roles in packaging, with the film-forming characteristics of polysaccharides and proteins showing significant potential.[7] Polysaccharides with functional characteristics are available from abundant sources, including traditional waste streams that can be leveraged to support circular value chains. Chitosan, carboxymethyl cellulose (CMC), and inulin are three

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prominent polysaccharides utilized in packaging systems for their techno-functional and bioactive properties. Chitosan's inherent antimicrobial properties make it an important candidate for food protection and the packaging industry.[8] CMC is a water-soluble cellulose derivative that has been used in combination for edible films, which exhibits toughness, tensile strength, and transparency necessary for packaging.[5] However, both chitosan and CMC exhibit low water resistance and poor mechanical barriers.[9,10]

Inulin has a high degree of polymerization and high microcrystal and gel-forming capabilities.[11] Additionally, ref 12 showcased that inulin served as a plasticizer in a cassava starch polymeric matrix, increasing the water vapor permeability and exhibiting prebiotic effects. Various biopolymers for edible packaging solutions demonstrate different characteristic strengths, but plasticizers are often needed to improve mechanical properties and flexibility.[13] Combining these polymers is essential for developing films that exhibit the necessary mechanical properties, enhance nutritional or health-promoting qualities, and ensure product performance.

While these biopolymers have been investigated for various edible packaging solutions, very few compare formulations using the three polymers for the dissolution of internal materials in hot water. This study investigated combinations of the biopolymers chitosan, CMC, and inulin to produce an edible pouch for instant noodle seasonings. These combinations were investigated for their physical and mechanical properties for food protection, as well as their applicability to degrade and release the seasoning upon the addition of hot water. This research shows novel formulations to preserve the quality of packaged seasonings and release the ingredients in RTE foods while removing the need for internal plastic within the product.

2. Materials and methods

2.1 Preparation of films

Composite films were prepared following a modified method based on that of Salama *et al.*,[14] using various combinations of chitosan, CMC, and inulin (Table 1). Chitosan was dissolved in 1% acetic acid and stirred for 8 hours; CMC in hot distilled water (75 °C, 1 hour); and inulin in warm water (40 °C, 30 minutes). The solutions were mixed with 3% glycerol as a plasticizer and stirred for 2 hours at room temperature. The final mixtures were cast onto plates and dried at 60 °C for 24 hours and then stored in a desiccator for conditioning.

Table 1 Composition of the prepared films

Sample number	Chitosan (g)	CMC (g)	Inulin (g)
S1.1	2.5	0	0.5
S1.2	2.5	0.5	0
S1.3	2	0.5	0.5
S1.4	1.5	1	0.5
S1.5	1.5	0.5	1
S1.6	1	1	1
S1.7	1	1.5	0.5
S1.8	1	0.5	1.5
S1.9	0.5	2	0.5
S1.10	0.5	0.5	2

2.2 Edible film characterization

2.2.1 Thickness, color and transparency. Film color was evaluated using a colorimeter based on the CIELAB parameters (L, a, and b^*) as described by Galus and Lenart,[15] and the total color difference (ΔE) was calculated. Transparency was assessed following the method of Woggum *et al.*[16] Film samples (4 × 1 cm) were placed on one side of a colorimetric cuvette, with an empty cuvette serving as the control. Transparency was measured at 600 nm using a Shimadzu UV-1800 UV-vis spectrophotometer. Film thickness was determined using an L&W Micrometer 51, with the final value representing the average of eight measurements taken from different areas of each film.[17]

2.2.2 FTIR. The infrared spectra of different films were recorded using a Fourier Transform Infrared (FTIR) spectrometer (Nicolet iS50, Thermo Scientific, USA). For each spectrum, scans were collected in the range of 400–4000 cm^{-1} at a resolution of 4 cm^{-1}.[18]

2.2.3 XRD. The structure of films was investigated by X-ray diffraction (Bruker AXS model D8 Advance, Germany) using Cu Kα radiation generated at 40 kV and 40 mA in the 2θ range of 5° to 70°.[19]

2.2.4 Tensile strength, elongation at break, and swelling ratio. The tensile strength and elongation at break of the developed films were evaluated using a TA.XT Plus Texture Analyzer (Stable Micro Systems, UK), following the method described by Alvarado *et al.*[20] Prior to testing, film samples were cut into strips measuring 1 × 9 mm. The average of eight replicates was used to determine both tensile strength and elongation at break. The swelling ratio was measured to assess water absorption. Film samples (3 × 3 cm) were weighed and then immersed in water at 22 °C for 20 minutes, as described by Puscaselu *et al.*[21] After immersion, the films were reweighed, and the swelling ratio was calculated based on the increase in weight.

2.2.5 Water vapor permeability and moisture content. Water vapor permeability (WVP) was assessed following a modified protocol based on that of Musso *et al.*[22] Film samples were cut into 5 × 5 cm^2 squares and used to seal circular aluminum cups containing 10 g of calcium chloride, serving as the desiccant. The films were fixed in place using paraffin wax to ensure airtight sealing. The initial weight of each sealed cup was recorded before placing them in a desiccator containing a saturated NaCl solution to maintain conditions of 25 °C and 75% relative humidity. After 24 hours of equilibration, the weight of each cup was measured hourly over an 8-hour period. Weight gain was plotted against time to determine water vapor transmission through the films. The moisture content of the prepared films was analyzed gravimetrically in a hot air oven at 25 °C for 24 h.[23]

2.2.6 Microbial load evaluation. The prepared films were tested for the presence of *E. coli*, yeast and mold using dehydrated selective culture media: Compact Dry EC for *E. coli* and

coliforms and YM for yeast and mold (NISSUI Pharmaceutical, Tokyo, Japan). For each test, 1 g of film was homogenized in 9 mL of buffered water. Then, 1 mL of the resulting solution was plated onto the respective culture media. The plates were incubated at 37 °C for 48 hours for *E. coli* and at 37 °C for 72 hours for yeast and mold. All microbiological tests were conducted in triplicate, following the protocol described by Puscaselu *et al.*[21]

2.2.7 Film solubility. Film solubility was evaluated using a modified method adapted from Cho, Lee, & Rhee.[24] Conditioned edible films (0.5 g each) were placed into separate beakers containing 10 mL of solutions with varying pH levels (2–9, adjusted using 2 M NaOH and 2 M HCl) or temperatures (25 °C, 50 °C, and 100 °C). Each setup was gently agitated at 40 rpm for 10 minutes. After treatment, undissolved film residues were collected, oven-dried at 105 °C for 24 hours, and weighed to determine the remaining insoluble matter. Film solubility was calculated by comparing the initial and final dry weights.

2.3 Product application

The developed edible pouch was used to package 5 g of instant noodle seasoning. Each pouch was sealed and conditioned in a desiccator for 24 hours. After conditioning, the pouches were submerged and stirred in boiling water for 5 minutes to simulate actual use. Once cooled, the resulting broth was analyzed for color, turbidity, pH, and total soluble solids (TSS).

2.4 Statistical analysis

SPSS and JMP software for Windows were used for the analysis of data. Results were determined through analysis of variance at a 95% confidence level ($p < 0.05$). One-way ANOVA was performed with *post hoc* tests, Tukey HSD and Dunnett, as appropriate. The experiments were completed in triplicate, and the results were presented as the mean values and standard deviation of three replicates.

3. Results and discussion

3.1 Physical and mechanical properties

Ten combinations were prepared according to the methods above, but samples S1.8 and S1.10 were excluded due to their adhesion to the casting equipment. Thickness, color, and transparency depicted in Table 2 are important physical characteristics that impact packaging production and consumer preference. The thicknesses of the composite films range from 0.05 ± 0.01 mm to 0.22 ± 0.17 mm, while S1.9 and S1.7, which contain the most CMC, exhibit the highest thickness. The hydrophilicity of the CMC enhances water-binding properties and contributes as a thickener.[25]

The negative a^* values and positive b^* values indicate green and yellow colors within the films, respectively. Small differences were observed in L^*, a^*, and b^* between samples, but did not exhibit a significant difference ($p > 0.05$) in ΔE. This may be attributed to the similarity of the biopolymer colors which are considered light and transparent materials.[12,26] These numbers for L^*, a^* and b^* are lower than observed in ref. 27 and 28, which represented a brown color, although this color was attributed to the source of the inulin.

Transparency is a critical component of packaging as it can impact both consumer acceptance and the protection of light-sensitive components of the package. Samples S1.4 and S1.2 had the lowest test values of 0.66 and 0.85, respectively, indicating the highest transparency. Similar values of film transparency were observed by Noshirvani *et al.* (2017)[28] in chitosan–CMC films. The S1.1 film exhibited the greatest opacity at 3.42, although with high variability, which aligns with the work in ref. 27. This work showed inulin and chitosan as opaque and transparent separately with the combination leading to a significant increase in the chitosan–inulin film opacity. Alternatively, in this study, the inulin did not affect the overall transparency of the chitosan–CMC–inulin composites.

3.2 FTIR

FTIR was performed for each sample as depicted in Fig. 1. The broad peak observed between 3200 and 3400 cm^{-1} can be attributed to hydroxyl (–O–H) and amine (–N–H) group stretching in chitosan, resulting from hydrogen bond formation between polymer molecules.[29,30] The peaks at 2920 and 2877 cm^{-1} are likely due to C–H stretching.[30] Sharp peaks at 1028 cm^{-1}, 1038 cm^{-1} and 1149 cm^{-1} indicate stretching vibrations of C–N and C–O that confirm the presence of chitosan.[31] Peaks observed between 800 and 1200 cm^{-1} are due to the saccharide structure attributed to fructose molecules with β-glycosidic linkages and are similar to those observed by Cao *et al.*, indicating the presence of inulin.[27]

Table 2 Physical properties of edible pouch samples[a]

Sample	Thickness (mm)	L^*	a^*	b^*	ΔE	Transparency (A_{600}/mm)
S1.1	0.11 ± 0.02^{b}	30.05 ± 3.57^{ab}	-1.02 ± 0.57^{e}	3.62 ± 1.82^{a}	—	3.42 ± 2.82^{a}
S1.2	0.05 ± 0.01^{c}	22.36 ± 4.17^{d}	-0.63 ± 0.24^{bcd}	3.21 ± 3.10^{a}	7.75 ± 2.05^{a}	0.85 ± 0.67^{c}
S1.3	0.12 ± 0.03^{b}	26.71 ± 6.07^{bc}	-0.84 ± 0.44^{de}	2.63 ± 2.17^{ab}	7.15 ± 2.05^{a}	1.42 ± 1.05^{bc}
S1.4	0.09 ± 0.04^{bc}	28.62 ± 2.56^{b}	-0.73 ± 0.33^{cd}	1.65 ± 0.58^{bc}	4.55 ± 2.04^{a}	0.66 ± 0.40^{c}
S1.5	0.10 ± 0.03^{b}	30.18 ± 10.38^{ab}	-0.73 ± 0.06^{cd}	3.51 ± 1.20^{a}	9.72 ± 8.94^{a}	1.03 ± 0.39^{c}
S1.6	0.10 ± 0.04^{b}	29.54 ± 4.81^{ab}	-0.47 ± 0.17^{ab}	1.67 ± 0.87^{bc}	4.02 ± 3.67^{a}	0.81 ± 0.41^{c}
S1.7	0.18 ± 0.07^{a}	23.81 ± 6.73^{cd}	-0.54 ± 0.45^{abc}	1.68 ± 0.97^{bc}	8.66 ± 4.94^{a}	1.50 ± 1.38^{bc}
S1.9	0.22 ± 0.17^{a}	32.58 ± 3.47^{a}	-0.38 ± 0.21^{a}	1.20 ± 0.91^{c}	3.72 ± 2.90^{a}	2.21 ± 1.59^{b}

[a] The letters indicate statistical differences between samples according to one-way ANOVA and Tukey *post hoc* tests.

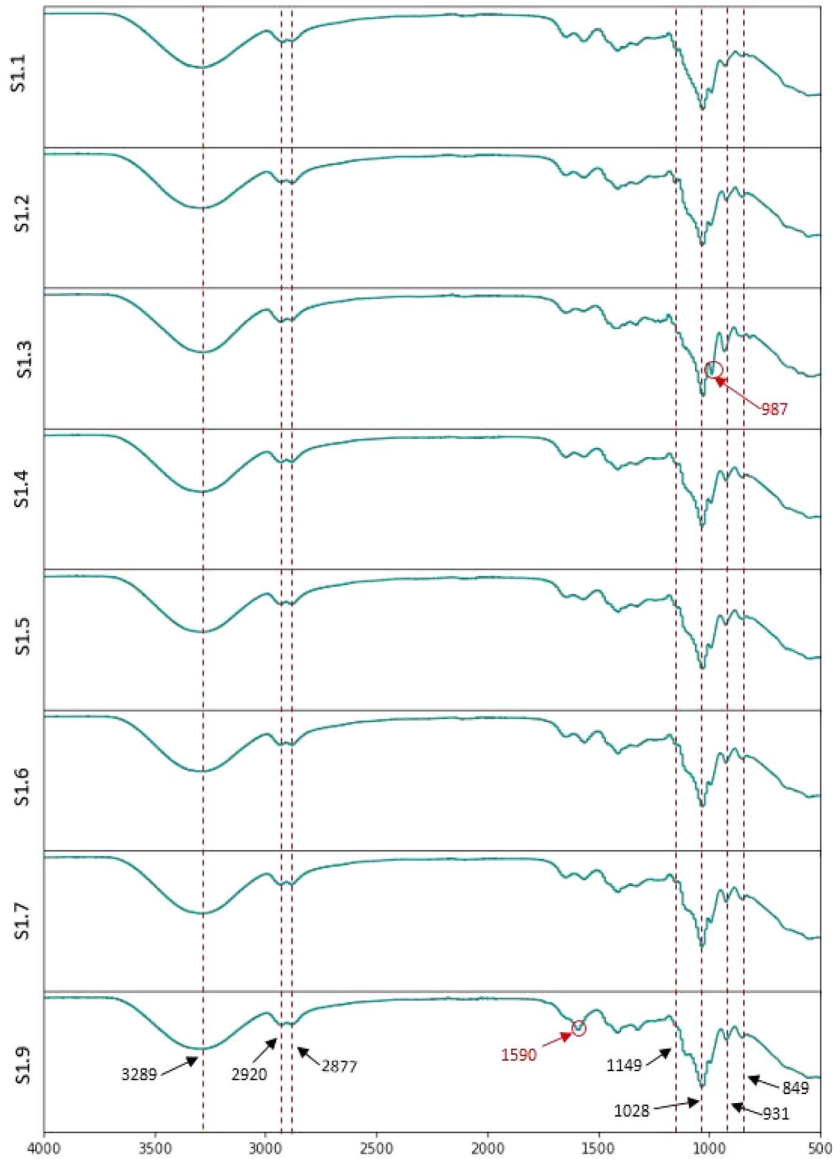

Fig. 1 FTIR spectroscopy of the film samples.

Samples S1.3 and S1.9 exhibited irregular peaks from the other composite films. In S1.3, the peak observed at 987 cm^{-1} is more pronounced, indicating C═C bending between molecules, which further connotes characteristics of glycosidic bonds.[27] In S1.9, the peaks observed at 1644 and 1563 cm^{-1} have shifted to 1590 cm^{-1}, suggesting that there has been an interaction between the hydroxyl group of CMC and the amino group of chitosan.[32] The overall similarity in patterns between composite film formulations indicates the miscibility of the components and indicates strong intermolecular interaction of the molecules within the matrix.[33]

3.3 XRD

The XRD patterns of the different composites of chitosan–CMC–inulin are shown in Fig. 2. All samples showed a diffraction peak at $2\theta = 20°$, indicating the films' amorphous crystalline structure. Moreover, the same peak indicates that the ingredient variation did not affect the crystallinity of the films. The intensity of the peak indicates an amorphous–crystalline characteristic of the developed films and a good miscibility of the samples.[34,35] The results shown in the XRD pattern agree with those of the FTIR analysis, showing a good miscibility of the samples.

The mechanical properties of an edible pouch for instant noodle seasoning require unique properties compared to other edible packaging. The protective qualities need to be maintained, although physical tolerances may be reduced due to the outer protective layer, but the pouch must dissolve and release the seasoning when hot water is applied. The mechanical properties tested included tensile strength, elongation at break, swelling ratio, water vapor permeability (WVP), and moisture content as displayed in Table 3. Additionally, the pouches were

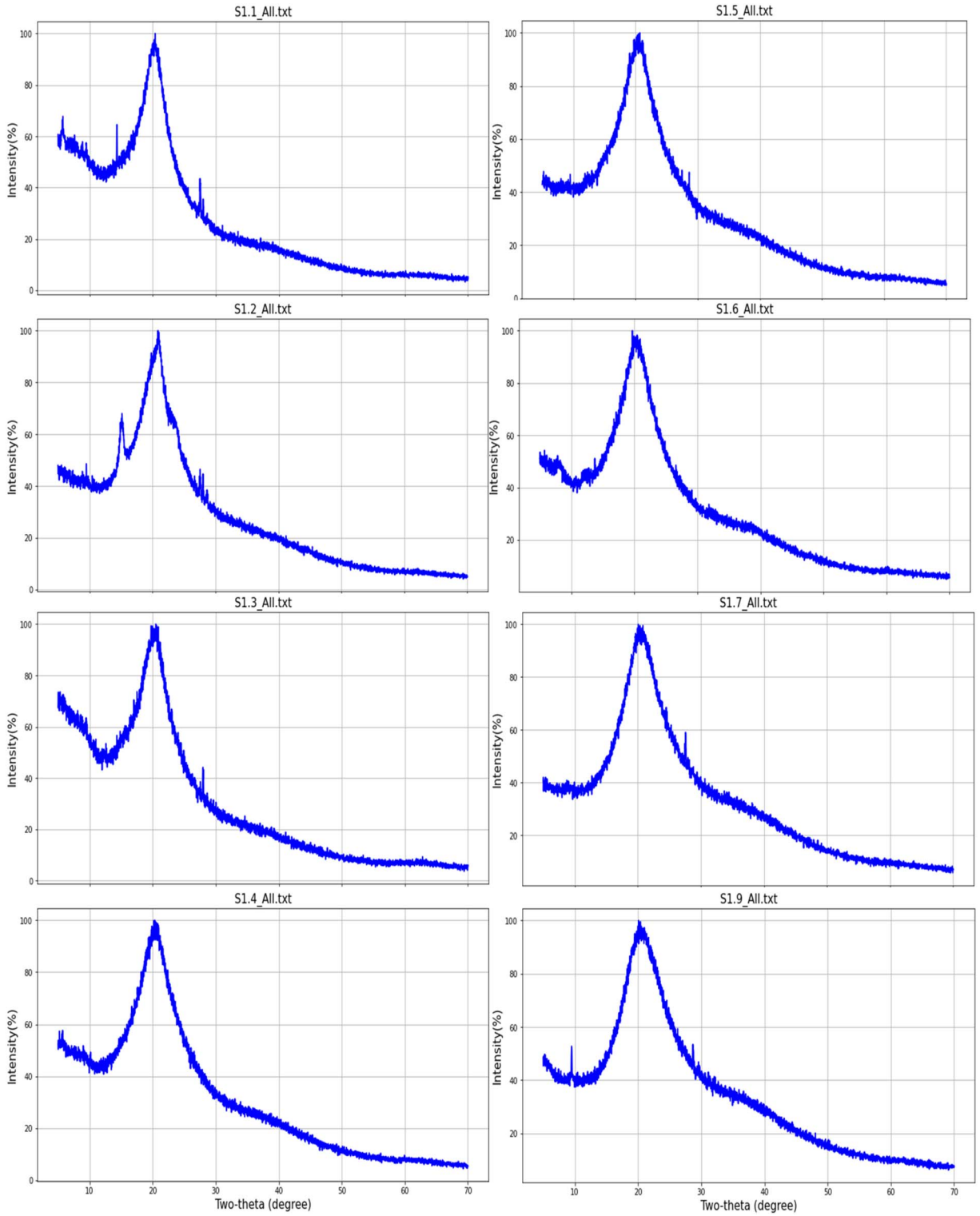

Fig. 2 XRD of film samples.

tested for their overall antimicrobial activity and solubility under different conditions.

Tensile strength is a useful parameter to describe the mechanical properties of films. More specifically, this parameter will determine the strength of the film. The highest tensile strength is seen in the following samples: S1.1 (2.04 MPa), S1.4 (2.18 MPa), S1.2 (6.42 MPa), and S1.3 (9.96 MPa). These samples have the highest amount of chitosan at 2.5 g for S1.1 and S1.2 and 2 g for S1.3. The tensile strength may be attributed to the rigidity of the chitosan and the hydrogen bonding between

Table 3 Mechanical properties of film samples[a]

Sample	Tensile strength (MPa)	Elongation at break (%)	Swelling ratio (%)	WVP (10^{-7} g H_2O per Pa m)	Moisture content (%)
S1.1	2.04 ± 0.79^{cd}	26.56 ± 8.16^{ab}	71.75 ± 11.06^{bc}	3.36 ± 0.85^{d}	24.99 ± 6.58^{b}
S1.2	6.42 ± 2.39^{b}	35.77 ± 18.71^{a}	54.90 ± 32.61^{bc}	1.36 ± 0.39^{e}	24.93 ± 4.43^{b}
S1.3	9.96 ± 2.40^{a}	10.72 ± 6.98^{d}	50.31 ± 46.23^{bc}	4.15 ± 2.41^{cd}	23.75 ± 1.34^{b}
S1.4	2.18 ± 0.87^{c}	20.87 ± 11.57^{bcd}	54.67 ± 48.04^{bc}	5.50 ± 6.61^{bc}	24.09 ± 6.15^{b}
S1.5	1.08 ± 0.40^{e}	16.02 ± 7.93^{cd}	22.06 ± 14.98^{c}	6.93 ± 1.96^{ab}	22.29 ± 1.70^{b}
S1.6	1.22 ± 0.46^{de}	29.11 ± 35.07^{ab}	53.58 ± 39.26^{c}	7.43 ± 0.08^{a}	23.78 ± 3.69^{b}
S1.7	0.78 ± 0.27^{e}	25.19 ± 9.55^{bc}	76.13 ± 45.57^{b}	5.46 ± 1.12^{bc}	30.73 ± 4.30^{a}
S1.9	0.74 ± 0.15^{e}	24.32 ± 4.26^{bc}	535.22 ± 200.22^{a}	8.18 ± 2.30^{a}	24.85 ± 3.08^{b}

[a] The letters indicate statistical differences between samples according to one-way ANOVA and Tukey *post hoc* tests.

NH_3^+ of the chitosan and the OH of the CMC or inulin as observed in FTIR. Alternatively, the tensile strength of the films is lower than those in previous studies such as ref 27 who observed 26.58 MPa. This difference may be attributed to the glycerol addition, which increases film flexibility by reducing hydrogen chain attraction.[36]

Elongation at break is indicative of the flexibility of the packaging as it is the ability to deform prior to breaking. The percent elongation for all samples ranges from 10.72% to 35.77%, with S1.3 showing the smallest value and S1.2 the highest value. Individually, chitosan biopolymers have poor flexibility, but the combined polymers have resulted in films with good elongation at break. The combination for S1.3 indicates a firm and more rigid structure compared to the other composites with a lower tensile strength but a higher elongation at break. This may be further attributed to the hydrogen bonding between chitosan and CMC and inulin.

The swelling ratio is related to the ability of films to trap water molecules in their matrix.[37] S1.9 had the highest swelling ratio of 535.22%, while S1.5 exhibited the lowest. The high swelling ratio of S1.9 aligns with the reduced rigidity from lower chitosan, less viscosity or gelling related to CMC, and the highly soluble nature of inulin that makes up the largest composition. This looser aperture structure may have facilitated the passage of water molecules and also aligns with the high WVP numbers seen for each of the films.[38] Again, S1.9 exhibits the highest WVP at 8.18, while the sample S1.2 exhibits the lowest, which was 1.36. The sample with the lowest WVP was exclusively CMC and chitosan, indicating that the hydrophilicity of inulin has a role in worsening the WVP of the pouches. Despite the high WVP and swelling ratio, these pouches are designed to be encased in an additional outer protective layer that reduces the need for moisture and humidity protection.

Similarly, moisture content in food products is a critical quality for storage stability over time, and the higher the moisture content, the greater the chance of microbial contamination.[39] The moisture content between samples showed no statistical difference ($p > 0.05$), while ranging from 30.73% for S1.7 to 22.29% for sample S1.5, with only sample S1.7 statistically different from the other samples. Previous studies have exhibited lower moisture content than the current study,[40] which may be attributed to the third hydrophilic polymer added or the difference in humidity between testing conditions.

3.4 Microbial load evaluation

The high moisture content in the pouches typically supports microbial growth, but each of the pouches showed 0 CFU g^{-1} for *E. coli*, yeast, and mold after inoculation with concentrated cells. The lack of microbial growth is likely explained by the antimicrobial activity of chitosan, which is present as at least 16% in each pouch.[8] Despite the prebiotic potential exhibited by inulin, the counts remained negligible in all formulations.

3.5 Solubility

Solubility at different temperatures is a critical property of these edible pouches. The ideal sample would exhibit low solubility at lower temperatures and increased solubility for temperatures around 90C upon the addition of hot water for noodle preparation. Additionally, the target pH of the pouches should be in the range of 5 to 6.5. This is supported by studies highlighting the pH-dependent solubility behaviors of chitosan and its derivatives, which align with expected conditions in noodle broths.[41]

Fig. 3 depicts the solubility across temperature and pH ranges for each sample. Across all temperature and pH levels, S1.2 exhibited the lowest overall solubility below 60% in all cases. This is likely due to the absence of inulin, which increased the swelling ratio and WVP. Despite this, the composite pouches exhibit solubility above 50% in all temperature ranges, which aligns with the solubility of ~65% observed by How *et al.* in chitosan–CMC films.[42] This can be largely explained by the incorporation of glycerol as a plasticizer, known to enhance solubility by weakening intermolecular interactions between polymer molecules.[43] The samples S1.1 and S1.9 demonstrate distinct variances in solubility performances with fluctuations in temperature. Previously, Wang *et al.* observed endothermic peaks in chitosan–CMC composites that were associated with hydrogen bonding breakdown, which may explain the increased solubility above 90C for indicated samples.[44] For instance, S1.1 exhibited the highest difference in solubility from 50 °C to 90 °C, showcasing heat-sensitive solubility, but the max solubility remained below or close to S1.6, S1.7, and S1.9. Furthermore, S1.9 showed the greatest solubility at 100C; however, the variability for this sample was much higher. This aligns with the significantly higher swelling ratio of this sample, which has the most inulin.

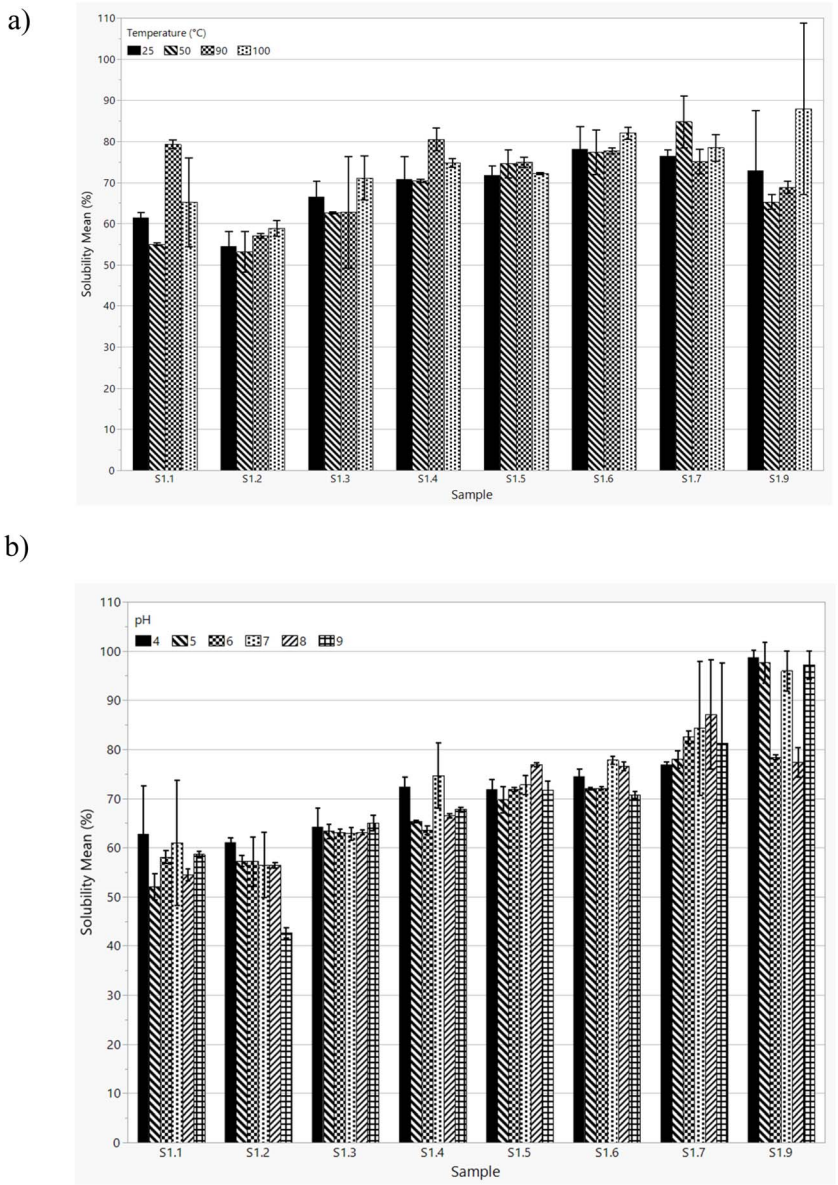

Fig. 3 Solubility measurements of pouch samples at (a) different temperatures and (b) different pH. (a) Solubility of pouch samples at different temperatures. Error bars represent the standard deviation. (b) Solubility of pouch samples at different pH. Error bars represent the standard deviation.

A significant difference ($p < 0.05$) was noted at pH 8 and pH 9. Sample S1.9 showed the highest solubility overall in most pH ranges while demonstrating a reduction in solubility at pH 6 and 8. The drop in solubility at pH 6 is likely due to chitosan precipitation or complexation with CMC near chitosan's pKa of ~6.5, shifting chitosan to an insoluble form.[45] While CMC has a pKa of ~3.5 and is less soluble under acidic conditions, the highly protonated structure of chitosan at that pH may have led to the greater overall solubility at lower pH.[46] In this study, samples with greater CMC and inulin exhibited higher overall solubility across various pH ranges, while the samples higher in chitosan exhibited less solubility across the range of pH changes aligning with results seen by Li *et al.*[47] This may be attributed to complex formation between chitosan and CMC when the pH is low due to chitosan protonation, and at greater pH, the insolubility of chitosan alone likely impacts the overall solubility. Despite solubility differences between samples, the overall solubility remains above 50% for all formulations, and the solubility of individual samples does not change dramatically with pH, particularly in the pH 5–6 range of soup broth, outside of sample S1.9.

3.6 Application performance

The aim of this study was to develop a packaging material that could disintegrate at the introduction of hot water to release its contents. Thus, the noodle seasoning was encased in the pouch and cooked to determine the effects of the edible pouch sample on the final product. Each pouch demonstrated moderate to

Table 4 Characteristics of pouch color after application[a]

Sample number	L^*	a^*	b^*	ΔE
Control	—	—	—	—
S1.1	14.15 ± 0.93^{d}	2.85 ± 1.75^{b}	13.42 ± 3.91^{c}	—
S1.2	15.11 ± 1.06^{c}	4.84 ± 1.92^{a}	16.31 ± 2.85^{ab}	4.36 ± 1.26^{b}
S1.3	16.38 ± 0.71^{b}	4.68 ± 0.55^{a}	17.29 ± 1.42^{a}	1.75 ± 1.11^{b}
S1.4	12.03 ± 1.71^{f}	2.09 ± 1.86^{bc}	9.13 ± 4.91^{d}	11.16 ± 3.99^{b}
S1.5	13.23 ± 0.88^{e}	1.59 ± 0.34^{c}	14.70 ± 0.50^{bc}	3.40 ± 3.07^{a}
S1.6	14.78 ± 1.50^{cd}	4.59 ± 0.49^{a}	13.77 ± 0.75^{c}	2.68 ± 0.72^{b}
S1.7	15.37 ± 0.62^{c}	4.53 ± 0.57^{a}	17.44 ± 0.53^{a}	2.25 ± 0.99^{b}
S1.9	17.81 ± 0.88^{a}	4.20 ± 0.41^{a}	14.74 ± 0.42^{bc}	2.36 ± 1.15^{b}

[a] The letters indicate statistical differences between samples according to one-way ANOVA and Tukey HSD *post hoc* tests.

high levels of solubility that suggested their potential for seasoning release. Color, pH, viscosity, and total soluble solids were examined as depicted in Table 4. After dissolution of the pouch and seasoning, the color of the prepared soup was similar according to ΔE for each sample except for S1.5. The L^* ranged from 12.03 to 17.81, indicating a dark shade, while the a^* results show positive values from 1.59 to 4.84, indicating a red color. The b^* values indicate a yellow coloring in the samples, ranging from 9.13 to 17.44.

Table 5 shows the characteristics of the dissolved pouch in soup as compared to a control of just the seasoning directly applied into hot water. The pH value of the samples ranges from 5.38 ± 0.04 to 5.84 ± 0.07, which falls within the pH range of 5.06–6.51 established in an assessment of instant noodle brands.[48] However, one-way ANOVA with the Dunnett *post hoc* test showed that S1.2, S1.3, S1.4, and S1.5 were statistically different from the control. Additionally, every pouch except S1.1 exhibited higher viscosity than the control, ranging from 5.06 to 8.37 cP. Only samples S1.3, S1.7, and S1.9 showed statistical differences in the broth viscosity. The control broth had a TSS of 1.13 while the samples ranged from 0.87 to 1.27, with samples S1.4 and S1.2 showing the minimum and maximum, respectively. Only samples S1.4 and S1.6 showed significant differences from the control. This indicates that the composite packaging did not significantly affect the dissolution of the seasonings and that the disintegration of the pouch into the medium easily dispersed and dissolved in the water.

Each of the 8 composite packaging samples showed minimal impact on the final broth with most only showing statistical differences for one parameter. S1.1 showed no statistical difference from the control for each parameter, despite exhibiting lower solubility than many of the other samples. Despite these differences, the changes in the broth still fall within expected ranges of the instant soup. Samples S1.1, S1.2, S1.5, and S1.6 show great potential as packaging systems due to their lack of change in the broth samples and acceptable range of pH change.

Table 5 Characterization of soup properties after application[a]

Sample number	pH	Viscosity (cP)	Total soluble solids
Control	5.43 ± 0.01	5.28 ± 0.04	1.13 ± 0.12
S1.1	5.53 ± 0.03^{ns}	5.06 ± 0.87^{ns}	1.07 ± 0.12^{ns}
S1.2	$5.60 \pm 0.05^{**}$	5.30 ± 0.35^{ns}	1.27 ± 0.31^{ns}
S1.3	$5.71 \pm 0.01^{**}$	$8.37 \pm 2.80^{**}$	1.20 ± 0.01^{ns}
S1.4	$5.84 \pm 0.07^{**}$	5.36 ± 0.24^{ns}	$0.87 \pm 0.12^{**}$
S1.5	$5.67 \pm 0.15^{**}$	6.03 ± 0.84^{ns}	1.07 ± 0.12^{ns}
S1.6	5.48 ± 0.20^{ns}	5.53 ± 0.30^{ns}	$0.93 \pm 0.12^{*}$
S1.7	5.38 ± 0.04^{ns}	$7.61 \pm 1.77^{**}$	$1.00 \pm <0.01^{ns}$
S1.9	5.48 ± 0.08^{ns}	$7.14 \pm 1.69^{*}$	1.13 ± 0.12^{ns}

[a] Dunnett test *post hoc* was used, where ns = not significantly different, * = $p < 0.05$, and ** = $p < 0.001$.

4. Conclusion

The rising market for RTE foods and the continued expansion of instant noodle products are leading to wider plastic pollution. This research shows the potential of biopolymer-based packaging to reduce the plastic within RTE instant noodles. Eight formulations of chitosan–CMC–inulin with glycerol as a plasticizer exhibited film formation with various physical and mechanical characteristics. The color and transparency of the different samples were not significantly different, while the mechanical properties, tensile strength, and elongation at break varied. Composite pouches S1.1, S1.2, S1.5, and S1.6 in particular exhibited the necessary mechanical strength for internal packaging and caused minimal changes to the final broth. Alternatively, the higher CMC and inulin samples S1.6, S1.7, and S1.9 showed less mechanical strength but greater overall solubility, which may still be beneficial for packaging protected by an outer layer. FTIR and XRD revealed that each of the sample pouches has high miscibility, indicating good formation and interaction of the compounds. Additionally, no growth from *E. coli*, yeast, or mold was detected in all eight pouches.

The eight formulations tested released the seasoning contents and dissolved in the noodle broth without significant effects on the noodle broth. Thus, the formulations met the initial goal of the study to provide a safe packaging pouch that delivers the seasonings without the need for plastic packaging.

Further testing to determine the shelf-life and nutritional impacts of the biopolymer ingredients is essential to determining key formulations for future packaging solutions. Edible pouch solutions from the biopolymers chitosan, CMC, and inulin show significant potential for use as a soluble delivery system for instant soup products.

Conflicts of interest

There are no conflicts to declare.

Data availability

All data supporting the findings of this study are included in the article. Additional raw data are available from the corresponding author upon reasonable request.

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