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Research article

Film Development of Chitosan from Mussel Shells and Pacific White Shrimp Shells

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Abstract: The rapid expansion of Thailand's aquatic food processing industry has generated significant waste, prompting environmental concerns. This research aims to repurpose waste, specifically mussel and shrimp shells, to extract chitosan, a natural alternative to harmful chemicals. The primary goal is to create compostable packaging materials and preservation techniques while adding value to industry waste. The study investigated the properties of the extracted chitosan, optimized the chitosan films, and explored their use as paper coatings. The study thoroughly investigates mussel and shrimp shell-derived chitosan properties, including color value, pH, moisture, ash, and nitrogen content. Chitosan yield is 35% for mussel shells and 13.3% for shrimp shells, with a bright color and pH values of 7.32 and 7.26, respectively. Mussel shells have lower moisture (0.38%) and higher ash content (96.50%) compared to shrimp shells (4.07% moisture, 10.67% ash). Nitrogen content is 6.40% for mussel shells and 7.99% for shrimp shells. Regarding chitosan films, Method 4, a mixture of cassava starch and chitosan at a 1:0.6 ratio with 40% glycerol by weight, is identified as the optimal production method. The resulting chitosan-coated paper exhibits similar properties, making it suitable for sustainable packaging. Therefore, this research emphasizes repurposing waste from the aquatic food processing industry to promote sustainability and create livelihoods for farmers while addressing environmental challenges. Mussel shells are recommended as the primary raw material due to their larger volume and lower cost than shrimp shells. This research highlights chitosan's potential to address environmental issues and foster sustainable practices in the food processing industry.

Keywords: Chitosan; mussel shell; Pacific white shrimp shells; biodegradable film

1. Introduction

Thailand boasts aquatic food processing industries across all regions, a vital component of the country's economic framework. However, this industry generates significant waste during production, contributing to growing environmental concerns regarding non-biodegradable waste accumulation. Addressing this issue has spurred research efforts to repurpose these wastes into valuable products, presenting an alternative means of deriving value from food processing byproducts [1]. In parallel, there has been a shift in the consciousness of both citizens and aquaculture operators towards nature conservation and environmental preservation. This shift has led to innovative approaches in agriculture, replacing harmful chemicals with natural alternatives, such as chitin and chitosan, which can be extracted from waste materials such as crab, mussels, and shrimp shells [2].

Chitin, abundant in nature, is the second most common biopolymer after cellulose, with an estimated annual production of 10^{10}-10^{12} tons [3]. Structurally, chitin is similar to cellulose, with an acetamide group (-NHCOCH$_3$) at the C-2 position. Chitosan, derived from chitin through deacetylation, is a linear, polycationic heteropolysaccharide composed of β-1,4-2-deoxy-2-amino-D-glucopyranose and β-1,4-2-deoxy-2-acetamido-D-glucopyranose glycosidic linkages [4]. Chitin and chitosan possess unique physical, chemical, and biological properties, making them valuable in various applications, including immunostimulation, antimicrobial properties, and metal ion absorption in water treatment [5,6]. Chitosan is versatile and can undergo chemical modifications [7], finding application in pharmaceuticals, textiles, agriculture, cosmetics, food, and water treatment [8-14].

The widespread use of plastics in the food industry, including films, bags, and trays, has raised concerns about their detrimental effects on human health and the environment. Plastics are non-renewable and non-biodegradable, contributing to soil, water, and air pollution. Additionally, they release harmful gases when burned, leading to various health issues. The increasing demand for plastics, particularly in food packaging, exacerbates these problems [15]. To address these issues, there is a growing need for environmentally friendly alternatives, such as naturally degradable films and coatings derived from renewable sources like polysaccharides [16].

Chitosan's versatile applications extend to food preservation, which can be used as a coating for food items, vegetables, and fruits to prolong their freshness [17]. Additionally, research suggests that chitosan holds promise as a food packaging agent, primarily in the form of edible films derived from agricultural waste materials [18-21]. Chitosan's appeal stems from its renewable source and its environmental advantages, aligning with sustainability goals [22]. Recent research has focused on developing biodegradable films based on chitosan. Bajić et al. compared films with natural plant extracts like oak, hop, and brown algae, noting variations in moisture content, tensile strength, antibacterial activity, and optical properties [23]. Wrońska et al. explored chitosan-based films as alternatives to plastic packaging [24]. Nguyen and coworkers investigated edible films with extracts like *Piper Betle* L. and *Sonneratia ovata*, examining their effects on film color, surface morphology, and food preservation properties [25]. De Carli et al. enhanced chitosan films with propolis extract for improved antioxidant and antimicrobial activities [26]. In addition, Kamdem and coworkers created composite films with xylan and carvacrol, focusing on mechanical properties and thermogravimetric behavior [27]. Zehra et al. optimized films using response surface methodology, adjusting chitosan, glycerol, and drying temperatures [28]. Bhargavi and coworkers compared films with natural extracts, assessing their structural, physicochemical, and antibacterial properties [29]. These studies highlight the importance of chitosan in developing biodegradable films. Furthermore, investigations into chitosan's use as a coating for paper products have shown promise. This is because chitosan uniquely forms robust films and fibers with low oxygen gas permeability. When applied to paper, chitosan enhances mechanical properties and tear strength and renders the paper more opaque. However, it is important to note that chitosan does not effectively block water vapor [30].

Driven by this interest, the researcher has embarked on a project to explore and advance the creation of compostable packaging materials using waste derived from aquatic animal processing. This endeavor encompasses not only the development of packaging materials but also the establishment of preservation techniques. Central to this effort is the extraction of chitosan, a vital component found in mussel and white shrimp shells, employing chemical methods that yield the highest quantity and quality of chitosan, adhering to the standards used in Thailand's food production industry. The overarching goal is to produce high-quality packaging materials serving various stakeholders, including entrepreneurs, farmers, and the general public. By disseminating academic knowledge about chitin and chitosan extraction methods and using these extracts in packaging materials, the project aims to facilitate the creation of sustainable livelihoods for farmers. Additionally, it seeks to add value to the waste generated by the fisheries food processing sector and, in doing so, contribute to mitigating future environmental challenges associated with these industries. As such, this study aims to repurpose waste from Thailand's aquatic food processing industry, specifically mussel and shrimp shells, by extracting chitosan to create compostable packaging materials and preservation techniques.

The characterization of the extracted chitosan, the optimization of chitosan films, and their application as paper coatings were investigated.

2. Materials and Methods

2.1 Preparation of mussel and shrimp chitosan

Figure 1 illustrates the step-by-step process for preparing mussel chitosan and shrimp chitosan. First, mussel shells and shrimp shells were collected and cleaned. This involved separating the meat and fat from the shells and thoroughly washing the shells with clean water. Subsequently, the cleaned shells were left to dry in the sun until completely moisture-free. Once dry, the shells underwent further treatment. Initially, they were treated with 4% HCl at room temperature for four days to demineralize them. After this treatment, the demineralized shells were filtered, and any remaining impurities were washed away using distilled water. To remove protein from the sample, 4% NaOH was added to the dried demineralized shells at room temperature for four days. The resulting mixture was filtered to separate insoluble solids and washed with distilled water. The deproteinized shells were then immersed in 95% alcohol (1 g: 20 ml ratio) with continuous stirring for five minutes, followed by a thorough rinse with distilled water. They were subsequently dried in an oven at 80 °C. The deacetylation of chitin was accomplished by reacting the dried chitin with 40% NaOH, with the reaction mixture heated to 140 °C and stirred for 15 minutes. The alkali was drained, and the remaining material was washed repeatedly with distilled water until it reached a neutral pH of 7. Finally, the chitosan was dried in an oven at 100 °C for one hour. The chitosan was then ground into a fine, homogenized powder with a particle size of 4 mesh. The percentage yield of mussel chitosan and shrimp chitosan was determined as follows:

$$\text{chitosan yield (\%)} = \frac{\text{weight of extracted chitosan}}{\text{weight of starting shells}} \text{ x } 100$$

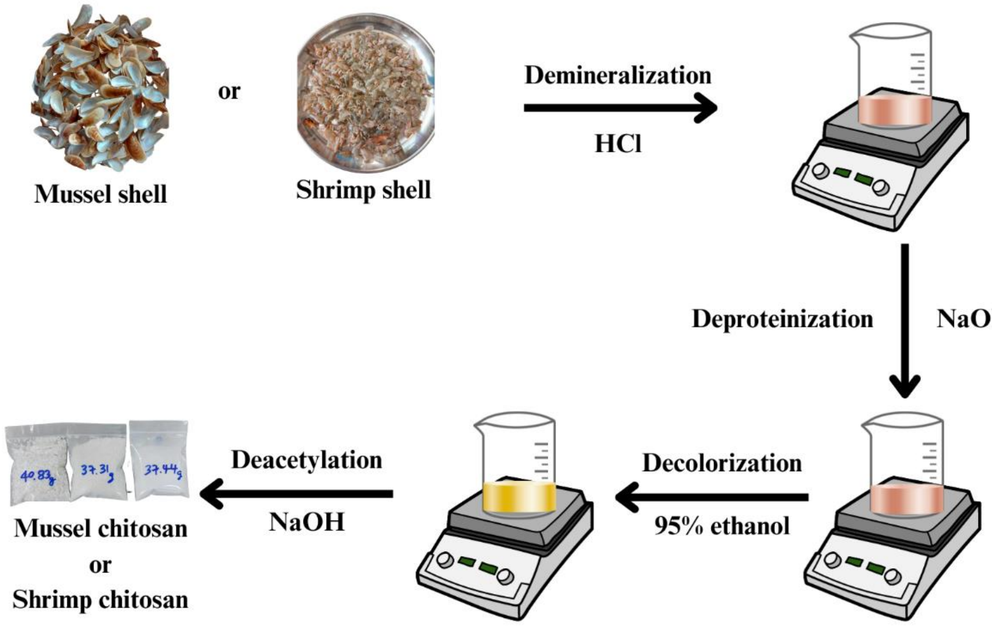

Figure 1. Extraction of chitosan from mussel and shrimp shells wastes.

2.2 Characterization of extracted chitosan

2.2.1 Color

The color of the chitosan samples was assessed using a HunterLab Colorimeter. One gram of each sample was placed on a plate. The Colorimeter measured the color value of the chitosan sample, which was then compared to a standard reference value to determine the color difference in terms of lightness (ΔL*), redness (Δa*), and yellowness (Δb*). The total color difference (ΔE) was calculated as follows:

$$\Delta E = (\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2})^{0.5}$$

2.2.2 pH

The chitosan powder was dissolved in distilled water at a concentration of 1% (w/v). The mixture was stirred for 30 minutes, and the pH was measured using a pH meter.

2.2.3 Moisture, ash and nitrogen content

These properties were assessed using the A.O.A.C. 2000 method [31].

For moisture content analysis, the empty dish and lid were dried in the oven at 105 °C for 3 hours and then transferred to a desiccator to cool. The empty dish and lid were weighed. Approximately 3 g of the sample were weighed and placed in the dish, ensuring uniform spread. The dish with the sample was placed in the oven and dried for 3 hours at 105 °C. After drying, the dish with the partially covered lid was transferred to the desiccator to cool. The dish and its dried sample were then reweighed. The moisture content was calculated as follows:

$$\text{Moisture content (\%)} = \frac{\text{weight of the sample before drying - the weight of the sample after drying}}{\text{weight of the sample before drying}} \times 100$$

For ash content analysis, the crucible and lid were placed in the furnace at 550 °C overnight to burn off any surface impurities. The crucible was then cooled in a desiccator for 30 minutes. The crucible and lid were weighed to three decimal places. Approximately 5 g of the sample was placed in the crucible, then heated over a low Bunsen flame with the lid half-covered. Once fumes were no longer produced, the crucible and lid were placed in the furnace and heated at 550 °C overnight without covering the lid during heating. After heating, the lid was placed on the crucible to prevent loss of fluffy ash. The crucible was cooled in the desiccator. The ash, crucible, and lid were weighed once the sample turned gray. If the sample had not turned gray, the crucible and lid were returned to the furnace for further ashing. The ash content was calculated as follows:

$$\text{Ash content (\%)} = \frac{\text{weight of ash}}{\text{weight of sample}} \times 100$$

For nitrogen content analysis, approximately 1 g of the sample was weighed in a digestion flask, with distilled water used as a blank. Five grams of Kjeldahl catalyst and 20 milliliters of concentrated H_2SO_4 were added. The flasks were placed in an inclined position and heated gently until frothing ceased, then boiled briskly until the solution cleared. After cooling, 50 ml of distilled water was cautiously added. The flask was immediately connected to a digestion bulb on the condenser, with the tip immersed in 40 ml of 4% w/v boric acid solution and mixed indicator solution in the receiver. The flask was rotated to mix the contents thoroughly, then heated while 40% w/v NaOH was added dropwise until all NH_3 had distilled. The receiver was removed, the condenser tip was washed, and the distillate was titrated with standard 0.02 N HCl solution. The nitrogen content was calculated as follows:

$$\text{Nitrogen content (\%)} = \frac{(\text{volume of HCl}_{\text{sample titration}} - \text{volume of HCl}_{\text{blank titration}}) \times \text{N of HCl} \times 1.4}{\text{weight of sample}} \times 100$$

2.3 Preparation of chitosan film

Films were prepared using previous methods with modifications [32,33]. To prepare the cassava starch solution, cassava starch was dissolved in distilled water to achieve a concentration of 5% (w/v). The mixture was heated to a temperature range of 70-80 °C while stirring with an electromagnetic stirrer until a clear gel formed. The solution was then allowed to cool to room temperature. Chitosan solutions at concentrations of 1%, 2%, 3%, 4%, and 5% (w/v) were prepared by dissolving chitosan in a 1% (v/v) acetic acid solution. This solution was stirred and heated to 70-80 °C until the chitosan was dissolved entirely. The solution was then filtered and collected using a vacuum filter set and allowed to cool to room temperature. Six methods were followed to create bioplastic films from cassava starch mixed with chitosan, with three repetitions each.

Method 1: cassava starch film without chitosan (1:0 ratio)
Method 2: cassava starch film mixed with chitosan at a ratio of 1:0.2
Method 3: cassava starch film mixed with chitosan at a ratio of 1:0.4
Method 4: cassava starch film mixed with chitosan at a ratio of 1:0.6
Method 5: cassava starch film mixed with chitosan at a ratio of 1:0.8
Method 6: cassava starch film mixed with chitosan at a 1:1 ratio

For each method, 100 ml of the 5% concentrated cassava starch solution was mixed with 100 ml of the corresponding concentrated chitosan solution. Glycerol was added at 40% by weight of solids [32] to enhance film flexibility. The solution was thoroughly stirred with a magnetic stirrer to avoid creating air bubbles. The mixture was then poured onto a tray to form a film and allowed to dry at room temperature. Once dry, the film was removed. The method that yielded the best results was selected to test the film's properties further.

2.4 Characterization of prepared chitosan film

2.4.1 Film thickness Following the ASTM D-645 and D-374 standards [34]. A film with a diameter of 9 cm was cut, and its thickness was measured with a micrometer at five different locations. The center and all four corners of the film were measured, and the average film thickness was calculated.

2.4.2 Oxygen transmission Following the ASTMD 3985 – 8 standard [34]. A film was removed from the desiccator and placed on the greased surface. The system was set to carrier purge mode to purge the air. The flow rate was then reduced to the desired value. After flushing the system with nitrogen, the sensor was inserted to divert the carrier gas, which had passed through both sides of the diffusion cell, into the sensor. Oxygen was switched into the test-gas side of the diffusion cell, an action automated in newer systems. The sensor output current gradually increased and stabilized at a constant value. The steady-state voltage value of the oxygen transmission rate was recorded.

2.4.3 Tensile strength and elongation Following the ASTMD 882-91 standard [34]. A film measuring 6.5 x 2.4 cm with a depth of 1.2 cm was cut into dumbbell shapes. The tensile strength and elongation percentage were measured using a Texture Analyzer model TA.XT. Plus, with the grip separation load distance set to 27 mm. The tensile strength (TS) and elongation percentage (%E) were calculated.

2.5 Preparation of chitosan-coated paper

Straw paper was coated with chitosan solution derived from mussel shells and another from shrimp shells, selected from the successful preparation of chitosan film. Ten milliliters of each solution were applied onto a sheet of straw paper measuring 29.5 × 21.0 cm and allowed to dry at room temperature. This coating process was repeated once more, and then the properties of the paper were tested.

2.6 Characterization of prepared chitosan-coated paper

2.6.1 Paper thickness Following the TAPPI T441-om97 standard [35].

2.6.2 Water adsorption Following the TAPPI T441 om-09 standard [36]. The water absorption capacity of the paper sheet was measured using Cobb's test, according to the TAPPI T441 om-09 standard, with a Cobb Sizing Tester (Kumagai Riki Kogyo Co. Ltd, Japan). The water absorption value was calculated as follows:

Water absorption = (weight of the paper after testing- weight of the paper before testing) x 100

2.7 Statistical analysis

Each measurement was conducted three times for accuracy. The data were presented as the mean ± standard deviation (SD) and analyzed using SPSS with analysis of variance (ANOVA). Statistical significance was determined at $p < 0.05$.

3. Results and Discussion

3.1 Extraction of mussel chitosan and shrimp chitosan

Chitosan derived from mussel shells resulted in a significantly higher percentage yield by dry weight than shrimp shells ($p < 0.05$). Specifically, the percentage yields were 35% for mussel shells and 13.3% for white shrimp shells (Table 1).

Table 1. Yield, pH, moisture, ash, and nitrogen content of the extracted chitosan from mussel and shrimp shell wastes.

Source	Yield	Chitosan composition*			
		pH	Moisture content	Ash content	Nitrogen content
Mussel shells	35.0	7.32 ± 0.06	0.38 ± 0.03	96.05 ± 0.01	6.40 ± 0.57
Shrimp shells	13.3	7.26 ± 0.07	4.07 ± 0.02	10.67 ± 0.03	7.99 ± 0.14

mean ± standard deviation (SD) from three times measurement

3.2 Characterization of mussel chitosan and shrimp chitosan

Tables 1 and 2 present the properties of chitosan obtained from mussel and shrimp shells. During the extraction process, it was observed that both chitosan samples from shrimp shells and mussel shells had a white appearance. Chitosan obtained from mussel shells exhibited a higher ΔL^* value than shrimp shells, while the Δa^* and Δb^* values tended to decrease. This color change is attributed to removing pigments while eliminating minerals and proteins from the shells. The Δa^* and Δb^* values may be influenced by carotenoids, with more pigments likely extracted from shrimp shells. However, the ΔL^* values for chitosan from shrimp shells and mussel shells did not differ significantly ($p < 0.05$), likely due to the minimal remaining pigments, resulting in a predominantly bright and white appearance.

Table 2. Color parameters of the extracted chitosan from mussel and shrimp shell wastes.

Source	Color parameters*			
	ΔL*	Δa*	Δb*	ΔE
Mussel shells	80.04 ± 0.64	1.07 ± 0.05	7.06 ± 0.34	80.34 ± 0.67
Shrimp shells	76.43 ± 0.13	1.90 ± 0.03	16.15 ± 0.08	78.14 ± 0.14

mean ± standard deviation (SD) from four times measurement

The pH measurement of the obtained chitosan was crucial to confirm the thorough removal of the solvent during the extraction process, ensuring the chitosan's neutrality. This step was essential to prevent adverse effects on the chitosan's subsequent applications. The pH values for chitosan obtained from white shrimp shells and mussel shells were found to be similar ($p > 0.05$), approximately 7.26 and 7.32, respectively, closely aligning with the pH of the distilled water used in the experiment (7.21).

The moisture content test results indicated that chitosan from shrimp shells contained more moisture than chitosan from mussel shells, with values of 4.07% and 0.38%, respectively. The ash content serves as an indicator of efficiency in removing calcium carbonate. Chitosan obtained from mussel shells had a higher ash content than that from shrimp shells, at 96.50% and 10.67%, respectively, possibly due to the presence of various minerals initially contained in shrimp and mussel shells, which are lost during the mineral removal process to produce chitosan.

Furthermore, the nitrogen content in chitosan obtained from white shrimp shells was higher than that from mussel shells, with values of 7.99% and 6.40%, respectively. This difference may be attributed to the loss of amine groups and potential contamination from other compounds like ash, which remains in the chitosan. Additionally, the chitosan produced in this experiment exhibited solubility in various organic acids, such as acetic acid and lactic acid. This suggests that removing the acetyl group enhances the presence of free amino groups, increasing the chitosan's positive charge and solubility [37].

From FT-IR spectra of chitin from mussel shells, the presence of the carbonyl (C=O) functional group in the amide molecule was detected at a wave number of 1655 cm^{-1}, along with the –N-H (bending) functional group at a wavenumber of 1554 cm^{-1}. Similarly, in the chitin portion derived from shells, the carbonyl functional group (C=O) of the amide molecule was identified at a wavenumber of 1655 cm^{-1}, while the –N-H (bending) functional group of the amide molecule was observed at a wavenumber of 1553 cm^{-1}. Moving on to the FT-IR spectra of chitosan from mussel shells, the amine molecule's functional group –N-H (bending) was detected at a wavenumber of 1589 cm^{-1}. Likewise, in the chitosan section obtained from shrimp shells, the amine molecule's functional group –N-H (bending) was also observed at a wavenumber of 1589 cm^{-1}.

3.3 Characterization of chitosan film

Cassava starch results in a hard and brittle film that is unsuitable for direct production into packaging material. To enhance the film's properties, making it stronger and more flexible, this experiment incorporated chitosan at various ratios and used glycerol as an additive. Research suggests that chitosan aids in the formation of cassava starch sheets and improves mechanical properties, particularly tensile strength [38]. Glycerol, on the other hand, enhances the film's flexibility and its resistance to water vapor permeability [39]. Glycerol is recognized as one of the most effective plasticizers for films. Compared to sorbitol and polyethylene glycol, it was selected as the preferred option at a concentration of 40% by weight of the solid material. This choice is based on reports indicating that glycerol contributes to superior film properties across various aspects [32].

The optimal process for producing chitosan film was Method 4, which involves creating a film by blending cassava starch and chitosan in a 1:0.6 ratio. The experimental findings revealed that this film could be easily formed into sheets, exhibiting flexibility that facilitated its removal from the acrylic mold. The resulting film was translucent, although it became slightly yellowish with higher chitosan content. Subsequently, various properties of the chitosan film, such as thickness, oxygen gas permeability, tensile strength, and elongation, were assessed, and the results are presented in Table 3.

Table 3. The thickness, oxygen transmission, tensile strength, and elongation of chitosan films from mussel and shrimp shell wastes.

Property	**Chitosan film**		
	No chitosan	**Mussel chitosan**	**Shrimp chitosan**
Thickness (mm)	0.28 ± 0.05	0.28 ± 0.07	0.29 ± 0.07
Oxygen transmission ($cm^3/m^2/day$)	1.35 ± 0.05	2.56 ± 0.07	2.61 ± 0.06
Tensile strength (kF/cm^2)	55.56 ± 0.79	120.8 ± 0.71	122.2 ± 0.56
Elogation (%)	70.59 ± 0.80	25.88 ± 0.93	23.71 ± 0.99

Table 3 indicates that the films without chitosan and those with chitosan derived from shrimp and mussel shells exhibit similar thicknesses: 0.282 mm, 0.288 mm, and 0.282 mm, respectively.

The oxygen transmission rate (OTR) assessment reveals that chitosan starch film exhibits excellent resistance to oxygen permeability, as indicated by OTR values less than 50 $cm^3/m^2/day$, in line with previous findings [40]. Specifically, the OTR values fall within the range of 2.56-2.61 $cm^3/m^2/day$ due to the crystalline structure of the powder and the cohesive forces held within the molecule through hydrogen bonds. This structural arrangement results in limited gas permeability [41], increasing values as the chitosan content rises. Significantly different values ($p<0.05$) were observed as follows: Films with a starch-to-chitosan ratio of 1:0 and 1:0.6 exhibited OTR values of 1.35, 2.61 (Shrimp chitosan), and 2.56 (mussel chitosan) $cm^3/m^2/day$, respectively. This variation in OTR values can be attributed to the processing of chitosan-starch film, wherein heat and humidity potentially reduce the crystallinity of both starch and chitosan, creating more space within the molecules. Consequently, this allows for increased gas permeability.

Tensile Strength (TS) is significantly influenced by adding chitosan due to its capacity to enhance film strength, consistent with prior research findings [39]. Consequently, films containing chitosan exhibit higher tensile strength values. Specifically, films lacking chitosan had the lowest TS value of 55.56 kF/cm^2. In contrast, cassava starch films with a starch-to-chitosan ratio of 1:0.6, derived from mussel shells and white shrimp shells, demonstrated TS values of 120.8 kF/cm^2 (11.85 MPa) and 122.2 kF/cm^2 (11.98), respectively. These values are comparable to the TS of blended chitosan film with tapioca starch (10.87 MPa) reported by Chillo [39] and to blended films with natural extracts (5.5-12.7 MPa) reported by Bajić [23] and Nguyen [25] (4.8-18.1 MPa). Adding chitosan from both sources indicates a substantial increase in tensile strength.

The film's percentage elongation (E) exhibited a consistent decrease with an increase in the chitosan ratio. This phenomenon aligns with the behavior of tensile strength in the film; when a film possesses higher tensile strength, it tends to have a lower percentage of elongation or stretching capability. Notably, the starch film lacking chitosan displayed the highest E value at 70.59%. This difference was statistically significant ($p<0.05$), likely because starch molecules could interact effectively with glycerol without interfering with chitosan molecules. Glycerol contributed to improved film flexibility, enabling it to stretch well. Subsequently, the film made from cassava starch mixed with chitosan at a ratio of 1:0.6, combining starch with chitosan from mussel shells and chitosan from white shrimp, demonstrated E values of 25.88 and 23.71, respectively. These values did not significantly differ ($p<0.05$). The reduced elongation percentage can be attributed to increased interaction forces between starch and chitosan molecules, resulting in a stronger film with reduced stretchability [39]. However, these results are consistent with the report on blended films with natural extracts, which showed E values of 14-31%, as reported by Bajić [23] and 10-30% by Nguyen [25].

3.4 Characterization of chitosan-coated paper

After applying the chitosan solution from white shrimp shells and the chitosan solution from mussel shells to the paper, the paper's thickness was measured at 0.44 mm and 0.46 mm, respectively. Regarding water absorption, both exhibited similar values of 0.05 g/cm^2 and 0.04 g/cm^2, respectively. These results suggest no significant differences ($p>0.05$) in the properties of the two types of coated straw paper. This lack of differentiation could be attributed to the consistent solution applied to both types, which may not have significantly impacted the paper thickness, as depicted in Table 4.

Table 4. Physical properties of chitosan uncoated and coated papers.

Property	Paper type		
	Chitosan uncoated	**Mussel chitosan coated**	**Shrimp chitosan coated**
Thickness (mm)	0.21 ± 0.03	0.46 ± 0.02	0.44 ± 0.03
Water adsorption (g/cm^2)	0.03 ± 0.003	0.04 ± 0.006	0.05 ± 0.005

4. Conclusions

The research findings demonstrate the successful extraction of chitosan from mussel and shrimp shells, yielding varying percentages. Characterization of the chitosan obtained from these sources has confirmed its neutrality, rendering it suitable for various applications. Furthermore, the research has shed light on the potential of chitosan-coated paper as a sustainable alternative to plastic packaging, boasting similar thickness and water absorption properties. In conclusion, this research underscores the significance of repurposing waste materials from aquatic food processing, such as shells, to harness the value of chitosan for sustainable packaging solutions. It addresses pressing environmental concerns and plays a pivotal role in fostering sustainable livelihoods and mitigating future challenges within the food processing industry, making it a substantial contribution to the field.

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