International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Edible Film from Milkfish (*Chanos Chanos*) Scale Gelatin as an Environmentally Friendly Packaging: Characterization and Applicative Potential

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A B S T R A C T

Edible films represent environmentally sustainable alternatives to traditional food packaging due to their biodegradability. The scales of milkfish (Chanos chanos), typically underutilized, offer potential as a gelatin source owing to their high collagen content. This study aimed to assess the impact of varying concentrations of gelatin derived from milkfish scales on the physical properties of edible films. Gelatin was extracted through a demineralization process using HCl, followed by hot water extraction (60–70°C), and subsequently formulated into edible films with the addition of 2% sorbitol as a plasticizer. The resulting films were evaluated for tensile strength, elongation, thickness, water vapor transmission rate (WVTR), solubility, and transparency. The findings revealed that gelatin concentration significantly affected ($p<0.05$) all parameters except solubility. The optimal formulation was achieved at a gelatin concentration of 5 g, resulting in a tensile strength of 2.206 MPa, an elongation of 160.58%, a WVTR of 1.615 g/m²/day, and a transparency of 2.554 A546/mm. This product exhibits ideal characteristics for water-soluble packaging, such as applications in instant coffee. This study underscores the potential of utilizing fish waste to produce sustainable value-added materials.

Keywords: Edible film, gelatine, milkfish scale, physical characteristics, environmentally friendly packaging

1. Introduction

Indonesia, a maritime nation, is renowned for its abundant marine and fisheries resources. The vast expanse of Indonesian waters positions this sector as one of the main pillars of the national economy, particularly in providing food sources and high-value products. One of the leading commodities in Indonesia’s fisheries sector is milkfish (*Chanos chanos*), which is not only widely consumed but also holds significant potential for development as raw Indonesia, renowned for its abundant marine and fishery resources, is a maritime nation where the vast aquatic territories constitute a fundamental component of the national economy, particularly in the provision of food and high-value products. Among the leading commodities in Indonesia's fisheries is milkfish (Chanos chanos), which is not only widely consumed but also possesses significant potential as a raw material for the processing industry. Nevertheless, the large-scale production of milkfish generates substantial organic waste, including fish heads, skin, bones, and scales. If inadequately managed, this waste can contribute to environmental pollution. Notably, some of these by-products remain rich in nutrients, especially proteins, and can be repurposed as alternative raw materials such as gelatin. Gelatin is a natural protein derived from the hydrolysis of collagen, the primary structural protein in animal connective tissues. Traditionally, gelatin has been sourced from the skin and bones of cattle or pigs. However, these sources present several challenges, including health risks such as allergies and zoonotic diseases, as well as ethical and religious concerns, particularly for Muslim communities. Consequently, there is an urgent need for alternative gelatin sources that are safe, halal, and environmentally sustainable. One promising alternative iss gelatin extracted from milkfish scales, which has been shown to contain high protein content and possess functional properties comparable to commercial gelatin derived from terrestrial animals.

In an industrial context, gelatin is widely recognized for its gelling ability, solubility in hot water, and capacity to form flexible, transparent films. These properties make gelatin an essential material in the production of **edible films**, thin, consumable layers used for food packaging (Riski et al., 2022). Edible films are particularly advantageous because of their biodegradable and eco-friendly nature, offering a potential solution for the growing issue of plastic waste in the food industry. Their relevance is increasing in tandem with rising public awareness of environmental issues and the demand for sustainable packaging innovations. Fish-based gelatin edible films exhibit superior packaging characteristics, including transparency, flexibility, and effective barrier properties against oxygen and water vapors. Additionally, these films can incorporate bioactive compounds, enabling them to serve as **active packaging**, not only functioning as a physical barrier, but also extending product shelf life through antioxidant or antimicrobial activity.

In recent years, the utilization of edible films has markedly increased, particularly in the packaging of ready-to-eat foods. A notable instance of this application is in the packaging of instant coffee or kopi tubruk in sachets. Coffee is a widely consumed beverage across diverse demographic groups. However, traditional plastic sachets significantly contribute to nonbiodegradable waste (Saputri et al., 2024). Edible films offer a viable and environmentally sustainable alternative for coffee packaging, as they dissolve in hot water during brewing, thereby reducing waste and enhancing consumer convenience. This study, therefore, examined the use of milkfish scales as a source for producing gelatin, which is subsequently employed in the creation of edible films. This approach not only adds value to fishery waste but also mitigates environmental pollution and supports the development of sustainable food products (Wati et al., 2023). In the production of edible films, gelatin derived from fish scales is combined with plasticizers such as glycerol or sorbitol to enhance the film's flexibility and mechanical properties. The formulation and concentration of gelatin are critical in producing films that are robust, flexible, and readily soluble in hot water. Previous studies have demonstrated that increasing gelatin concentration influences the physical properties of edible films, including thickness, tensile strength, elongation, solubility, and water vapor transmission rate (WVTR). However, there is a paucity of research specifically focusing on the use of milkfish-scale gelatin for edible films in specialized applications such as instant coffee packaging. Further investigation is warranted to explore this potential.

The aim of this study was to assess the impact of varying gelatin concentrations derived from milkfish scales on the physical and functional characteristics of the resultant edible film. The primary objective is to identify the optimal formulation that produces edible films with desirable properties for application in water-soluble, safe, and environmentally friendly packaging. Additionally, this research seeks to propose an alternative use for fish waste that adds economic value and contributes to the reduction of plastic usage within the food industry.

2. Materials and Methods

Materials

This study utilized fresh milkfish (Chanos chanos) scales sourced from waste generated during the processing of "otak-otak bandeng" in Semarang City, Central Java. Additional materials included hydrochloric acid (HCl) as the solvent for the demineralization process, sorbitol as a plasticizer, and distilled water (aquadest) as the primary solvent.

Production of milskfih scale gelatin and and edible film

The production of gelatin from milkfish scales was initiated by thoroughly cleansing the scales. Subsequently, the scales underwent a demineralization process through immersion in hydrochloric acid (HCl) to remove calcium content. The extraction process involved soaking the demineralized scales in distilled water while applying heat. The methodology employed in this study is depicted in Fig. 1.

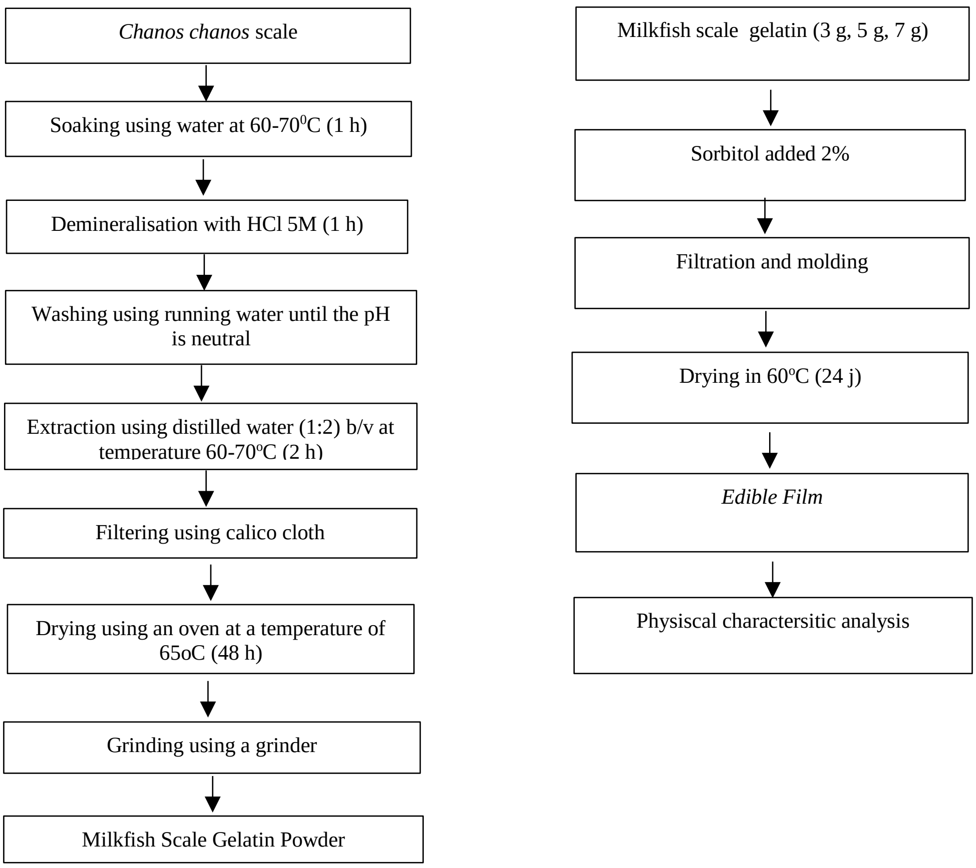

Fig. 1. (a) flowchart of gelation milk fish scale production, (b) flowchart of milk fish edible film production.

Tensile Strength Test

A Texture Profile Analyzer (TPA) was utilized to assess the tensile strength of the edible film. The instrument provided values indicating the force required to achieve maximum tensile extension for each product sample. The tensile strength test was conducted by securing both ends of the strip-shaped sample in the machine. The initial length of each sample was measured prior to testing. The start button on the computer was then activated, causing the machine to pull the sample at a constant speed of 1.0 mm/s until rupture occurred. Tensile strength was calculated by dividing the maximum stress by the cross-sectional area of the sample. The cross-sectional area was determined by multiplying the initial width of the sample by its initial thickness. The results from the three treatments were averaged and incorporated into the formula described by Setiani et al. (2013).

$$\tau = \frac{Fmax}{A} \quad (1)$$

Where:

τ = tensile strength (MPa)

Fmax = maximum tension (N)

A = cross sectional area (mm^2)

Elongation Test

Elongation refers to the maximum length a film can reach before breaking. It is expressed as the percentage increase in the film length when subjected to tensile force until rupture, compared to its original length. An elongation percentage exceeding 50% is generally considered indicative of high flexibility, whereas a value below 10% is deemed poor. The elongation value was calculated using the formula provided by Salimah et al. (2016).

$$Elongation\ (\%) = \frac{\text{Final film length} - \text{Initial film length}}{Initial\ film\ length} \times 100\%$$

Thickness Test

The thickness of the edible film was measured using a micrometer screw gauge with an accuracy of 0.01 mm. Each sample was tested in triplicate to ensure accuracy and repeatability. The average thickness of the edible films was calculated based on the measurement results (Sunardi and Maulana, 2021).

Solubility Test

The solubility test was conducted by cutting the film samples into 3 × 3 cm squares, which were then placed in aluminum dishes and dried in an oven at 100°C for 30 minutes. The dried samples were weighed to determine their initial dry weight. Subsequently, the samples were immersed in water for 24 hours. After immersion, the undissolved portions of the edible film were collected, oven-dried at 100°C for 2 hours, and placed in a desiccator for 10 minutes. The final dry weight was measured and used in the solubility calculation formula (Gontard 1993).

$$Solubility\ (\%) = \frac{W0 - W1}{\text{W0}} \times 100\%$$

Where:

Wo = Initial sample

W1 = Insolubilized sample after drying

WVTR Analysis

The Water Vapor Transmission Rate (WVTR) was measured by cutting an edible film to match the diameter of the dish surface. Silica gel (3 g) was placed inside the dish. The edible film was then sealed on the dish surface using wax. The setup was maintained at room temperature for 24 hours. After the exposure period, the final weight of the sample was recorded, and the WVTR was calculated using the formula based on ASTM E96-01 (1997).

$$WVTR\ (\%) = \frac{\text{W} - \text{W0}}{\text{t} \times \text{A}}$$

Where:

W = Initial sample weight (g)

W1 = Final weight after 24 h

t = time (24 h)

Transparency Test

The test was conducted by cutting the edible film into dimensions of 1 x 4 cm, followed by measuring its thickness (x). The cut film samples were then placed in a glass cuvette for transparency analysis using a spectrophotometer. The spectrophotometer was set to use light at a wavelength of 546 nm. Transparency was measured using the formula provided by Warkoyo et al. (2021):

$$T = \frac{\text{absorbace at546 nm}}{X}$$

Where:

T = Transparency

X = Thickness

3. Results and Discussion

The data on the characteristics of edible films made from milkfish (Chanos chanos) scale gelatin are presented in Table 1.

Table 1. Results of the characteristic tests of edible films with varying concentrations of milkfish scale gelatin.

Treatments	Tensile Stregth (MPa)	Elongation (%)	Thickness (mm)	WVTR (g.m-2.day-1)	Transparency (A546/mm)	Solubility (%)
A	1.492±0,154[a]	133.573±1.321[a]	0.160±0.020[a]	2.512±0.234[b]	3.242±0.282[c]	82.717±4.495[a]
B	2.206±0.597[b]	160.587±3.012[b]	0.197±0.012[b]	1.615±0.144[a]	2.554±0.196[b]	80.016±3.676[a]
C	1.787±0.175[a]	134.687±3.819[a]	0.233±0.006[c]	1.654±0.378[a]	1.855±0.289[a]	81.704±5.313[a]

Tensile Strength and Elongation

Tensile strength is a critical parameter used to evaluate the quality of edible films, particularly in determining their resistance to mechanical forces (Supeni et al., 2015). The results of this study indicate that the concentration of gelatin derived from milkfish (Chanos chanos) scales significantly affects the tensile strength ($p<0.05$). The treatment with 5 g gelatin yielded the highest tensile strength value of 2.206 MPa, compared to 1.492 MPa for 3 g and 1.787 MPa for 7 g. These findings are consistent with those reported by Asmudrono (2019), who observed tensile strength values ranging from 0.69 MPa to 3.85 MPa. These results suggest that a balanced ratio of gelatin to sorbitol as a plasticizer leads to optimal intermolecular bonding. Sorbitol and glycerol act as plasticizers to reduce hydrogen bonding and increase the intermolecular distances (Hidayati et al., 2015). A low gelatin concentration produces films that are too thin and easily torn, whereas an excessively high concentration results in stiff and brittle films. The combination of 5 g gelatin and 2% sorbitol provided the best balance between flexibility and mechanical strength.

The elongation test measures the extent to which the film stretches before breaking. Treatment B (5 g gelatin) exhibited the highest elongation value of 160.587%, whereas Treatments A and C showed relatively similar values of approximately 134%. These results are consistent with the tensile strength test, where a balanced ratio of gelatin and plasticizer maximizes flexibility without causing brittleness. The addition of glycerol or sorbitol aims to reduce the intermolecular forces in cellulose by disrupting the long chains, making the biodegradable film more elastic. Increasing the gelatin concentration beyond the optimal level strengthens intermolecular bonds, resulting in a dense and inflexible structure (Prasetyo and Nurainy, 2024). Conversely, a concentration that is too low results in weak intermolecular interactions, making the film prone to tearing. The gelatin source also influences the outcome, as the protein content and gel strength of milkfish scale gelatin contribute to the mechanical properties of the film. According to Wijayani et al. (2021), the protein content and gel strength of gelatin affect its tensile strength, elongation percentage, and water vapor transmission rate. These characteristics directly influence the elongation performance of edible films.

Thickness

Thickness testing revealed that an increase in gelatin concentration significantly enhanced the thickness of edible films. The thickness measurements for Treatments A, B, and C were 0.160, 0.197, and 0.233 mm, respectively, all of which adhered to the maximum thickness limit set by the Japanese International Standard (0.25 mm). However, research by Putri et al. (2022) indicated that the typical thickness of edible films ranges from 0.11 mm to 0.14 mm. The greater thickness observed in this study is attributed to the varying concentrations of gelatin and sorbitol used. These findings suggest that higher gelatin concentrations increased the total solids in the film-forming solution, resulting in thicker films. The thickness is also influenced by materials such as sorbitol, which do not evaporate during the drying process. Excessive addition of gelatin and sorbitol can lead to films that are excessively thick and less transparent. According to Masru'ah and Warkoyo (2024), an increase in the concentration of edible film components elevates the total solids content, thereby increasing the film's thickness. Gelatin and sorbitol concentrations directly influence film thickness due to their non-volatile nature during oven drying.

The Water Vapor Transmission Rate (WVTR)

WVTR is a crucial parameter for assessing the ability of edible films to serve as a barrier against water vapor. The lowest WVTR was recorded in Treatment B (1.615 g/m²/day), followed by Treatments C (1.654 g/m²/day) and A (2.512 g/m²/day). Lower WVTR values indicate enhanced performance in preventing water vapor transmission. An optimal gelatin concentration (5 g) formed a denser matrix structure, minimizing pore formation and reducing permeability. These findings suggest that edible films derived from milkfish-scale gelatin have potential applications in food packaging requiring moisture resistance. A denser film structure reduces the likelihood of moisture ingress, which can compromise the quality of packaged products. According to Indarti et al. (2022), a decrease in the WVTR signifies an improved barrier function of the edible film against moisture transfer. The high-density polymer structure of edible films effectively impedes water vapor migration. The film's permeability influences the shelf life of the packaged product. Permeability refers to the ability of a packaging material to hinder the passage of substances, such as oxygen, water vapor, carbon dioxide, and other gases. Therefore, the WVTR value determines how effectively the edible film can preserve the quality of the packaged product by resisting environmental effects.

Water Vapor Transmission Rate (WVTR)

WVTR is a critical parameter in evaluating the capacity of edible films to act as barriers against water vapor. The lowest WVTR was recorded in Treatment B (1.615 g/m²/day), followed by Treatments C (1.654 g/m²/day) and A (2.512 g/m²/day). Lower WVTR values indicate better performance in preventing water vapor transmission. An optimal gelatin concentration (5 g) forms a denser matrix structure, minimizing pore formation and reducing permeability. These findings suggest that edible films made from milkfish scale gelatin have potential applications in food packaging that requires moisture resistance. A denser film structure reduces the likelihood of moisture ingress, which can degrade the quality of packaged products. According to Indarti et al. (2022), a decrease in WVTR indicates improved barrier function of the edible film against moisture transfer. A high-density polymer structure in edible films effectively impedes water vapor migration. The film's permeability will influence the shelf life of the packaged product. Permeability refers to the ability of a packaging material to hinder the passage of substances such as oxygen, water vapor, carbon dioxide, and other gases. Therefore, the WVTR value determines how effectively the edible film can preserve the quality of the packaged product by resisting environmental influences.

Fig. 3. Edible Films from Milkfish Scales (a) 3 g gelatin from milkfish scales, (b) 5 g gelatin from milkfish scales, (c) 7 g gelatin from milkfish scales.

Transparency

Transparency is a critical factor in assessing the aesthetic and visual appeal of packaging materials. The findings of this study demonstrate that an increase in gelatin concentration significantly diminishes the transparency of the films. Specifically, Treatment A (3 g) exhibited the highest transparency (3.242 A546/mm), whereas Treatment C (7 g) recorded the lowest transparency value (1.855 A546/mm). The observed reduction in transparency with increased thickness and solid content of the film-forming solution is a logical outcome of the addition of more gelatin. As noted by Warkoyo et al. (2014), an increase in film thickness with higher concentrations of active ingredients results in decreased clarity. As the gelatin concentration rises, the resulting edible film tends to become more opaque and yellowish, thereby reducing its brightness. The increased thickness and polymer density impede light transmission through the film, rendering it opaque. This characteristic is less advantageous in the context of product packaging, where the visual appearance of the content is emphasized.

Solubility

Solubility is a vital parameter for edible films intended to dissolve upon consumption or brewing. The solubility values for all three treatments (A, B, and C) ranged from 80 to 83% and did not exhibit significant differences ($p > 0.05$). This consistency can be attributed to the uniform use of sorbitol (2%) across all treatments. Sorbitol tends to impede solubility due to its chemical structure, which is rich in -OH groups, forming strong molecular bonds. According to Harumarani and Ma'ruf (2016), the concentration of glycerol affects the solubility of edible films, as glycerol is challenging to dissolve within each molecule, thereby restricting polymer molecular movement. The increased use of plasticizers renders edible films more difficult to dissolve. The uniform application of the same plasticizer across all treatments resulted in no significant differences in the solubility of the edible films. The consistent concentration of sorbitol across all treatments rendered the effect of gelatin concentration on solubility insignificant. Nevertheless, the high solubility values support the application of edible films for ready-to-drink products such as "kopi tubruk" (traditional Indonesian coffee), where the film will dissolve when brewed in hot water.

5. Conclusion

The variation in gelatin concentration significantly affected the physical properties of the edible films, including the tensile strength, elongation, thickness, Water Vapor Transmission Rate (WVTR), and transparency. Lower concentrations resulted in thin films that were easily torn, whereas higher concentrations produced thicker, stiffer, and more opaque films. However, the solubility was not affected by the use of the same plasticizer. Among all treatments, 5 g gelatin produced the edible film with the best and most balanced characteristics, making it the most effective formulation for use as an environmentally friendly packaging material

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