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The Utilization of Purple Yam Mucilage for Yam Starch-Based (*Dioscorea alata L.*) Edible Film

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Abstract :

Edible films are thin layers used to coat food products and can be consumed along with the product itself. Previous studies have utilized purple yam starch as a base material for edible films; however, these films exhibit limitations in terms of mechanical and barrier properties. This study aims to utilize purple yam mucilage to improve the mechanical and barrier properties of purple yam starch-based edible films. The experimental design employed a randomized complete block design (RCBD) with five ratios of water to purple yam mucilage (1:0.5, 1:1, 1:1.5, 1:2, and 1:2.5). The results showed that increasing the proportion of purple yam mucilage improved the mechanical and barrier properties of the edible films, while reducing their solubility in water to as low as 33.23%. The best film characteristics were achieved at a ratio of 1:2.5, with a thickness of 0.14 mm, a compressive strength of 3.73×10^{-4} MPa, a water vapor transmission rate (WVTR) of 21.94 g/m²·day, a transparency value of 8.33 %T/mm, and a solubility of 33.23%.

Keywords: Edible film, purple yam mucilage, purple yam starch, ratio.

1. Introduction

Edible film is a thin layer used to coat food products and can also be eaten with the product. The advantages of edible film are its biodegradability, edibility, biocompatibility, elastic appearance, and ability to act as a barrier against oxygen and physical stress during transportation and storage. According to Vianna et al., (2021) edible film can be produced from one type of polysaccharide, such as starch, which is naturally abundant in cereals, tubers, fruits, and vegetables. Due to its biocompatibility and biodegradability, as well as its high availability, starch has been widely applied in the development of edible films and coatings as an alternative material for food packaging.

Purple yam (*Dioscorea alata L.*) is a tuber crop that can be found in almost all regions of Indonesia. It is distributed across various islands, with major production areas in Sumatra, particularly in the provinces of Bengkulu and Jambi. Purple yam tubers contain carbohydrates (70.8%–73.9%) (Oko & Famurewa, 2015), protein (1.3–6.9%), cellulose (1–7.5%), sugars (0.5–1.2%), and fat (0.05–0.2%) (Ochoa & Osorio-Tobón, 2024). Other important components in this tuber include dioscorin, diosgenin, and water-soluble polysaccharides (WSP). These compounds are known to contribute to health benefits, such as acting as enzyme inhibitors, supporting steroid hormone biosynthesis, preventing colon cancer, inhibiting cholesterol absorption, and reducing blood glucose levels under hyperglycemic conditions. (Adu et al., 2021)

Research on edible films derived from purple yam starch has been conducted by Ulyarti et al. (2018), showing that starch-based edible films from purple yam exhibit a high solubility value of up to 80%. Improving the characteristics of purple yam starch edible films by incorporating mucilage is expected to reduce film solubility. As reported by Beigomi (2017), edible films made from seed mucilage (*Dracocephalum moldavica*) have solubility values ranging from 46–54%, thickness of 0.050–0.055 mm, and water vapor permeability of 1.31–1.90 g/msPa. Furthermore, Sadeghi-Varkani (2017) reported that edible films from balangu seed mucilage showed the best solubility values of 9.48%–11.54%. In addition, edible films produced from okra mucilage and

corn starch demonstrated low water vapor permeability (1.32–2.84 g/msPa), low solubility (around 15%), and good thermal and mechanical properties according to Araújo (2018).

According to Lismawati (2017), the solubility of edible films is largely determined by their constituent materials. Highly hydrophilic components, such as glycerol in starch solutions, tend to weaken intermolecular interactions within the starch matrix. As a result, this reduces network density, creates free volume within the matrix, and ultimately increases the film's solubility and water sensitivity (Basiak et al., 2018). The incorporation of mucilage into purple yam starch-based edible films is expected to fill these free spaces within the matrix, thereby reducing the solubility of the edible film.

Yam mucilage extracted with water contains protein and mannan components that are water-soluble; however, when the mannan component is separated from the mucilage, it becomes insoluble in water. Furthermore, another study reported that mucilage from *Dioscorea batatas* contains glycoproteins as the main component, in which some amino acids exhibit hydrophobic properties, such as arginine, lysine, histidine, tryptophan, and mannose. The hydrophobic nature of yam mucilage can reduce the solubility of edible films. In addition, Patidar et al. (2018) stated that mucilage from *Dioscorea* species, after being dried and subsequently dissolved in water, shows reduced solubility.

The solubility of edible films is a critical parameter, particularly for applications in food packaging of products with high moisture content and water activity. Films with low solubility are better able to maintain their structural integrity and functional properties upon contact with water, thereby providing more effective protection for food products. This characteristic is largely influenced by film composition, especially the balance between hydrophilic and hydrophobic components, which governs the film's interaction with water (Falguera et al., 2011).

In contrast, edible films with higher solubility exhibit advantages in terms of biodegradability, as they can degrade more readily in natural environments, making them a promising alternative to conventional plastics, particularly for primary packaging. However, films with lower solubility are more suitable for high-moisture food products due to their superior water resistance. Therefore, the solubility of edible films should be tailored to the specific characteristics and requirements of the food products being packaged.

The hydrocolloid properties of yam mucilage can be utilized as a novel polymer source in the production of edible films, as hydrocolloid-based films generally exhibit excellent characteristics and strong potential for food packaging applications. Such films offer several advantages, including transparency, neutrality in odor and taste, chemical stability, environmental friendliness, and safety. In addition, they can extend the shelf life of fresh foods, provide effective oxygen barrier properties, and demonstrate good resistance to oils (Ghadermazi et al., 2019).

Considering Indonesia's abundant natural resources for yam production and the potential of yam mucilage as a novel hydrocolloid-based polymer for edible film formation, further research into the development of purple yam starch–based edible films with the addition of yam mucilage is warranted. In particular, this study focuses on the effect of the water-to-yam mucilage ratio, as this parameter is expected to influence the mechanical and barrier properties of the resulting edible films.

2. Method

Materials

Yam tuber was freshly harvested from local forest. Glycerol, $Mg(NO_3)_2$, $CaCl_2$, and NaCl were of analytical grades. Brookfield Texture Analyzer (LFRA) and spectrophotometer UV-Vis were used for analysis.

Purple yam mucilage extraction

Purple yam mucilage extraction was carried out as follows: the purple yams were thoroughly washed to remove any adhering soil from the tuber surface by brushing, and then rinsed again. After cleaning, the purple yams were thinly sliced to a thickness of 0.5 cm and soaked in distilled water, with a tuber-to-water ratio of 2:1. The purple yam slices were then gently rubbed to release the mucilage attached to the tuber flesh, and the extracted mucilage was collected.

Edible film preparation

The preparation of edible films followed the method reported by Ulyarti et al. (2020), with slight modifications. Five different ratios of water to yam mucilage were applied in this study, as presented in Table

1. The films were produced using the casting method. Starch was dissolved in distilled water and heated on a hot plate at 79–80 °C under continuous stirring with a magnetic stirrer until gelatinization occurred. Subsequently, yam mucilage was added according to the treatment, and the mixture was reheated to 85 °C. Glycerol was then incorporated into the film-forming solution as a plasticizer. The resulting homogeneous solution was cast onto a Petri dish (25 g per mold) and dried in an oven at 50 °C for 24 hours. The films were then stored in a desiccator containing a saturated $Mg(NO_3)_2$ solution at least 24 hours before analyzed.

Table 1. Edible film formulation

Composition	1:0.5	1:1	1:1.5	1:2	1:2.5
Distilled water	96	72	57.6	48	41.15
Mucilage	48	72	86.4	96	102.85
Glycerol	2	2	2	2	2
Starch	4	4	4	4	4

Thickness

The thickness of the edible film was measured using a micrometer with an accuracy of 0.01 mm. Measurements were taken at five different points to obtain an average thickness representative of the sample.

Compressive strength

Compressive strength was measured using a Brookfield Texture Analyzer (LFRA). The probe used for the edible film was type TA 7 (60 mm). The instrument was set with the following parameters: trigger force of 2 g, distance of 2 mm, and speed of 2 mm/s. The film was cut into dimensions of 5 × 2 cm, and the sample was placed under the probe. After pressing start, the probe compressed the film, and the strength value was displayed on the Brookfield Texture Analyzer (LFRA) screen.

Water vapor transmission rate

The water vapor transmission rate (WVTR) was determined following the method reported by Piñeroz Hernández (2017). A tube containing calcium chloride was sealed with the edible film and accurately weighed. The tube was then placed in a desiccator maintained at 75% relative humidity using a saturated sodium chloride solution. The change in the tube's weight was recorded over time and plotted as a function of time. The WVTR of the edible film was calculated using Eq.1.

$$WVTR = \text{Slope}/A \quad (1)$$

Note:
WVTR = water vapor permeability ($g/m^2/day$)
Slope = slope in grams/minute
A = edible film area (m^2)

Transparency

The transparency was determined following the method reported by Piñeroz Hernández (2017). The edible film was cut into squares (50x10 mm) and placed in the spectrophotometer cell. The percent transmittance (%T) was measured using a UV-Vis spectrophotometer at a wavelength of 600 nm. The transparency of the edible film was calculated using Eq.2.

$$\text{Transparency} = \text{Log } T / \text{Thickness} \quad (2)$$

Solubility

The solubility of the edible film was determined following the method reported by Nazarudin et al. (2023). The filter paper was first dried and weighed (W_2). The film sample was cut into 2 × 2 cm pieces and weighed (W_3), then immersed in 50 mL of distilled water and soaked for 24 hours with periodic stirring. The solution is then filtered, and the filter paper and the insoluble film are dried at 105°C for 24 hours. The amount of insoluble

film and the dried filter paper are then weighed (W_1). The percentage (%) of solubility was calculated using Eq.3.

$$\% \text{ Solubility } = 100 - (W_1-W_2)/W_3 \text{ x } 100 \% \quad (3)$$

Data analysis

Data were analyzed using analysis of variance (ANOVA) and Duncan's New Multiple Range Test (DNMRT) when applicable.

3. Results and Discussion

Based on Table 2, it can be explained that purple yam mucilage has a yellow-red color with a lightness value (L*) of 27.9, along with a slippery texture and gel-like form. This is supported by the high viscosity value of the mucilage, which is 18.89 cPs, and a low moisture content of 18% in its dried state. This viscosity value is considered high compared to the findings of Patidar et al. (2018), where the viscosity of mucilage from *Dioscorea* species was reported to be 1.1032 cPs

Table 2. The Characteristics of Purple Yam Mucilage

No	Properties	Results
1	Color	Yellow Red
		L* 27.9
		a* 5.2
		b* 20.6
		^{o}Hue 75.83
2	Texture	Slippery
3	Viscosity	18.89 cPs
4	Water Content	
	a. Wet Purple Yam Mucilage	99.25%
	b. Dry Purple Yam Mucilage	18%
5	Solubility	
	a. *Acid solution* (HCl, pH 4)	36.08%
	b. *Alkaline solution* (NaOH, pH 10)	38.09%
	c. Distilled water	54.72%
	d. Hot Water (80 °C)	85.17%

1:0.5 1:1 1:1.5 1:2 1:2.5

Figure 1. Edible films with various water to mucilage ratios

Table 3. The characteristics of purple yam starch-based edible films with the addition of purple yam mucilage

Treatment (water: mucilage)	Thickness (mm)	Compressive Strength (MPa)	Water Vapor Transmission Rate ($g/m^2.day$)	Transparency (%T/mm)	Solubility (%)
1:0.5	0.09^{a}	$2.20 \times 10^{-4\,a}$	47.38^{a}	16.47^{a}	46.37^{a}
1:1	0.11^{ab}	$2.42 \times 10^{-4\,ab}$	42.04^{ab}	13.57^{ab}	43.13^{ab}
1:1.5	0.12^{bc}	$2.66 \times 10^{-4\,abc}$	38.60^{ab}	11.79^{bc}	38.80^{bc}
1:2	0.13^{bc}	$3.56 \times 10^{-4\,bc}$	34.10^{b}	9.81^{cd}	35.52^{c}
1:2.5	0.14^{c}	$3.73 \times 10^{-4\,c}$	21.94^{c}	8.33^{d}	33.23^{c}
Purple Yam Starch-Based Edible Film (Ulyarti, 2018)	0.13±0.01	0.049 ± 0.005	$1.08 \times 10^{-2} \pm 4.14 \times 10^{-4}$	12.42 ± 1.13	84.36 ± 1.19

Note: Values followed by different lowercase letters within the same column indicate significant differences at the 5% level according to Duncan's New Multiple Range Test (DNMRT)

Thickness

Thickness is an important parameter influencing the application of films in the formation of packaged products. However, in practice, the thickness of edible films must be adjusted to the characteristics of the product being packaged. The results of this study indicate that increasing the amount of purple yam mucilage leads to an increase in the thickness of the edible film (Table 3). This increase in thickness is attributed to the rise in total dissolved solids as more purple yam mucilage is incorporated into the film-forming solution. Purple yam mucilage contains approximately 55.36% protein and water-soluble polysaccharides, which contribute to the increase in total solids.

Previous studies reported lower thickness values, such as 0.06 mm for edible films derived from okra mucilage and corn starch (Araujo, 2018), 0.054 mm for films made from *Dracocephalum moldavica* seed mucilage (Beigomi, 2017), also 0.059 mm for films derived from balangu mucilage (*Lallemantia iberica F. & C. M.*) (Sadeghi-Varkani, 2017). Compared to these studies, the incorporation of purple yam mucilage in purple yam starch-based edible films resulted in significantly higher thickness values, ranging from 0.09 to 0.14 mm. However, when compared to the study by Reski et al. (2025), which reported thickness values of 0.16–0.30 mm for edible films based on cocoa pulp and watermelon rind, the films produced in this study exhibited lower thickness. According to the Japanese Industrial Standard (2019), a good packaging thin plastic film should have a thickness of less than 0.25 mm. All edible films produced in this study meet this requirement. The relatively thin film thickness is advantageous, as it enhances flexibility and promotes more efficient material usage.

Compressive strength

Compressive strength is a mechanical property that is closely related to the chemical structure of edible films. It represents the maximum force required to break the film. Compressive strength reflects the ability of the material to withstand applied pressure when subjected to maximum stress. Mechanical properties are largely dependent on the strength of the materials used in the production of edible films.

The results of this study indicate that purple yam mucilage increases the compressive strength of the films. In comparison, purple yam starch-based edible films without mucilage exhibited a compressive strength of 0.049 ± 0.005 MPa. The compressive strength of edible films ranged from 2.2×10^{-4} to 3.73×10^{-4} MPa, indicating that the mechanical strength of the film is still relatively low compared to conventional plastic films (Sothornvit, 2001). This is due to the hydrophilic nature of biopolymers and the dominance of hydrogen bonds in the film

structure. However, the increase in compressive strength with the addition of purple yam mucilage indicates an improvement in the film matrix structure. This is attributed to the fact that starch-based edible films are biopolymer materials with lower mechanical strength compared to synthetic plastic films such as polyethylene or polypropylene. The semi-crystalline and hydrophilic nature of starch limits its mechanical resistance. Nevertheless, the compressive strength values obtained in this study are still within the typical range reported for starch-based edible films in various studies, indicating their potential application as biodegradable food packaging materials.

Water vapor transmission rate

WVTR indicates the rate at which water vapor permeates through the edible film ($g/m^2 \cdot day$) per unit area, reflecting the film's ability to resist moisture transfer. Therefore, its permeability to water vapor should be as low as possible, as WVTR is a key parameter that describes the effectiveness of a film or packaging material in preventing moisture migration and maintaining product quality. Therefore, its permeability to water vapor should be as low as possible (Mualimin et al., 2025). The WVTR values obtained in this study are presented in Table 3.

The results showed that increasing the amount of purple yam mucilage added tended to reduce the water vapor permeability of the edible film. WVTR represents the permeability of water vapor under specific relative humidity (RH) conditions and is influenced by several factors such as water activity (aw), relative humidity, temperature, film thickness, plasticizer type and concentration, and the nature of film-forming materials (Fahrullah et al., 2024). The decrease in WVTR values indicates that higher concentrations of purple yam mucilage enhance the film's ability to inhibit water vapor transfer. This occurs because an increased polysaccharide content forms a denser film structure and reduces porosity, thereby hindering water vapor diffusion. A more compact matrix structure results in longer and more difficult diffusion pathways for water vapor.

The incorporation of purple yam mucilage as a film-forming material significantly reduces the water vapor transmission rate (WVTR) of the films. This effect is attributed to the structural characteristics of the biopolymer matrix, in which hydrophobic interactions among non-polar constituents promote the formation of a dense and cohesive network. As a result, the diffusion of water vapor molecules through the film is restricted, leading to improved barrier properties (Fahrullah et al., 2024).

Bourbon et al. (2021) reported that CMC-based films containing free curcumin exhibit reduced water vapor diffusion due to the hydrophobic nature of curcumin, which influences the film matrix structure. Thus, the ratio between hydrophilic and hydrophobic components in the film significantly affects the WVTR. Increased hydrophobicity results in lower water vapor transmission. The water vapor permeability value of 21.94 $g/m^2/day$ indicates that the developed film exhibits moderate to high permeability, which is typical for starch-based edible films. Previous studies have reported that polysaccharide-based films generally show high water vapor permeability due to strong interactions between water molecules and the polymer matrix (Bertuzzi et al., 2007). This phenomenon is mainly attributed to the hydrophilic nature of starch, which facilitates water absorption and diffusion through the film structure. Furthermore, the incorporation of purple yam mucilage, which is rich in hydrocolloids, likely increased the number of hydrophilic groups and enhanced polymer chain mobility, resulting in greater free volume and water vapor transmission. Similar findings have been reported in recent studies highlighting that high WVTR remains a major limitation of polysaccharide-based edible films. Compared to films modified with hydrophobic or reinforcing agents, the obtained film still demonstrates relatively lower barrier properties, indicating that hydrophilic interactions dominate the polymer network (Bertuzzi, 2007; Saidi et al., 2025). This is due to the hydrophilic nature of starch and purple yam mucilage, which readily interact with water, resulting in relatively high water vapor permeability. This characteristic is commonly observed in starch-based edible films.

Transparency

The transparency of edible films can be determined by the amount of light transmitted through the film. Based on analysis of variance, the ratio of water to purple yam mucilage had a significant effect ($p > 0.05$) on the transparency of purple yam starch-based edible films.

As shown in Table 3, purple yam mucilage tends to decrease the transparency of the edible film. This is attributed to the increased total solids and molecular interactions, which enhance light scattering and make it more difficult for light to pass directly through the film. Purple yam mucilage contains protein–mannan compounds and water-soluble polysaccharides, as well as anthocyanin pigments, all of which contribute to the reduction in film transparency.

In general, the addition of various solutions or components to film-forming solutions reduces film transparency, as reflected by increased opacity or decreased light transmittance. For example, Asfaw et al. (2023) reported that the addition of additives caused initially transparent pectin films to become less transparent. Purple yam mucilage-based edible films exhibited color values of L (lightness) = 27.9, a (redness) = 5.2, and b (yellowness) = 20.6. In addition to the materials used, increased film thickness due to higher concentrations of active components also contributes to reduced clarity. The appearance of purple yam starch-based edible films with added purple yam mucilage is shown in Figure 1.

Dick et al. (2015) reported that edible films derived from chia seed mucilage exhibited transparency values at a wavelength of 600 nm ranging from 53.36 to 55.59, while synthetic plastics such as OPP and LDPE showed transparency values of 89.1 and 86.9, respectively. Transparency values are important in determining the UV light absorption capacity of biodegradable films, which is critical for packaging applications. The ability of materials to absorb UV radiation plays a key role in extending the shelf life of fatty foods that are susceptible to oxidative degradation catalyzed by UV exposure. Lower transparency values indicate a greater ability of the edible film to protect products from UV radiation (Shiku et al., 2004). The relatively low transparency of purple yam starch-based edible films with the addition of purple yam mucilage suggests their potential application in protecting products from photo-oxidation caused by UV light. The transparency value of balangu mucilage (*Lallemantia iberica F. & C.M.*) is reported to be 37.60 ± 0.60 %/mm, whereas the transparency of purple yam starch-based edible films with added purple yam mucilage ranges from 8.33 to 16.47 %T/mm. These results indicate that edible films based on purple yam starch with the addition of purple yam mucilage are more effective in preventing UV-induced photo-oxidation compared to films made from balangu mucilage.

Solubility

Film solubility is an important factor in determining the biodegradability of films when used as packaging materials. Depending on the type of product being packaged, films may be required to have either high or low solubility. Solubility is a physical property of edible films that indicates the percentage of dry weight dissolved after immersion in water for 24 hours. The solubility of a film is strongly influenced by the source of the raw materials used in its preparation. Edible films with high solubility are more easily consumable, whereas low solubility is an important requirement for edible films used as food packaging, particularly those in contact with water, as they function to protect food products.

The results of this study show that the addition of purple yam mucilage reduced the solubility of purple yam starch-based edible films in water by up to 33.23%. The solubility values of edible films with added mucilage ranged from 33.23% to 46.37%, whereas previous studies reported a solubility of 84.36% for edible films based solely on purple yam starch. Based on analysis of variance at the 5% level, the ratio of water to purple yam mucilage had a significant effect ($p > 0.05$) on the solubility of starch-based edible films, with higher mucilage concentrations leading to lower solubility values. The utilization of mucilage in edible film production has been widely studied. Beigomi (2017) reported that edible films derived from *Dracocephalum*

moldavica seed mucilage exhibited solubility values ranging from 46% to 54%. Meanwhile, Sadeghi-Varkani (2017) reported that edible films made from balangu seed mucilage showed optimal solubility values between 9.48% and 11.54%. In addition, edible films made from okra mucilage and corn starch demonstrated relatively low solubility (approximately 15%), as reported by Araújo (2018).

Mucilage extracted from *Dioscorea batatas* contains glycoproteins as the main component, with several amino acids exhibiting hydrophobic properties, such as arginine, lysine, histidine, tryptophan, and mannose. Furthermore, a study reported that the mucilage contains amino acids such as alanine, isoleucine, valine, methionine, leucine, phenylalanine, and proline, which are classified as hydrophobic amino acids (Estiasih et al., 2016). These hydrophobic characteristics contribute to the reduced solubility of edible films as the concentration of purple yam mucilage increases. In addition to amino acids, the presence of mannan compounds in the mucilage also contributes to the low solubility of the edible film. During the extraction of mucilage from *Dioscorea batatas* using water, both protein and mannan are soluble; however, when mannan is separated from the mucilage, it becomes insoluble. In edible film production, mucilage containing protein–mannan complexes undergoes heating, which may disrupt the interaction between protein and mannan. The absence of strong interactions between these components reduces the solubility of the edible film in water.

4. Conclusion

The ratio of water to purple yam mucilage had a significant effect on the characteristics of purple yam starch-based edible films. The incorporation of purple yam mucilage was shown to enhance mechanical strength, while reducing the water vapor transmission rate (WVTR) and the solubility of the films in water. The optimal ratio of water to purple yam mucilage for producing edible films with the best overall characteristics was 1:1.25. At this ratio, the film exhibited a thickness of 0.14 mm, a compressive strength of 3.73×10^{-4} MPa, a water vapor permeability of 21.94 g/m²/day, a transparency value of 8.33 %T/mm, and a solubility of 33.23%. These results indicate that the incorporation of purple yam mucilage improves the mechanical and barrier properties of purple yam starch-based edible films.

For future research, it is recommended that the hydrocolloid compounds present in purple yam mucilage be directly utilized as the primary material for edible film production without the addition of starch. This approach is expected to provide deeper insights into the potential of purple yam mucilage as a natural film-forming agent and enable a more comprehensive evaluation of the physical, mechanical, and functional properties of the resulting edible films.

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