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Research Article

Application of Edible Film from Mung Bean Starch with the Addition of Glycerol Plasticizer on Broccoli

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ABSTRACT

The research on making edible film from mung bean starch with glycerol plasticizer as broccoli packaging aims to determine the characteristics of the edible film from mung bean starch with glycerol addition and its effect on broccoli weight loss. This study involved three stages, which include producing mung bean starch, making and characterizing the edible film, and applying the edible film on broccoli. The glycerol concentrations added were 25.2%, 31.5%, and 37.8% of the starch weight used. The edible film characteristics tested were thickness, tensile strength, elongation, Young's modulus, water vapor transmission rate (WVTR), and ash content. The application test on broccoli lasted 9 days. Results showed that thickness, tensile strength, and ash content met edible film standards, while elongation, Young's modulus, and WVTR did not meet applicable standards. Broccoli coated with the edible film had lower weight loss compared to the control.

Keywords: Broccoli, Edible film, Glycerol, Mung bean starch

1. Introduction

Broccoli (*Brassica oleracea* var. Italica) is a widely consumed vegetable due to its high nutritional value. The nutritional content of broccoli includes water, carbohydrates, calcium, iron, vitamin A, and fiber [1]. Broccoli has a relatively short shelf life because of its high water content and its florets, which are composed of young tissues that are highly susceptible to damage. Additionally, the relatively high respiration rate of broccoli causes it to wilt quickly and lose weight.

Packaging is one method that can be used to slow the rate of quality degradation in broccoli. Synthetic polymer plastic packaging is widely used for food wrapping due to its low cost and easy availability. However, this type of packaging is non-biodegradable, leading to environmental pollution [2]. Therefore, an alternative, more environmentally friendly packaging is needed to replace it. One such alternative that is currently being developed is edible film [3].

Edible film functions as a barrier to mass transfer, such as moisture, oxygen, and dissolved substances in food [4]. Edible film is made from natural materials. The main ingredients for making edible film are lipids, hydrocolloids, and composites. The natural raw materials for edible film production are abundant in Indonesia. One of the natural materials that can be used as a raw material for edible film is starch [5]. Starch is a polysaccharide classified as a hydrocolloid, composed of two types of polymers: branched amylopectin and linear D-glucan amylose chains [6]. According to research by [7], edible film made from polysaccharides has several advantages, including selectivity towards oxygen (O_2) and carbon dioxide (CO_2), non-greasy appearance, and low calorie content.

One source of starch is green beans (Vigna radiata) which are abundant in Indonesia. [8] stated that national green bean production in 2019 reached 296,928 tons per hectare with a total planting area of 254,717 hectares. However, edible films made from starch have a drawback in that they are less elastic and easily brittle. Glycerol ($C_3H_8O_3$) is a hydrophilic plasticizer that is water-soluble, polar, and has a high boiling point [9]. The use of plasticizers can improve the physical and mechanical properties of edible films. Therefore, when applied to food products, it is expected to extend their shelf life.

The use of mung bean starch as a base material for edible film production has previously been studied by [6]. The study aimed to examine the effect of varying concentrations of CMC (Carboxy Methyl Cellulose) as a stabilizer and glycerol as a plasticizer on the characteristics of mung bean starch-based edible films. The concentrations of CMC and glycerol used were 1%, 2%, and 3%, respectively. Based on the scoring method, the results showed that edible films with CMC 1% and glycerol 2% (sample 1); CMC 1% and glycerol 3% (sample 2); and CMC 2% and glycerol 2% (sample 3) exhibited the best organoleptic responses (texture, appearance, color, and chemical response). The selected samples were then subjected to mechanical and physical response tests, including tensile strength, elongation, and water vapor transmission rate. This research aims to examine the potential use of mung bean starch and the effect of plasticizer addition on the characteristics of mung bean starch-based edible films, as well as their application in reducing the physical weight loss of broccoli.

2. Materials and Methods

2.1 Materials

The materials used in this research include mung beans, technical glycerol (85%) from Chem-mix Pratama, pure acetic acid Merck (100%), distilled water from Jaya Santosa, silica gel, and salt. The equipment utilized includes a Fourier Transform Infrared spectrophotometer model IR Prestige-21 Shimadzu (FTIR), manual micrometer, and Universal Testing Machine.

2.2 Mung Bean Starch Extraction

The process of producing mung bean starch is a modification of the studies by [10] and [11], with adjustments to the base material used for edible film production. Dried mung beans that have undergone peeling and washing are blended until smooth. The mung bean powder is then extracted using distilled water at a ratio of 1:2 (powder to water). The extraction results are allowed to settle for 24 hours. The obtained sediment is dried in an oven for 2 hours at 50°C. The resulting dry starch sediment is then sifted. Subsequently, the mung bean powder is analyzed for its functional groups using FTIR, and a starch content test is performed.

2.3 Preparation and Characterization of Edible Film

The preparation of the edible film refers to [11] research. A total of 3.5 grams of mung bean starch is dissolved in 25 mL of distilled water, and 12.5 mL of 1% acetic acid is added. The mixture is stirred and heated for 25 minutes. Next, glycerol plasticizer is added to the mung bean starch solution at varying concentrations of 25.2%, 31.5%, and 37.8% of the starch weight used. The mixture is stirred again until homogeneous while continuing to heat for 15 minutes until it reaches the gelatinization temperature of 70°C. The solution is cooled at room temperature while stirring for 20 minutes and then allowed to sit for 5 minutes. The solution is transferred to acrylic molds and spread evenly using a spatula. It is dried in an oven at 55°C for 50 minutes. The resulting edible film layer is then cooled and stored at room temperature for 24 hours. The produced edible film is analyzed for its functional groups using FTIR, followed by characteristic tests, including thickness, tensile strength, elongation, Young's modulus, water vapor transmission rate (WVTR), and ash content.

2.4 Application of Edible Film on Broccoli

The cleaned broccoli is weighed to obtain the initial weight. The mung bean starch edible film is cut into 5x5 cm pieces and applied to the broccoli, ensuring that the entire surface is perfectly covered. The edible film is then secured in place with adhesive tape. Weight measurements are taken on days 1, 3, 6, and 9 to conduct weight loss tests. The results are compared with the control broccoli, which is not coated with the edible film.

3. Result and Discussion

3.1 Mung Bean Starch

The mung bean starch undergoes functional group analysis and testing for pure starch content. The purpose of the FTIR functional group analysis is to confirm that the extracted powder is indeed starch. The FTIR analysis results of the starch powder are shown in **Figure 1**. The pure starch content in the mung bean powder is relatively high, at 83.68%, indicating that it can be used as a raw material for producing edible films. The FTIR analysis of starch is performed in the mid-IR region (4000-400 cm^{-1}) to observe the functional groups of the molecular components that make up mung bean starch [12].

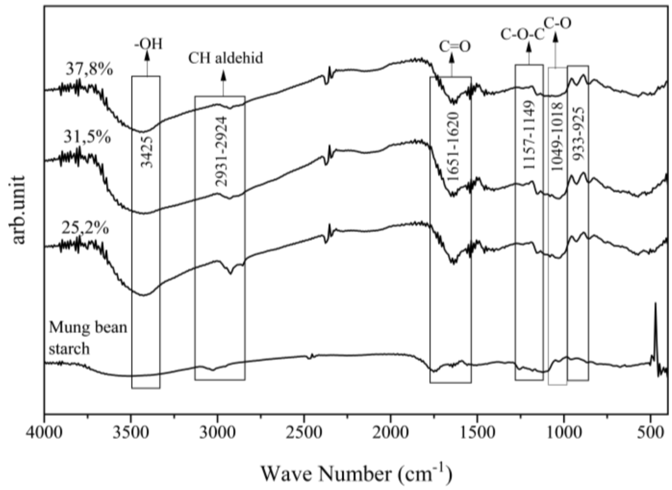

Figure 1. Spectra of Mung Bean Starch and Edible Film

Based on the starch spectrum in **Figure 1**, there are five absorption regions corresponding to the functional groups in mung bean starch, as stated in the literature in **Table 1**, namely -OH, aldehyde CH, C=O, C-O-C, and C-O absorption bands. These functional groups are the main components of amylose and amylopectin. The sharp band with weak intensity at a wavenumber of approximately 933 cm^{-1} is a characteristic absorption peak for the α-1,4 glycosidic bond present in the amylose and amylopectin molecules that make up the starch [13]. The comparison of the absorption of mung bean starch from the literature with the absorption of mung bean starch and edible film in this study is shown in **Table 1**.

Table 1. Comparison of Mung Bean Starch Absorption in Literature with Absorption in Mung Bean Starch Research and Edible Film at 25,2, 31,5 and 37,8% Concentrations [14]

Literature (cm^{-1})	Mung Bean Starch Research	25,2 %	31,5 %	37,8 %
OH (3253)	3425	3425	3425	3425
CH Aldehyde (2933)	2924	2924	2931	2924
C=O (1653)	1651	1620	1620	1620
C-O-C (1158)	1157	1157	1149	1157
C-O (995)	1018	1018	1018	1049

3.2 Preparation and Characterization of Edible Film

The gelatinization process occurs when starch granules absorb water, leading to swelling and the loss of birefringence and crystallinity at temperatures of 58-70°C [15]. Acetic acid acts as a catalyst that accelerates the cleavage of glycosidic bonds in starch, speeding up the hydrolysis reaction, which facilitates easier bonding with glycerol. Protons (H+) from the hydronium ions produced from the reaction of acetic acid with water will attack the oxygen atom in the α-(1-4)-D-glycosidic bond of the starch chain, causing the glycosidic bond between two glucose units to weaken and become unstable, subsequently breaking down into glucose. The hydrolyzed starch then forms an edible film solution [16]. Glycerol (25.2%, 31.5%, 37.8%) is added as a plasticizer to enhance the film's elasticity by forming hydrogen bonds between the hydroxyl groups of glycerol and starch.

The edible films produced from a mixture of mung bean starch, acetic acid, and glycerol yield spectra with absorption peaks that closely resemble those of the starch spectrum. This indicates that the three variations of edible films are the result of a physical blending process, as no new functional groups are formed [17]. All three edible films exhibit sharp absorption peaks with strong intensity at a wavenumber of 3425 cm^{-1}, indicating the presence of hydrogen bonds. This hydrogen bonding signifies that the edible films have been successfully created.

The average results of the edible film characteristic tests are shown in **Table 2**. The addition of glycerol can increase the thickness by enhancing the viscosity of the solution. However, the glycerol variation of 31.5% resulted in a lower thickness compared to 25.2%. This may be due to the uneven distribution of the edible film solution in the mold and the amount of edible film solution left in the glass during pouring into the mold, which reduces the volume of the solution and consequently decreases the thickness. All variations of edible film thickness meet the JIS standards with a maximum value of 0.25 mm.

Table 2. Results of Edible Film Characterization Tests

Standard Edible film	Concentrations of Glycerol		
	20%	25%	30%
Thickness Max 0,25 mm (JIS)	0,1955	0,147	0,2085
Tensile strength Min 0,39 Mpa (JIS)	1,4442	1,0739	0,8440
Elongation >50% (JIS)	9,8382	10,4821	9,4261
Modulus Young Min 0,35 Mpa (JIS)	0,1469	0,1036	0,0898
WVTR Max 7/m2/jam (JIS)	14,1852	16,6296	19,3333
Ash content 5% (SNI)	2,5740	2,3263	2,1320

Based on **Table 2**, the tensile strength of the edible film decreases as the concentration of glycerol added increases. As the concentration of glycerol in the edible film solution increases, the amount of amylose binding with glycerol also increases, weakening the hydrogen bonds between the starch chains and resulting in a decrease in the tensile strength of the produced edible film. All variations of the edible film have met the specified standards.

The ability of glycerol as a plasticizer to reduce hydrogen bonding in the polymer chains of the edible film matrix results in a looser and more elastic film structure. However, adding plasticizers in excessively high concentrations can break hydrogen bonds and weaken the chemical structure of the film, leading to a decrease in the elasticity of the edible film and making it more prone to breaking [18].

The Young's modulus value indicates the stiffness level of an edible film and is derived from the comparison of stress (tensile strength) and strain (percentage elongation). The Young's modulus of the edible film is directly proportional to its tensile strength. According to JIS, the minimum Young's modulus value for edible films is 0.35 MPa. Therefore, the three variations of the edible film produced do not meet the standards for use as packaging.

The tensile testing of the edible film records the force and elongation to create a graph of their relationship until the film breaks. Based on **Figures 2, 3, and 4**, all variations of the edible film only exhibit an elastic region and lack a plastic region. The high concentration of added glycerol makes the edible film more elastic and brittle. Therefore, a yield point is not observed, and the film breaks at the maximum force. The elongation of the film continues to increase as the applied force increases. Thus, when the tensile force is removed, the film tends to return to its original shape.

The water vapor transmission rate is an important parameter in testing edible films, as it indicates the film's permeability to water vapor. The addition of glycerol weakens the interactions between molecules, reducing molecular density and creating empty spaces in the film matrix. This results in the film being more permeable to water vapor [3]. None of the three variations of the edible film meet the applicable standards.

The ash content test indicates the safety of mung bean starch edible films for consumption. The gravimetric method is used with combustion at a temperature of 550°C, which oxidizes organic matter and leaves inorganic ash. An increase in glycerol concentration leads to a decrease in ash content due to the increased water content, which can dissolve minerals in the edible film [19]. The ash content of the produced edible film meets the applicable standards.

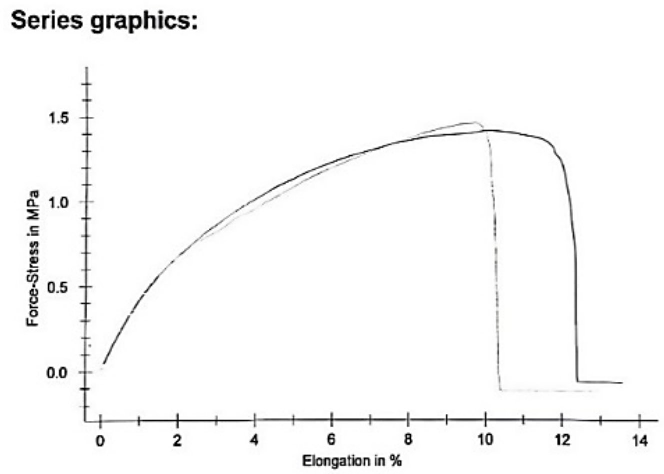

Figure 2. Edible Film Stress-Strain Graph 25,2%

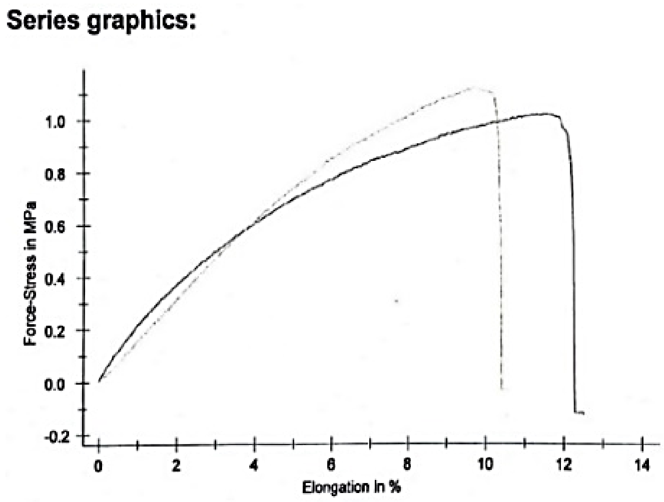

Figure 3. Edible Film Stress-Strain Graph 31.5%

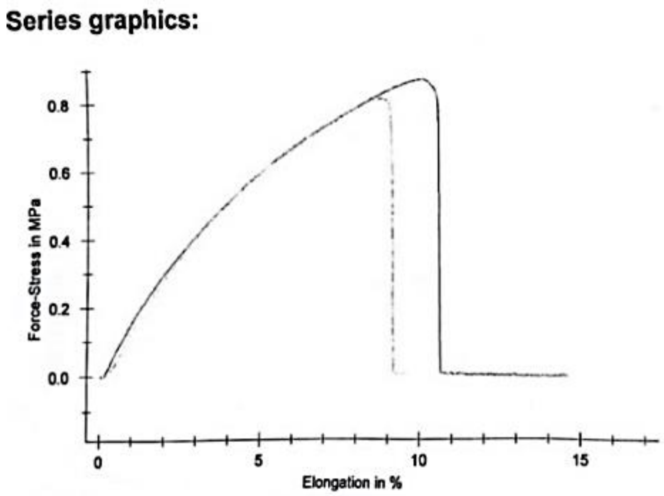

Figure 4. Edible Film Stress-Strain Graph 37,8%

3.3 Application of Edible Film on Broccoli

The application of edible film on broccoli is one effort to maintain its quality after harvest. Weight loss was measured to determine the effect of edible film packaging on the quality of broccoli during a 9-day storage period. Weight loss measurements were taken on the first, third, sixth, and ninth days of storage using an analytical balance. The measurement results shown in **Table 3**, indicate that all treatments experienced a significant decrease in weight on the first and third days, but the weight loss on the sixth and ninth days was not as significant. Based on the observations on the first day, the control samples experienced the greatest weight loss. The edible film layer was able to reduce the rate of weight loss in broccoli. The weight loss of broccoli increased with the increasing concentration of glycerol.

Edible films function as barriers to gases and water vapor, thereby reducing the level of physiological damage during postharvest. If the matrix structure of the film is dense and can completely seal the packaged product, it can minimize water evaporation. The density of the film matrix can be influenced by the addition of plasticizers. The addition of glycerol can alter the internal structure of the starch network, causing the polymer chains to move, increasing the flexibility of the film, and making the film matrix less dense [20]. Gaps in the film matrix facilitate the entry of oxygen from the environment, leading to an increased respiration rate in broccoli.

Table 3. Broccoli Weight Loss Value

Sample	Day 1	Day 3	Day 6	Day 9
Control	54,7261	86,5254	89,1942	89,9706
Glycerol 25,2%	23,6009	47,1250	52,5743	54,5061
Glycerol 31,5%	28,2721	52,4549	54,0383	56,2677
Glycerol 37,8%	32,0648	54,9068	55,2508	60,1450

Based on **Table 3**, the weight loss of broccoli coated with edible film containing 37.8% glycerol on the first day was 32.0648%, while the weight loss of broccoli coated with edible film containing 31.5% and 25.2% glycerol was 28.2721% and 23.6009%, respectively. The weight loss showed a significant increase on the third day. The control sample's weight loss was 86.5254%. Broccoli samples coated with edible films containing 37.8%, 31.5%, and 25.2% glycerol exhibited weight losses of 54.9068%, 52.4549%, and 47.1250%, respectively. On the sixth day, the control sample's weight loss was 89.1942%, while broccoli samples coated with edible films containing 37.8%, 31.5%, and 25.2% glycerol showed weight losses of 55.2508%, 54.0383%, and 52.5743%. The control sample continued to exhibit the highest weight loss on the ninth day of observation, reaching 89.9706%. The weight loss percentages for broccoli samples coated with edible films containing 37.8%, 31.5%, and 25.2% glycerol were 60.1450%, 56.2677%, and 54.5061%, respectively.

Broccoli will undergo transpiration and respiration processes during the storage period. This leads to the breakdown of complex compounds contained within the cells, such as carbohydrates, into simpler molecules like carbon dioxide (CO_2) and water (H_2O), which easily evaporate. The evaporation of these molecules results in weight loss in broccoli. The transpiration process causes a loss of water content in broccoli, which is one of the main causes of quality decline. As a result, the mass of the broccoli decreases, making it appear wilted, and its nutritional value also diminishes.

4. Conclusion

The increase in glycerol concentration in the edible film tends to enhance thickness, elongation, and water vapor transmission rate (WVTR), while decreasing tensile strength, Young's modulus, and ash content of the edible film. The thickness, tensile strength, and ash content parameters have met the standards for edible films, whereas the elongation, Young's modulus, and WVTR parameters have not yet met the standards. The application of the edible film as a packaging for broccoli has proven to be quite effective in reducing weight loss in broccoli. Based on the observations, the weight loss value of broccoli increases with the addition of glycerol concentration in the edible film.

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