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Characterization of Cassava Starch–Based *Edible Film* (*Manihot esculenta*) and Seaweed Na-Alginate with Variations in Drying Time

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ABSTRACT

Edible films are biodegradable and consumable packaging materials that protect food products from environmental influences. This study aimed to produce and characterize cassava starch–based edible films with sodium alginate from seaweed, glycerol as a plasticizer, and garlic extract as an antibacterial agent using the solvent casting method. The research variables included cassava starch mass (4, 5, and 6 g) and drying time (4, 9, 14, 19, and 24 hours). Film thickness, tensile strength, elongation, moisture content, solubility, and microbiological properties were analyzed. Results showed that starch mass and drying time significantly affected the physical and mechanical properties of the films. The optimum drying time was 14 hours, at which all samples met the Indonesian National Standard (SNI) for moisture content (10–<16%). The best performance was obtained with 6 g starch, producing films with a tensile strength of 5.034 MPa, elongation of 13.48%, and low microbial counts (4–9 cells/100 mL) with negative *Escherichia coli*, complying with SNI 2897:2008. The addition of garlic extract contributed to the films' antimicrobial properties. Overall, the formulation demonstrates a balanced combination of mechanical, physical, and microbiological characteristics, providing a practical foundation for developing biodegradable cassava starch–based edible films for food packaging applications.

INTRODUCTION

Edible films are thin, edible layers that function to protect food from environmental influences and are generally made from natural materials such as polysaccharides, proteins, or lipids. Cassava starch (*Manihot esculenta*) is considered a promising raw material due to its high starch content of up to 90%, wide availability, low cost, and biodegradability. Data from the Indonesian Central Bureau of Statistics (BPS) show that cassava production increased from 15.73 million tons in 2021 to 16.76 million tons in 2023, which is equivalent to approximately 15 million tons of starch. This condition provides Indonesia with a comparative advantage in the development of starch-based food packaging (Wendi Pradana et al., 2017). However, edible films made solely from starch still exhibit several limitations, including low mechanical strength and poor water vapor resistance. The addition of alginate, a polysaccharide derived from seaweed that is capable of forming gels and exhibits flexible properties, has been shown to improve film characteristics, particularly tensile strength and moisture stability (Ngadi Parida et al., 2019).

Previous studies have reported the preparation of edible films from cassava starch. (Yudha et al., 2024) investigated the production of edible films using garlic extract (*Allium sativum* L.) as an antibacterial agent. Using cassava starch concentrations of 3 g, 4 g, and 5 g, and garlic extract concentrations of 0%, 1%, 2%, and 3%, the best inhibition zone against *Escherichia coli* was obtained at 5% cassava starch and 3% garlic extract, yielding an inhibition zone of 6.55 mm (moderate category). Meanwhile, the best inhibition zone against *Staphylococcus aureus* was also achieved at 5% cassava starch and 3% garlic extract, with a value of 13.52 mm (strong category). (Dewi et al., 2023) studied the production of cassava starch–based edible films with the addition of bilimbi leaf extract and glycerol as a plasticizer. The results showed that a formulation containing 4% cassava starch, 1.75% glycerol, and 0.5% bilimbi leaf extract produced the best physical and mechanical characteristics, with a solubility value of 37.95% and a water vapor transmission rate of 0.815 $g/m^2 \cdot h$. Furthermore, (Rohmah et al., 2021) investigated edible films based on sodium alginate and sago starch with glycerol as a plasticizer. The optimal formulation, with a sodium alginate to sago starch ratio of 0.5:2.5 and 0.2 mL of glycerol, resulted in a film thickness of 0.03 mm, tensile strength of 15.33 MPa, elongation at break of 67.1%, and a water vapor transmission rate of 6 $g/m^2 \cdot day$.

The novelty of this study lies in the development of cassava starch–based edible films incorporating sodium alginate derived from seaweed (*Laminaria digitata*), glycerol as a plasticizer, and garlic extract as an antibacterial agent, formulated using the solvent casting method. This study aims to determine the effect of variations in the mass of cassava starch and the addition of sodium alginate on the physical and mechanical quality of the edible film produced and to determine the effect of variations in drying time on the physical and mechanical quality of the edible film.

RESEARCH METHODS

Materials and Equipment

The materials used in this study were cassava starch, sodium alginate, glycerol, garlic extract, and aquadest. The equipment used in this study included a stove or hot plate, magnetic stirrer, knife, beakers, grater, 80-mesh sieve, acrylic mold (25 × 25 cm), oven, and storage containers.

Research Design

This research was conducted at the Chemical Engineering Microbiology Laboratory, Faculty of Industrial Technology, National Institute of Technology Malang. This research uses the solvent casting method which aims to produce thin films so as to determine the effect of variations in cassava starch mass and the addition of sodium alginate as well as drying time on physical and mechanical quality. This method was chosen because it controls certain variables that can influence the results. The variables in this research consist of two variables, namely the control variable and the changed variable. Control variables include 0,5 gram sodium alginate, 100 mL aquadest, 1.75% w/v glycerol, 3% w/v garlic extract, 60°C drying temperature. The variables that were changed were, cassava starch mass 4, 5, 6 grams and drying time, namely 4, 9, 14, 19, 24 hours.

Formulation of Edible Film

Cassava starch (4, 5, or 6 g) and sodium alginate (0.5 g) were dissolved in 100 mL of aquadest and stirred until a homogeneous solution was obtained. The solution was heated to a temperature of 70 °C while continuously stirring to induce gelatinization. Then added glycerol (1.75% w/v) as a plasticizer and garlic extract (3% w/v) as an antibacterial agent. After stirring gently, the solution was cooled to room temperature, cast on an acrylic mold (25 x 25 cm) with a constant volume (6.25 mL). Then dried in an oven at 60 °C for 4, 9, 14, 19, and 24 hours to form edible film. The dried film was conditioned at room temperature before physical and mechanical testing. Tests carried out include thickness tests, water content, tensile strength, elongation, solubility and microbiological supporting tests.

Data Analysis

The main analysis used was water content (gravimetric method) for 15 samples. Furthermore, from the test results the best samples are taken according to SNI standards. The best sample results will be subjected to further testing, namely thickness tests (digital micrometer), tensile strength, elongation (tensile strength instrument), solubility (gravimetric method) and microbiological supporting tests (MPN method).

RESULTS AND DISCUSSION

Figure 1. Cassava Starch Edible Film

Figure 1 shows the edible film samples based on cassava starch with the addition of sodium alginate derived from seaweed produced during the research process. The resulting edible films exhibited relatively smooth surfaces, good transparency, and were not easily torn, indicating that the solvent casting method was successfully applied. The drying process was conducted at 60°C with various drying times to obtain optimal film characteristics.

Analysis of Moisture Content

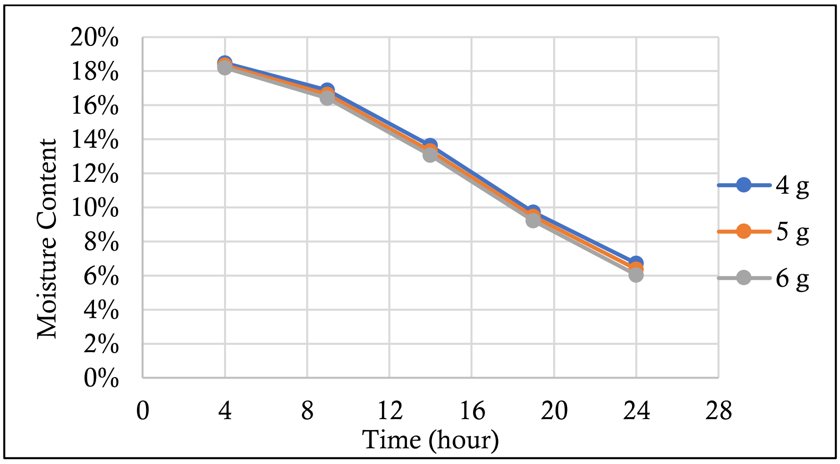

Figure 2. Moisture Content Test Analysis Graph

The analysis showed that increasing the drying time significantly reduced the moisture content of the edible films across all cassava starch mass variations. Longer drying times led to lower moisture content due to increased evaporation of free water during oven drying. According to SNI 06-3735-1995, the permissible moisture content for edible films ranges from 10 to 16%. In this study, at a drying temperature of 60 °C, the moisture content meeting the standard was obtained at a drying time of 14 hours, with values of 13.06% for 4 g starch, 13.31% for 5 g starch, and 13.64% for 6 g starch. Quantitatively, increasing the cassava starch mass raised the moisture content by 0.25% and 0.58% at 14 hours of drying, indicating a positive correlation between starch mass and film moisture content.

According to Deden & Rahim, (2020) and Tanjung et al., (2021), low moisture content is critical as it directly affects the mechanical stability, shelf life, and microbiological resistance of edible films. These results are consistent with the findings of HMSaleh et al., (2017) and Wahab (2023), who reported that drying times between 12 and 18 hours at 60

°C produced edible films with optimal moisture content. Excessive drying beyond 18 hours tends to cause excessive moisture loss, resulting in stiffer films prone to brittleness (Nury et al., 2023).

The best results in this study were obtained from samples dried for 14 hours with cassava starch masses of 4, 5, and 6 g, which were therefore selected for further testing.

Analysis of Thickness

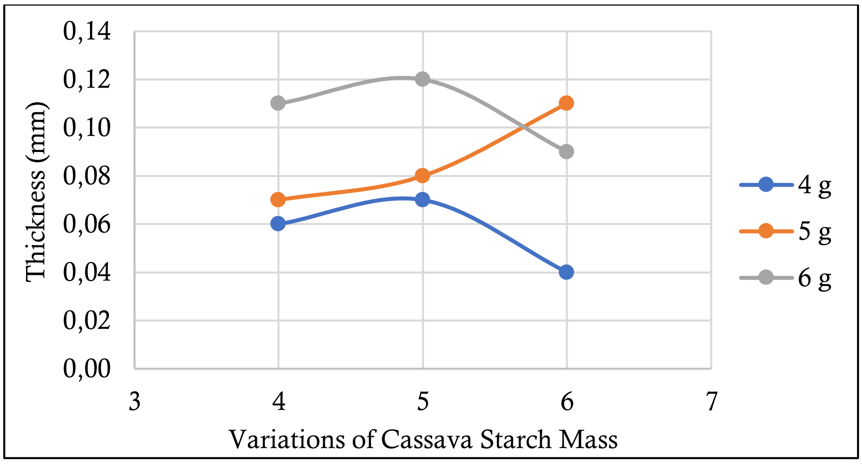

Figure 3. Thickness Test Analysis Graph

The thickness of the edible films increased with increasing cassava starch content at all drying time variations. The formulation containing 6 g of cassava starch produced the thickest films compared to those containing 4 g and 5 g of starch. This phenomenon is attributed to the higher total solid content in the film-forming solution, which resulted in a larger volume of the polymer matrix formed during film casting.

Preliminary moisture content analysis at different drying times indicated that all films reached a stable moisture content of approximately 16% after 14 hours of drying. Therefore, a drying time of 14 hours was selected as the optimum condition for subsequent thickness evaluation to ensure comparable moisture levels among samples.

According to (Dewi et al., 2023), increasing starch concentration enhances the number of interacting polymer chains that form the film structure, leading to an increase in film thickness. Furthermore, the addition of Na-alginate contributes to the reinforcement of the film structure through the formation of a denser gel network, which improves the structural integrity of the edible film (Syarifuddin et al., 2025).

All measured film thickness values were within the range of 0.02–0.10 mm, complying with the ASTM D6988 standard. Therefore, the produced edible films are considered suitable for application as food packaging materials.

Analysis of Tensile Strength

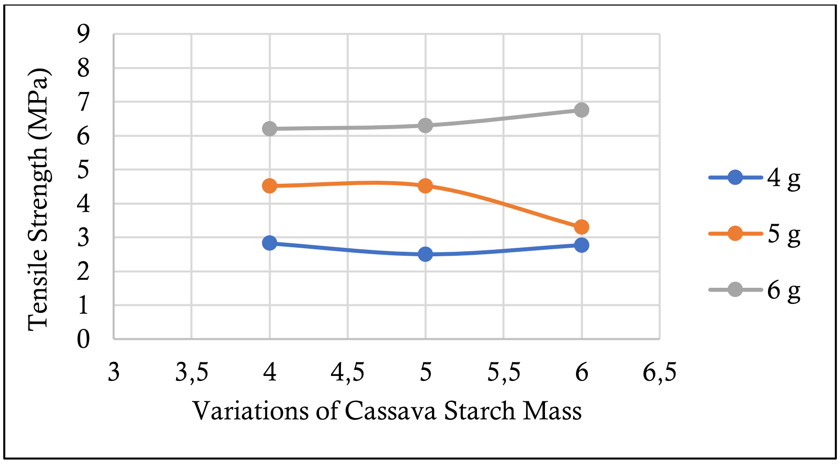

Figure 4. Tensile Strength Test Analysis Graph

Based on Figure 4, the results indicate that the highest tensile strength was obtained from the formulation containing 6 g of cassava starch with a drying time of 14 hours, reaching a value of 5.034 MPa. In contrast, the lowest tensile strength was observed for the formulation containing 4 g of cassava starch at the same drying time of 14 hours, with a tensile strength value of 2.1104 MPa. This result is consistent with (Dewi et al., 2023), who reported that increasing starch concentration leads to the formation of a denser polymer matrix, thereby increasing the force required to break the film.

The lower tensile strength compared to the literature can be attributed to differences in polymer–plasticizer ratios and formulation conditions. Previous studies reported higher tensile strength when higher polymer concentrations or lower plasticizer contents were applied (Rohmah et al., 2021). In this study, the glycerol concentration was kept constant, allowing the plasticizing effect to remain influential on the mechanical properties of the film.

From a molecular perspective, increasing cassava starch mass enhances the number of polymer chains rich in hydroxyl (–OH) groups, which promote intermolecular hydrogen bonding and result in a denser and more rigid film matrix (Permana et al., 2025). At higher starch mass, the reinforcing effect of the polymer network outweighs the softening effect of glycerol, leading to increased tensile strength. This behavior is consistent with the findings of Sanyang et al. (2016) and HMSaleh et al. (2017).

Analysis of Elongation

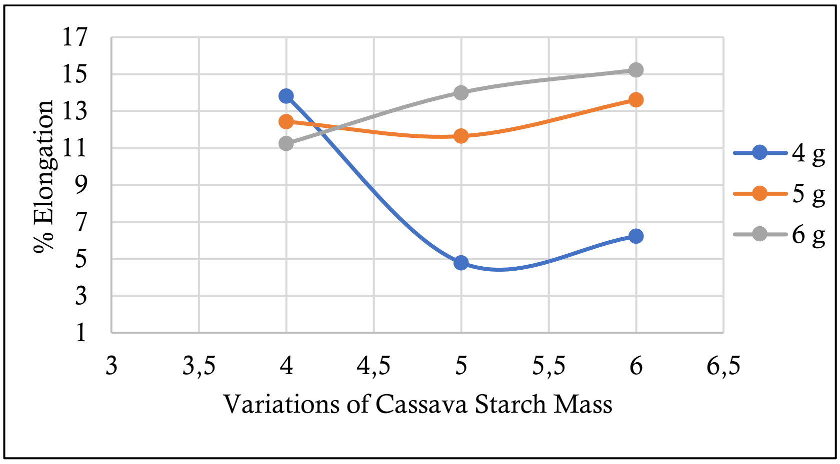

Figure 5. Elongation Test Analysis Graph

Based on Figure 5 shows that the highest elongation value was obtained for the formulation containing 6 g of cassava starch with a drying time of 14 hours, reaching 13.488%. In contrast, the lowest elongation value was observed for the formulation containing 4 g of cassava starch at the same drying time of 14 hours, with an elongation value of 8.277%.

Although the maximum elongation value remains below the ASTM standard range (20–80%), the observed trend is consistent with the typical mechanical behavior of starch-based edible films. The relatively low elongation values are closely associated with the increase in tensile strength observed at higher starch content. In agreement with the findings of Rohmah et al. (2021) an increase in tensile strength is generally accompanied by a reduction in elongation due to the formation of a denser and more rigid polymer matrix. This behavior indicates an inverse relationship between mechanical strength and film elasticity (Polnaya et al., 2016).

From a molecular mechanism perspective, increasing starch mass enhances the number of polymer chains rich in hydroxyl (–OH) groups, which strengthens intermolecular hydrogen bonding and increases the density of the polymer network. This compact structure restricts polymer chain mobility when subjected to tensile stress, thereby reducing plastic deformation and elongation. In addition, maintaining a constant glycerol concentration while increasing starch content leads to a lower plasticizer-to-polymer ratio, resulting in reduced plasticizing effectiveness (Sanyang et al., 2016).

According to Murni et al. (2013), the balance between tensile strength and elongation is strongly influenced by the type and concentration of plasticizer, as well as the biopolymer ratio in film formulations. In this study, increasing cassava starch content as a natural polymer intensified intermolecular interactions and produced a more compact and rigid film matrix. Similar decreasing elongation trends with increasing starch concentration have been reported by Wahab (2023) and Rizkyati and Winarti (2022).

Overall, the relatively low elongation values observed in this study can be attributed not only to increased starch concentration and film thickness, but also to reduced plasticizer effectiveness and the dominance of a rigid polymer matrix resulting from strengthened intermolecular interactions.

Analysis of Solubility

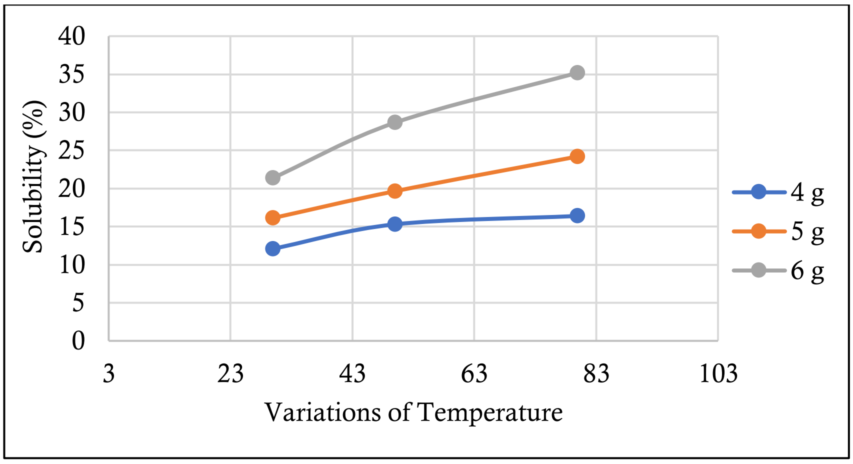

Figure 6. Solubility Test Analysis Graph

Based on Figure 6, cassava starch mass and temperature had a highly significant effect on the solubility of the edible films. At 30 °C, solubility increased from 12.10% for films containing 4 g starch to 16.13% and 21.40% for those containing 5 g and 6 g starch, respectively, representing an increase of approximately 77% from the lowest to the highest starch content. This confirms that starch mass was the dominant factor governing film solubility.

The increase in solubility with higher starch content is attributed to the hydrophilic nature of cassava starch, which contains abundant hydroxyl (–OH) groups that enhance water–polymer interactions and facilitate water penetration into the film matrix. The solubility values obtained are consistent with those reported for glycerol-plasticized starch-based films in previous studies (Haryani et al., 2022; Mojo-Quisani et al., 2024).

Temperature exerted a strong influence on solubility, with the maximum value of 35.21% observed at 80 °C, nearly three times higher than that at 30 °C. Elevated temperature increases water molecule kinetic energy, weakens intermolecular hydrogen bonding, and promotes partial starch gelatinization, thereby accelerating film dissolution (Choque-Quispe et al., 2021).

From a molecular perspective, increasing starch mass at a constant glycerol concentration reduces the plasticizer-to-polymer ratio, forming a denser matrix at low temperatures but one that becomes readily disrupted at higher temperatures. Overall, the solubility values ranged from approximately 10% to 40%, complying with the modified ASTM E96 standard and indicating suitability for edible film applications (Distantina et al., 2018).

Analysis of Most Probable Number

Table 1. Most Probable Number Test Analysis Results

Number of Positive Tubes	Cassava Starch Mass		
	4 gr	5 gr	6 gr
10^{-5}	1	1	2
10^{-6}	0	0	0
10^{-7}	0	0	0

Microbiological testing was conducted as a supporting assessment to ensure that the produced edible films are safe for consumption, particularly with regard to potential microbial contamination. According to SNI 2897:2008, the maximum allowable coliform count in food products is <20 cells/100 mL.

In this study, the microbiological quality of the edible films was evaluated using the *Most Probable Number* (MPN) method for coliform bacteria on the three best samples obtained at a drying time of 14 hours. For films prepared with cassava starch masses of 4 g and 5 g, the confirmation test showed a positive tube combination of 1–0–0, corresponding to a coliform count of 4 cells/100 mL. Meanwhile, the film with a starch mass of 6 g showed a positive tube combination of 2–0–0, corresponding to 9 cells/100 mL based on the MPN index table.

The low coliform counts were attributed to the addition of garlic extract, which contains allicin, a bioactive compound with antibacterial and antifungal properties. According to Yudha et al., (2024), garlic extract is effective against both Gram-positive and Gram-negative bacteria, and a concentration of 3% has been reported as the optimal level for application in edible films. This concentration was adopted in the present study. Microscopic observations after the confirmation test showed negative results for *Escherichia coli*. These results further confirm that the incorporation of garlic extract effectively inhibited microbial growth in the edible films, thereby enhancing their microbiological safety.

CONCLUSION

This study confirms that cassava starch mass and drying time significantly influence the physical, mechanical, and functional properties of cassava starch–sodium alginate edible films. A drying time of 14 hours was optimal, producing films with moisture content below 16% (SNI 06-3735-1995), while longer drying times caused brittleness. Increasing starch mass increased film thickness and tensile strength, with the highest tensile strength (5.034 MPa) obtained at 6 g starch and 14 hours, but reduced elongation, indicating greater stiffness. Film solubility increased with starch mass and temperature due to starch hydrophilicity and met the modified ASTM E96 standard. Overall, the formulation containing 6 g cassava starch and 14 hours of drying exhibited the most balanced properties and shows potential as biodegradable food packaging. Future studies should focus on formulation optimization and application testing to support industrial-scale implementation.

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