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Fabrication and Characterization of Environmentally Friendly Bioplastic Film Based on Chitosan from Cassava Peel Starch

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Abstract

Bioplastics are renewable materials capable of natural degradation and can be synthesized using bio-organic compounds such as cellulose, chitosan, carboxymethyl cellulose (CMC), and glycerol. Cassava peels, an agricultural byproduct, are a rich source of starch and cellulose, making them a promising raw material for bioplastic production. This study aims to fabricate and characterize chitosan-based bioplastic films using cassava peel starch, with a focus on optimizing their mechanical and biodegradation properties. Bioplastic films were prepared by combining cassava peel starch, chitosan, CMC, and glycerol, with chitosan concentrations varied at 45% and 75%. The films were evaluated for surface morphology using Scanning Electron Microscopy (SEM), tensile strength, elongation at break, water absorption capacity, and biodegradability. SEM analysis revealed that chitosan concentration significantly influenced the film morphology, which in turn affected mechanical and swelling properties. The highest tensile strength (0.07 MPa) and elongation (22.5%) were observed in films with 75% chitosan. Water absorption peaked at 93.32% for the same formulation. Biodegradability tests showed complete degradation (100%) within 12 days for films with 45% chitosan. These findings demonstrate that cassava peel starch combined with chitosan can produce biodegradable films with tunable properties, offering a sustainable alternative for packaging and other applications.

Keywords: biodegradable bioplastics; chitosan; cassava peel starch; sustainable packaging; solution casting method; environmental waste valorization

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INTRODUCTION

Conventional petroleum-based plastics have become indispensable in modern industries due to their durability, lightweight nature, water resistance, and low production cost (Kumari et al., 2023). However, their non-biodegradable nature poses significant environmental challenges. The accumulation of plastic waste contributes to pollution, disrupts ecosystems, and exacerbates urban issues such as flooding and land degradation (Fayshal, 2024). These concerns have prompted global efforts to seek sustainable alternatives that minimize environmental impact.

Bioplastics have emerged as a promising solution, offering renewable and biodegradable properties that align with environmental sustainability goals. Derived from natural polymers such as starch, cellulose, lignin, and pectin, bioplastics can be decomposed by microorganisms and produced from abundant biomass resources (Priyadarshi & Rhim, 2020). Among these, starch is particularly attractive due to its availability, affordability, and ease of processing. However, starch-based bioplastics often suffer from limitations such as poor mechanical strength and low water resistance, which restrict their practical applications (Ancy et al., 2024).

Cassava peel, an agricultural byproduct rich in starch and cellulose, presents a valuable opportunity for bioplastic development. As one of the world's leading cassava producers, Indonesia generates large volumes of cassava peel waste, which remains underutilized. Transforming this biomass into bioplastic not only adds economic value but also supports waste reduction and circular economy practices (Fayshal, 2024). Moreover, cassava peel starch has shown potential as a base material for environmentally friendly packaging, especially when combined with other biodegradable polymers (Nayanathara Thathsarani Pilapitiya & Ratnayake, 2024).

To enhance the performance of starch-based bioplastics, natural additives such as chitosan are often incorporated. Chitosan, a polysaccharide derived from chitin, is known for its excellent film-forming ability, biodegradability, and antimicrobial properties. Its compatibility with starch allows for the formation of homogeneous biopolymer matrices with improved mechanical strength and water resistance (Syuhada et al., 2020). Additionally, plasticizers like glycerol and stabilizers such as carboxymethyl cellulose (CMC) are commonly used to improve film flexibility and durability.

The fabrication process plays a crucial role in determining the quality of bioplastic films. In this study, the solution casting method is employed, preceded by a dialysis step to neutralize the pH of the chitosan-starch mixture (Kumari et al., 2023; Kusumawati et al., 2025; Sangroniz et al., 2019; Stanley et al., 2025). This approach ensures better polymer interaction and structural stability during film formation. By varying chitosan concentrations, the study investigates their effects on key film properties, including tensile strength, elongation, water absorption, and biodegradability. These parameters are essential for evaluating the suitability of bioplastics in real-world applications, particularly in sustainable packaging (Stanley et al., 2025).

Previous studies have explored various bioplastic sources, such as tapioca starch (Ancy et al., 2024) and seaweed . While tapioca is commercially valuable and edible, seaweed-based bioplastics have shown relatively low tensile strength (8.65 MPa). In contrast, cassava peel offers a low-cost, non-edible alternative with high starch content, making it ideal for eco-friendly material development (Ramadhani & Said, 2024). Combining cassava peel starch with chitosan and varying glycerol concentrations may significantly improve bioplastic performance in terms of strength, water resistance, and degradation rate (Kusumawati et al., 2025).

Therefore, the objective of this research is to fabricate and characterize environmentally friendly bioplastic films based on chitosan and cassava peel starch, using a controlled solution casting method. The study aims to optimize film properties for sustainable packaging applications while promoting the valorization of agricultural waste. The expected outcome is the development of biodegradable films with enhanced mechanical and environmental performance, contributing to green technology innovation and supporting national goals for sustainable development.

METHOD

Materials and Preparation of Cassava Peel Starch

Cassava peels were collected from local agricultural sources in Indonesia, washed, dried, and ground into fine flour to extract starch. Chitosan (medium molecular weight), carboxymethyl cellulose (CMC), and glycerol were obtained from commercial suppliers and used without further purification. Distilled water was used throughout the preparation process (Priyadarshi & Rhim, 2020).

Cassava peel flour was suspended in distilled water and heated at 70–80 °C with continuous stirring to extract starch (Kusumawati et al., 2025; Syuhada et al., 2020). The slurry was filtered and the filtrate allowed to settle. The precipitated starch was dried at 50 °C and stored in airtight containers for further use. The work procedure for this research consisted of two stages, namely the production of bioplastics and the characterisation of the research results (Sangroniz et al., 2019).

Bioplastic Film Fabrication

The fabrication of bioplastic films was conducted using two treatment variations: First, Chitosan–cassava peel starch bioplastic with chitosan added at 45% of the starch weight, along with 5% plasticizer and stabilizer based on the total weight. Second, Chitosan–cassava peel starch bioplastic with chitosan added at 75% of the starch weight, along with 5% plasticizer and stabilizer based on the total weight (Fayshal, 2024; Kumari et al., 2023; Nayanathara Thathsarani Pilapitiya & Ratnayake, 2024; Priyadarshi & Rhim, 2020).

The extraction of cassava peel starch began by cleaning 100 grams of cassava peels to obtain a clean, white material. Then, 100 mL of distilled water was added to facilitate the blending process. The peels were blended into a slurry and subsequently filtered. The filtrate was allowed to settle for 30 minutes to obtain starch sediment. After settling, the supernatant was discarded, and the sediment was rehydrated with water and allowed to settle again for another 30 minutes. The resulting sediment was then dried in an oven at 70 °C for 30 minutes.

Chitosan was dissolved in a 1% acetic acid solution at a weight ratio of 1:100 (chitosan to acetic acid) and stirred for 2 hours at room temperature. Separately, cassava peel starch was dissolved in distilled water at a weight ratio of 1:2 (starch to water). The starch solution was then mixed with the chitosan solution to achieve a chitosan-to-starch ratio of 45% for variant 1 and 75% for variant 2. The mixture was stirred using a magnetic stirrer and heated to 70 °C.

The combined solution was subjected to dialysis to neutralize the pH. Once neutral, the solution was stirred for an additional hour and supplemented with glycerol and carboxymethyl cellulose (CMC) at 5% of the total weight for both variants. The final mixture was poured into glass molds measuring 20 cm × 20 cm and left to dry at room temperature for 24 hours to form bioplastic films.

Mechanical Characterisation of Bioplastic Films

The fabricated bioplastic films were subjected to a series of characterization tests to evaluate their physical and environmental performance. Surface morphology was examined using Scanning Electron Microscopy (SEM) to assess the uniformity and structural integrity of the film matrix. Mechanical properties, including tensile strength and elongation at break, were measured using a universal testing machine in accordance with ASTM D882 standards. To determine water absorption capacity, the films were immersed in distilled water for 24 hours, and the percentage of water uptake was calculated based on weight change. Biodegradability was assessed by burying the films in soil under controlled conditions and monitoring their degradation over a 12-day period, during which weight loss was recorded to quantify the rate of decomposition (Sabara et al., 2022).

Tensile strength is the maximum force that bioplastic film can withstand during testing. Tensile strength can be calculated using equation (1):

$$\sigma = \frac{\mathrm{F}max}{\mathrm{A}} \tag{1}$$

Percentage elongation is the maximum change in length when stretching occurs until the film breaks. Percentage elongation can be calculated using equation (2):

$$\text{Percentage elongation (\%)} = \frac{\mathrm{L1-L0}}{\mathrm{L0}}\text{x}100\% \tag{2}$$

The modulus of elasticity is also a measure of a material's stiffness or the degree of difficulty a material experiences in deforming when subjected to a load. The modulus of elasticity can be calculated using equation (3):

$$\text{The modulus of elasticity} = \frac{\text{Tensile stress}}{\text{Strain}} \tag{3}$$

Characterisation of Biodegradability

The biodegradability of the film was tested using the soil burial test, in which bioplastic samples were buried in soil . The biodegradability value can be calculated using equation (4):

$$\text{The biodegradability value } (\%) = \frac{W0-W1}{W0} \quad (4)$$

Characterisation of Swelling

Water absorption capacity is the resistance of bioplastics to absorb water. Water absorption capacity can indicate the occurrence of polymer bonds and polymer structures determined by the addition of polymer weight after water absorption. The swelling value can be calculated using equation (5):

$$\text{The swelling value } (\%) = \frac{W1-W0}{W0} \quad (5)$$

Morphological Analysis

The morphological analysis of the resulting film aims to determine the surface structure, cracks, and smoothness of cassava starch chitosan bioplastic. The analysis was conducted using a Scanning Electron Microscope (SEM) at magnifications of 15x, 30x, 50x, and 100x.

RESULTS AND DISCUSSION

Bioplastic Film Characterisation Results

The tensile test results show **Table 1** that chitosan-cassava starch bioplastic with a chitosan concentration of 75% has the highest tensile strength of 0.07 N/mm^2, while a concentration of 45% only has a strength of 0.03 N/mm^2. The increase in tensile strength with increasing chitosan concentration is due to its ability to inhibit the movement of starch molecular chains, thereby increasing the energy required to break the bioplastic. However, both values are still below the JIS 2-1707 1946 standard of 0.3 MPa, meaning that they do not yet meet the tensile strength standard for bioplastics.

Table 1. Tensile strength test results

Variation	Cross-sectional area (mm^2)	Maximum force (N)	Tensile strength (N/mm^2)
1	198.4	5.7	0.03
2	104	7.1	0.07

Based on the data, chitosan-cassava starch bioplastic with 75% chitosan has the highest strain of 0.225 mm and elongation of 22.5%, while a concentration of 45% only has a strain of 0.1625 mm and elongation of 16.25%. Thus, only bioplastics with a chitosan concentration of 75% meet the SNI 7188.7:2016 standard (21–220% elongation) **(Table 2)**, while the 45% concentration does not meet this standard (Kusumawati et al., 2025; Nissar et al., 2025; Sangroniz et al., 2019; Syuhada et al., 2020).

Table 2. Elongation test results

Variation	Initial length (mm)	Length Increase (mm)	Final length (mm)	Strain (mm)	Elongation (%)
1	40	6.5	46.5	0.1625	16.25
2	40	9.00	49.00	0.225	22.5

Based on **Table 3**, chitosan-cassava starch bioplastic with a chitosan concentration of 75% has the highest elastic modulus of 0.3 N/mm^2, while a concentration of 45% has the lowest value of 0.18 N/mm^2. The higher the Young's modulus value, the stiffer the material and the more difficult it is to bend or stretch. However, if it is too high, bioplastics can lose their elasticity.

Table 3. Elastic modulus data results

Variation	Stress (N/mm^2)	Strain (mm)	Elastic modulus (N/mm^2)
1	0.03	0.1625	0.18
2	0.07	0.225	0.3

The biodegradability test results **(Table 4)** show that chitosan-cassava starch bioplastic with 45% chitosan reached 100% degradability on the 12th day, while the 75% concentration only reached 100% on the 16th day, with 79.15% degradability on the 12th day. The higher the chitosan concentration, the slower the degradation rate, as chitosan is more resistant to soil microorganisms (Kusumawati et al., 2025; Priyadarshi & Rhim, 2020; Syuhada et al., 2020). Nevertheless, all samples have been proven to be biodegradable, both biologically and chemically, and have met SNI 7188.7:2016 as they have a degradability of over 60%.

Table 4. Biodegradability test results

Variation	Initial Weight (grams)	Weight Loss (%) Long Days -			
		4	8	12	16
1	0.2192	40.51%	68.50%	100%	100%
2	0.3697	23.45%	40.38%	79.15%	100%

Based on swelling testing **(Table 5)**, chitosan-cassava starch bioplastic with 75% chitosan had the highest water absorption capacity of 93.32%, while the 45% concentration had the lowest absorption capacity of 74.89%. This increase in absorption capacity is due to the greater number of hydrogen bonds between chitosan and starch, which makes it more difficult for water molecules to separate the polymer chains (Antarnusa et al., 2018; Sangroniz et al., 2019). Both values are still below the SNI 7188.7:2016 standard of 99%, so the water resistance of bioplastics is considered to meet the standard.

Table 5. Swelling test results

Variation	Water Absorption Capacity		
	Initial Weight (gram)	Final Weight (gram)	Water Absorption (%)
1	0.2192	0.873	74,89%
2	0.3697	3.82	93.32%

Morphological observation of bioplastic film with 45% chitosan at 100× magnification **(Figure 1)** shows cracks on the surface. These cracks were caused by a lack of glycerol (plasticiser) and excessively high drying temperatures. In this test, glycerol was used at 5% of the total weight, and the drying process was carried out in an oven at 70°C for 30 minutes.

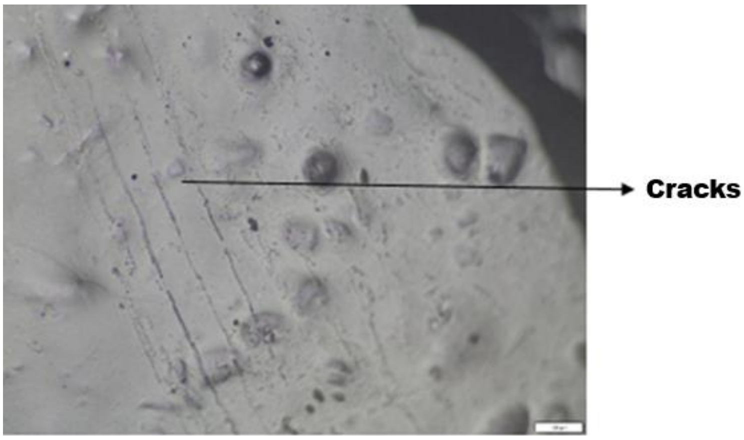

Figure 1. SEM test results of cassava peel starch chitosan bioplastic specimens with a chitosan concentration of 45% at 100x magnification.

Morphological observation of bioplastic films with 75% chitosan **(Figure 2)** shows a more even distribution of material in the matrix compared to the 45% concentration (Bednarikova et al., 2023; Soltanpour et al., 2024). The increase in chitosan and the addition of CMC as a stabiliser play an important role in the formation of the matrix structure (Ubaidilah et al., 2025). CMC has hydrophilic properties, is easily soluble in water, forms a layer, and is stable against fats, thus helping to produce bioplastics with better mechanical characteristics.

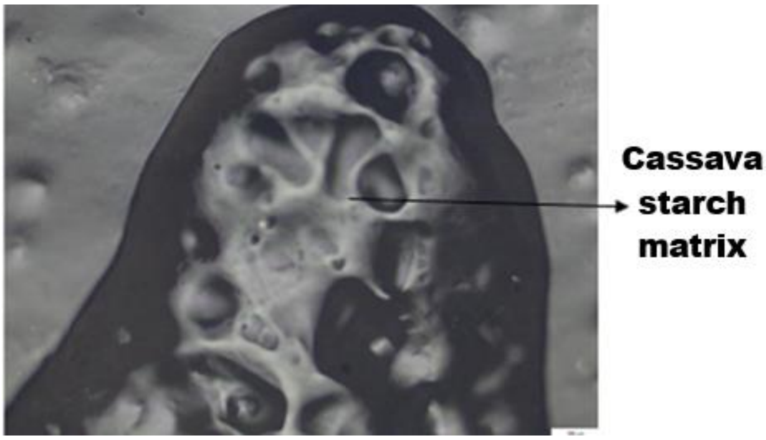

Figure 2. SEM test results of cassava peel starch chitosan bioplastic specimens with a chitosan concentration of 75% at 100x magnification.

CONCLUSION

The fabrication and characterization of environmentally friendly bioplastic films based on chitosan and cassava peel starch with varying chitosan concentrations (45% and 75%) have been successfully conducted. Several tests were performed to evaluate the mechanical properties, surface morphology, water absorption capacity, and biodegradability of the resulting films. SEM analysis revealed that the film structure and surface morphology were influenced by chitosan concentration, which correlated with mechanical strength, swelling behavior, and degradation performance. Tensile strength testing showed that films with 75% chitosan achieved a maximum strength of 0.07 MPa, while those with 45% chitosan reached only 0.03 MPa—both values falling below the minimum requirement of 0.3 MPa set by the Japanese Industrial Standard 2-1707:1946. Elongation tests indicated that the 75% chitosan film met the SNI 7188.7:2016 standard with a value of 22.5%, whereas the 45% variant did not meet the minimum threshold of 21%. Water absorption tests demonstrated that the 75% chitosan film had the highest swelling capacity at 93.32%, compared to 74.87% for the 45% variant; although both values were below the SNI standard of ≥99%, they were considered acceptable for water-resistant bioplastics. Biodegradability assessments showed complete degradation (100%) of the 45% chitosan film by day 12, while the 75% variant reached full degradation by day 16—both exceeding the minimum requirement of 60% within 16 days as specified by SNI 7188.7:2016. The addition of CMC and glycerol did not significantly improve mechanical properties but contributed positively to biodegradability. However, the combination of chitosan and glycerol still resulted in morphological defects such as cracks and surface irregularities, which adversely affected tensile strength. Therefore, while the developed chitosan–cassava peel starch bioplastics show promise for environmental applications, they are not yet suitable as full replacements for conventional synthetic plastics.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest concerning the publication of this article. The authors also confirm that the data and the article are free of plagiarism.

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