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Characterization of the Physical and Biodegradation Properties of Biodegradable Plastic from Carboxymethyl Cellulose, Young Coconut Shells and Cassava Starch

Putri Faradilla[1*], Rini Selly[1], Adelia Febriyossa[2], Moondra Zubir[1], Siti Rahmah[1], Dwi Sapri Ramadhan[1], Tesalonika Bela[1]

[1] *Department of Chemistry, Faculty of Mathematics and Natural Science, Universitas Negeri Medan, North Sumatera, 20221, Indonesia*

[2] *Department of Biology, Faculty of Mathematics and Natural Science, Universitas Negeri Medan, North Sumatera, 20221, Indonesia*

**Corresponding author: putrifaradilla@unimed.ac.id*

ABSTRACT

Biodegradable plastics derived from renewable biomass were synthesized using carboxymethyl cellulose (CMC) isolated from young coconut husk and cassava starch at different CMC:starch ratios (1:1, 1:2, and 2:1). Physical characterization included tensile strength, elongation, Young's modulus, and water resistance, while biodegradation performance was assessed through a 15-day soil burial test. The tensile strength reached its highest value at a ratio of 2:1 (2.0068 MPa), fulfilling the JIS 2-1707 requirement for biodegradable films. Elongation values were inversely related to CMC content, with the highest elongation (62.69%) observed at the 1:2 ratio. Water resistance was also optimal at the 1:2 ratio, indicating lower hydrophilicity compared to CMC-rich films. Biodegradation tests showed that bioplastics with higher CMC content (2:1) degraded fastest, achieving 97.37% mass loss on day 15. These findings demonstrate that the CMC:starch ratio significantly affects mechanical stability, moisture sensitivity, and biodegradation rate. Overall, the bioplastic films developed in this study exhibit promising properties for eco-friendly and lightweight packaging applications.

Keywords: bioplastic, carboxymethyl cellulose, cassava starch, mechanical properties, biodegradation

1. INTRODUCTION

The use of conventional plastics has become a very important aspect of many modern industries, offering advantages such as durability, cost, and ease of processing.[1] However, the massive scale of global production and consumption, dominated by petrochemical-based polymers, has reached an ecological tipping point.[2] The non-degradable nature of most plastics causes chronic waste accumulation that pollutes oceans, land, and the

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atmosphere, threatening biodiversity and the global food chain.[3] Therefore, finding and developing sustainable materials that can replace traditional plastics has become an urgent scientific and social imperative.[4]

In response to this pollution crisis, biodegradable plastics have emerged as the most promising solution. This material is designed to be enzymatically decomposed in the natural environment by microorganisms into harmless byproducts such as water, CO_2, and biomass within a certain period of time.[5] The development of bioplastics, especially those sourced from renewable natural polymers, offers two environmental benefits at once: reducing dependence on fossil resources and reducing the impact of non-degradable solid waste accumulation.[6]

Many current studies focus on utilizing abundant natural resources, such as starch and cellulose, to create high-performance bioplastic composites. Cassava starch, which is widely available and inexpensive in many countries, is an ideal matrix biopolymer, although its weak mechanical properties and moisture sensitivity require modification.[7] To improve material strength, carboxymethyl cellulose (CMC), an environmentally friendly cellulose derivative, is often integrated as a blending agent due to its strong film-forming and binding properties.[8] Moreover, the use of lignocellulosic waste such as young coconut shell powder as a natural fiber reinforcement can significantly improve the mechanical properties of the resulting bioplastics, such as elastic modulus and tensile strength.[9]

Based on the need for environmentally friendly packaging materials, this study aims to characterize the physical and morphological properties of biodegradable plastics developed from a combination of carboxymethyl cellulose, cassava starch, and young coconut shell powder filler. Specifically, this study will evaluate how variations in the ratio and interaction of these three biomass-based components affect critical properties such as mechanical strength, water resistance, and surface structure homogeneity, thereby providing a strong data foundation for the design of composite bioplastics.[10]

2. EXPERIMENTAL

2.1. Chemicals, Equipment and Instrumentation

The equipment utilized consists of a grinding machine and sieve for sample preparation, blender, oven, a hot plate with a magnetic stirrer, and glass molds for bioplastic preparation. Bioplastic characterization was performed using a tensile testing instrument to measure Tensile Strength, Elongation, and Young's Modulus, an analytical balance for Water Resistance and Biodegradation tests, and a micrometer to determine film thickness.

Materials used include young coconut husk, cassava starch, Sodium Hydroxide (NaOH) 17.5%, Aquadest, sodium chloroacetate 1.75%, H_2O_2 10%, $NaNO_2$, Glycerol.

2.2. Research Procedure

Sample Preparation

Young coconut husks were separated into small fibers. Then washed with water and dried in the open air until dry. The dried young coconut husks were cut into smaller pieces of 1-2 cm. Then the young coconut husks were ground using a grinding machine and sieved with a 60 mesh sieve. The young coconut powder is dried again in an oven for 1 hour at 60°C.

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Isolation of α-Cellulose from Young Coconut Husk

About 75 g of young coconut husk powder was added to a mixture of 1 L of 3.5% HNO3 and 10 mg of NaNO2. It was heated at 90°C for 2 hours, then filtered and the residue was washed with distilled water until the pH of the filtrate was 7. Next, 350 mL of 2% NaOH and 350 mL of 2% Na2SO3 were added and heated at 50°C for 1 hour, after which it was filtered and the residue was washed with distilled water until the pH of the filtrate was 7. Next, 250 mL of 1.75% NaOCl solution was added and heated at 70°C for 30 minutes, filtered, and the residue was washed with distilled water until the pH of the filtrate reached 7. Then, 500 mL of 17.5% NaOH solution was added and heated at 80°C for 0.5 hours, filtered, and the residue was washed with distilled water until the pH of the filtrate reached 7. Next, 500 mL of 10% H2O2 was added at 60°C, filtered, and washed with distilled water until the pH of the filtrate reached 7. The resulting α-cellulose was dried for 1 hour in an oven at 60°C.

Preparation of Carboxymethyl Cellulose (CMC)

A total of 5 g of α-cellulose powder was mixed with 150 mL of isopropanol solution and 15 mL of 25% NaOH solution in a beaker while stirring for 1 hour. The solution was mixed with 6 g of sodium chloroacetate and stirred for 1.5 hours. The resulting solution was heated in an oven at 55°C for 3.5 hours. After heating, the solution was soaked in 100 mL of methanol for 24 hours. The solution was neutralized with 90% (v/v) acetic acid and filtered. The residue is washed 3 times using 70% (v/v) ethanol (200 mL) for 10 minutes to remove unwanted byproducts. The final product obtained is washed with methanol (100 mL) and dried in an oven at 55˚C for 18 hours.

Isolation of Cassava Starch

The 100 g cassava pulp was washed thoroughly and then drained. Cut the cassava tubers into 2 cm pieces and add 100 mL of water (distilled water), then blend until smooth. Once smooth, a cassava pulp will form. Filter the resulting filtrate and let it sit for 1 hour so that the starch (sediment) forms. The starch sediment was washed, then stirred and precipitated for 1 hour. In the oven, the obtained starch precipitate was dried for 30 minutes at 60°C. The obtained starch was ground into a powder and sieved through a 60-mesh sieve to achieve a uniform particle size.

Preparation of Bioplastics

A total of 3 g of CMC was dissolved in 100 ml of distilled water and heated on a hot plate while stirring with a magnetic stirrer at a temperature of 80°C for 10 minutes. A total of 3 g of CMC was dissolved in 1% acetic acid with stirring at a temperature of 80°C for 10 minutes. Then, 3 ml of glycerol was added. The mixture wasthen homogenized using a magnetic stirrer for 15 minutes. After that, it was heated for 7 minutes at 80°C. The solution was cooled to approximately 20-25°C. As much as 30 ml of the mixture was then poured into a 15 cm x 5 cm glass mold. The mold is then cooled at 25°C. The same procedure was also carried out for CMC: glycerol variations of 1:2 and 2:1. The bioplastic sheets were then characterized by tensile strength, elongation, Young's modulus, water resistance test, and biodegradation.

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3. RESULTS AND DISCUSSION

3.1. Analysis of the Physical Properties of Bioplastics

3.1.1 Tensile Strength Test

The tensile test on this bioplastic was conducted to determine the effect of carboxymethyl cellulose (CMC) as a reinforcing agent with cassava starch on the tensile strength properties of bioplastics. Based on Table 1, the tensile test values of bioplastics were obtained, which were influenced by the addition of CMC and starch. The tensile strength test on bioplastics made from cassava starch showed the best results with more CMC added at a ratio of CMC : Starch 2:1, which reached a tensile strength value of 2.0068 MPa, compared to 1:1 which produced 1.448 MPa and 1:2 which produced 1.9659 MPa. Based on the JIS 2-1707 Standard Test, the minimum tensile strength value for bioplastics is 0.3 MPa, which means the results are good. The JIS K-1761 Standard Test for conventional plastics states a tensile test value of 8-75 MPa. CMC has hydroxyl (-OH) and carboxyl (-COOH) groups that can interact with the hydroxyl groups on the starch molecules through hydrogen bonds. This interaction helps form a cross-link between the starch molecules and CMC, which increases the physical strength of the resulting film or bioplastic.

Table 1. Tensile test results (Mpa) of bioplastics with variations of carboxymethyl cellulose (CMC) with cassava starch

CMC : Starch	Tensile strength (Mpa)
1:1	1.448
1:2	1.9659
2:1	2.0068

3.1.2 Elongation

Elongation refers to the maximum change in length that occurs when a material is stretched until it finally breaks.

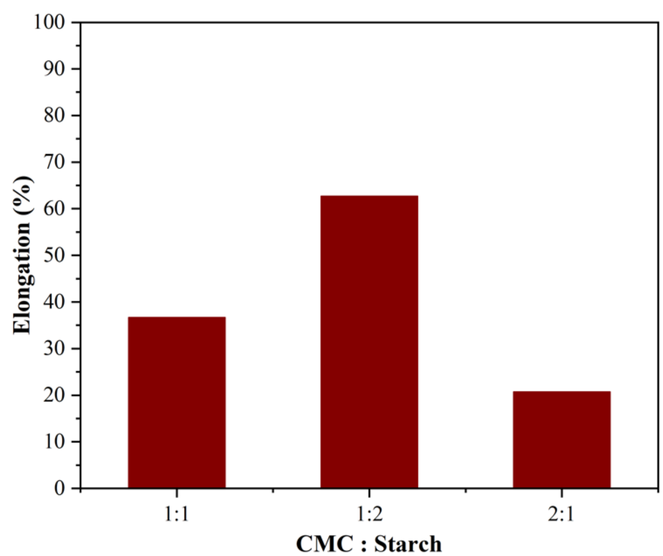

Figure 1. Elongation test of bioplastics with variations of CMC : cassava starch

Based on Figure 1, the elongation test on bioplastics made from cassava starch showed the best results with a higher starch ratio, namely CMC:Starch with a variation in the CMC:Starch ratio of 1:2, which achieved

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a tensile strength value of 62.69%. Conventional plastic standard testing JIS K-1761 states an elongation test value of 10-650%. Previous research [11] states that the elongation value is inversely proportional to the tensile strength and Young's modulus when more cellulose is added. The thickness of bioplastics affects the elongation value; the thicker the bioplastic, the lower the elongation value tends to be. This is because thicker materials become stiffer and more difficult to stretch, and have unequal stress distribution when subjected to tensile force. At a CMC:starch ratio of 2:1, the bioplastic becomes thicker, most likely due to excess CMC absorbing more water and uneven mixing.

3.1.3 Young's Modulus

Young's Modulus (elasticity test) is conducted to determine the stiffness of the material produced; the higher the value, the stiffer the material. The results of the young's modulus test on bioplastics with various compositions of CMC and cassava starch are presented in Figure 2.

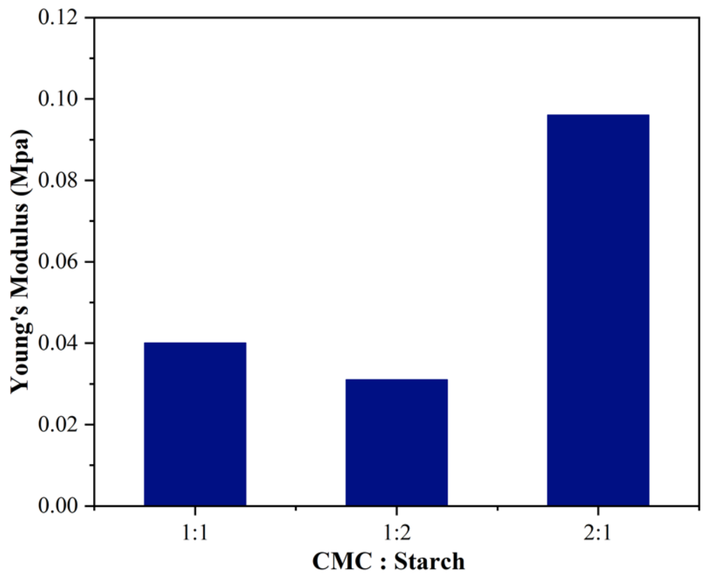

Figure 2. Young's Modulus test of bioplastics with variations of CMC with cassava starch

The Young's modulus test values of bioplastics were obtained, which were affected by the addition of CMC and starch. Conventional plastic testing standard JIS K-1761 states that the Young's modulus test value is 100-3500 MPa. According to the Japanese Industrial Standard (JIS), the minimum standard value for the Young's modulus of bioplastics is 0.35 MPa.[12] The Young's modulus test on bioplastics made from cassava starch showed the best results with more CMC added at a ratio of 2:1, reaching a value of 0.096 MPa, which can be concluded that this bioplastic is less rigid and very flexible. The results of this Young's modulus test show that the addition of CMC concentration has a positive effect on increasing the Young's modulus value.

3.1.4 Water Resistance (Swelling Test)

The water resistance of bioplastics was measured using a swelling test, which shows the percentage of bioplastic expansion due to the presence of water. The lower the water absorption value, the better the bioplastic properties. On the contrary, if the water absorption value is high, the bioplastic will be more

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vulnerable to damage. The water absorption test on bioplastics was conducted to determine how well bioplastics can absorb water. The data table for testing the water resistance of bioplastics with variations in carboxymethylcellulose (CMC) with cassava starch is presented in Table 2.

Table 2. Water Resistance Test Data for CMC:Starch Variations

CMC:Starch	Water Absorption (%)	Water Resistance (%)
1:1	68.07	**31.93**
1:2	56.76	**43.24**
2:1	**68.83**	**31.17**

Based on table 2, Bioplastics prepared with a 2:1 ratio showed the lowest water resistance, which was 31.17%. In contrast, the best water resistance was found in bioplastics with a 1:2 ratio, which reached 43.24%.

3.2 Analysis of Biodegradability

Biodegradation tests are conducted to determine how long it takes for bioplastics to decompose in the environment. This test was conducted by burying film samples in soil. The process of plastic biodegradation in the environment begins with chemical degradation, namely the oxidation of molecules in the plastic film structure. Next, biological degradation occurs, in which microorganisms such as bacteria, fungi, and algae attack, and there is intracellular and extracellular enzyme activity.[13] The results of the weight change of biodegradable bioplastics were calculated from days 1-15 for bioplastics with various compositions of CMC and cassava starch and are presented in graph form in Figure 3.

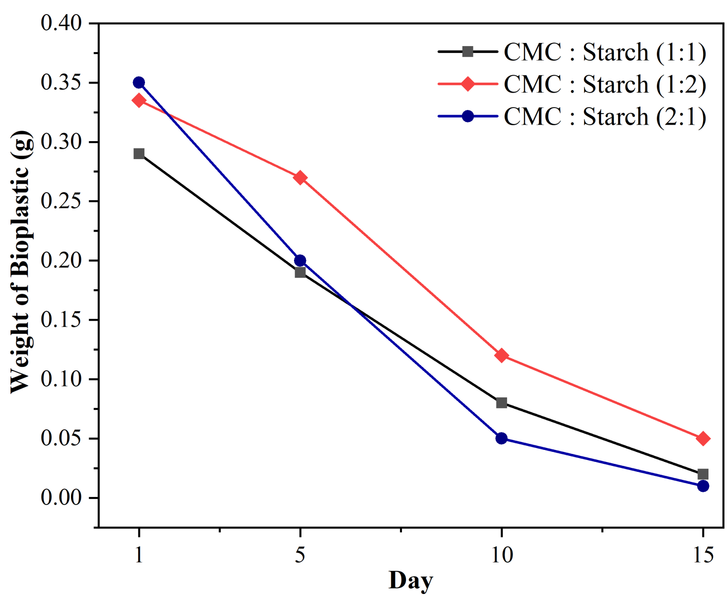

Figure 3. Mass variation of bioplastic samples during a 15-day biodegradation period

Based on Figure 3, bioplastics made from young coconut husk CMC with cassava starch exhibit changes in mass from days 1-15, where 2:1 has a rapid decomposition process compared to other ratios, due

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to the addition of CMC which causes a fast decomposition process because CMC is hydrophilic and quickly absorbs water in the soil. The results of the biodegradation test on bioplastics with various compositions of CMC and cassava starch were presented in graph form in Figure 4.

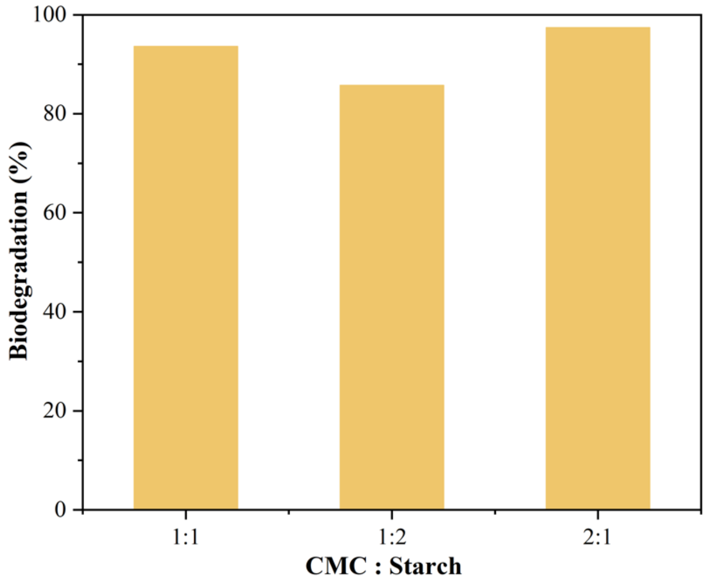

Figure 4. Biodegradation rate (%) of bioplastics with various compositions of cmc and cassava starch

As depicted in Figure 4, the biodegradation analysis results were affected by the addition of CMC and starch. The biodegradation analysis of bioplastics made from cassava starch showed the best results with more CMC added at a ratio of 2:1, yielding a result of 97.37%. The study shows that with increasing CMC filler content, the biodegradation value of the bioplastics produced has high value.

4. CONCLUSION

This study successfully synthesized and characterized biodegradable plastics based on carboxymethyl cellulose (CMC) from young coconut shells and cassava starch with varying CMC:starch ratios. The results showed that the physical and mechanical properties and degradability of bioplastics were greatly influenced by the ratio of the biopolymers. Overall, the resulting biodegradable plastic shows great potential as an environmentally packaging material that is easily degradable and has sufficient mechanical strength for light weight applications. The CMC:Starch composition of 1:2 offers the best balance between flexibility and water resistance, while the 2:1 composition is most optimal for tensile strength and degradation rate.

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