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Utilization of Plantain Peel (*Musa sapientum*) and Sweet Potato Starch (*Ipomea batatas*) Waste in Combination with Glycerol Addition to Produce Biodegradable Plastic

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Abstract

Starch is a natural polymer derived from plants, known for its biodegradability, environmental friendliness, wide availability, and affordability. Glycerol, with its low molecular weight, serves as an effective plasticizer. Its addition enhances the physical and mechanical properties of plastics and provides protection against microbial degradation. This study aims to investigate the impact of glycerol addition on the mechanical properties of biodegradable plastics made from sweet potato starch and plantain peel waste. The research is an experimental to achieve this goal. The results indicated that all samples achieved 100% degradation, with elongation percentages ranging from 93.59% to 137.56%. The sample containing 10 grams of sweet potato starch and 5 grams of banana peel starch exhibited the lowest water absorption percentage at 73.43%. Additionally, the bioplastic sample consisting of 5 grams each of sweet potato starch and banana peel starch showed the highest thickness at 0.36 mm, meeting the established SNI standards. In conclusion, the mechanical properties, biodegradability, and transparency of bioplastics are influenced by variations in sweet potato starch and plantain peel starch composition, as well as by the addition of glycerol.

Keywords: bioplastics, glycerol, plantain peel starch, sweet potato starch.

1. Introduction

Plastic is a synthetic organic polymer and mostly derived from petrochemical basic materials [1]. It is often chosen as the basic material or as packaging because it has many advantages over other materials, including its stable, waterproof, lightweight, transparent, lightweight, flexible, and strong and the price is relatively cheap so that it is affordable by all circles [2,3]. Due to its unique properties, global plastic production has a high growth rate. The amount of plastic produced commercially worldwide was recorded at 359 million tons in 2018 and in the next 20 years, this amount is expected to increase threefold [4]. Every year, almost 400 million tons of plastic are manufactured [5]. It is due to every product on the market uses plastic as a base material or as a packaging.

Plastics that are widely used today are the result of the synthesis of hydrocarbon polymers from petroleum. They made from petroleum have low degradation properties, at least it takes 500-1,000 years for plastics to decompose completely [5], The method of processing plastic waste using the incineration or burning method is one solution that is often used as an option; however, incineration can pollute the environment by releasing reaction products in the form of dangerous gases. The decomposition of plastic waste using the incineration method is associated with the release of CO, CO_2, ammonia (NH_3), nitrous oxide (N_2O), and nitrogen oxide (NO_x) [6,7]. Moreover, petroleum which is used as raw material for making plastic is also a non-renewable resource and is very limited in quantity [8]. Based on this, there is a need for alternative plastic materials made from readily available natural materials that are abundant in nature.

One of the solutions in overcoming the problem of plastic waste is by making biodegradable plastics that are more environmentally friendly because it can degrade easily in nature. Biodegradable plastics are plastics that can be used for conventional plastics but will be easily destroyed by the activity of microorganisms into water and carbon dioxide gas after being used and disposed into the nature [3]. In addition to its degradable characteristic, the manufacturing process of biodegradable plastics also produces less carbon emissions than the manufacturing process of conventional plastics [9].

Therefore, the selection of primary materials should prioritize those with high natural degradability. Additionally, certain plants contain polysaccharides that can serve as substitutes for synthetic polymers typically used in traditional plastics [10]. Polysaccharides possess properties such as water resistance, flexibility, and mechanical strength due to their long-chain structure and hydrogen bonds. These characteristics make polysaccharides suitable candidates for replacing conventional plastic materials [11,12].

Starch is one of the natural polymers from plant extraction that can be used to produce biodegradable materials due to its environmentally friendly nature, easy degradation process, large availability and affordability [5]. Utilisation of starch as a raw material for making biodegradable plastics has great potential, starch itself is produced from various plants.

One of the natural materials that is often used in making biodegradable plastic is tubers, such as sweet potatoes [13]. The manufacture of biodegradable plastics from sweet potato starch can produce quite good performance, sweet potato starch was found to be better chemical resistant, better tensile strength, and faster rate of soil biodegradation [14].

In addition to use starch derived from tubers, fruit peel waste can also be used as a source of starch which is a natural compound, such as banana peel waste. Both large and small-scale farmers grow banana in more than 130 nations. Commercial banana production takes place in tropical and subtropical regions around the world with Asia as the leading producing region in 2017 with a contribution of 54.18% of worldwide production [15]. The weight of banana peel reaches 40% of the fruit [16]. As a waste material, banana peels are generally immediately thrown away as waste without any further use. Although the starch content in banana peels can be useful in various applications. Starch content of several banana varieties was studied, namely the resistant starch content of plantain peel starch of 30.66%, 29.60% *Musa paradisiaca* var. Corniculata, 29.37% *Musa acuminata* x balbisiana (ABB Group), and 27.70% *Musa Paradisiaca* L. Var. Bluggoe. Based on the results of these studies, the largest starch content is owned by the plantain peel. Thus, in this study we will also use starch from plantain peels as a base material for making biodegradable plastics [17].

The low mechanical characteristics of plastics and their hydrophilic nature are two drawbacks in the production of biodegradable polymers from starch. Furthermore, like normal plastics, biodegradable plastics are brittle or inflexible quickly [18]. Thus, plasticizers are required to produce biodegradable polymers. Plasticizer is a low molecular weight organic material that is added with the intention of weakening the stiffness of the polymer, while increasing the flexibility and extensibility of the polymer [18]. One the other hand, glycerol is a hydrophilic material that is commonly used as a plasticizer when it binds to polysaccharide bonds [11]. The presence of glycerol can increase water absorption due to its hydrophilic nature which can help in the biodegradation process of bioplastic. Glycerol's ability to bond with polysaccharides also reduces the cohesive strength between polymers. This reduction enhances the softness and flexibility of bioplastics, making them more pliable and adaptable for various applications [19]. Based on these conditions, this research will focus on producing bioplastics from banana peels and sweet potato starch using varying concentrations of glycerol as a plasticizer to investigate their characteristics.

2. Materials and Method

2.1 Materials

The materials required include unoxidized plantain peels that are still in good condition, sweet potato, as the main ingredient of bioplastics, then glycerol as a plasticizer, and distilled water as solvent. In addition, there are tools used including a mixer, oven, square baking mold, analytical balance, and stove.

2.2 Preparation of starch from plantain peels

The raw materials used are unoxidized plantain peels that have not blackened on the entire surface and are still in good condition. The steps to produce starch from plantain peels are as follows: the plantain peels are washed with running water, then the banana peels are cut into small pieces and soaked in ice water for a few minutes, then the banana peels are mixed until smooth and then filtered. The mashed banana peel filtrate was then sedimented for 24 hours, dried in the sun for 2-3 days and mashed.

2.3 Preparation of starch from sweet potatoes

Sweet potato starch can be produced by peeling and washing sweet potatoes. The purpose of the peeling and washing process is to remove the dirt from the sweet potato. The sweet potatoes are then finely grated. Then 1 kg of material is soaked in 2 liters of water and the sediment is filtered. Next, the starch is dried in the sun, then the dried starch is mashed and sieved.

2.4 Bioplastic preparation

The first step in making bioplastics is to mix plantain peel starch and sweet potato starch in sequential ratios of 1:2, 1:1, and 2:1. Then 15 grams of starch, 10 grams and 15 grams each are put into the container, then distilled water is added with the ratio of starch and distilled water was 1:20, cellulose is added with ratio of starch and cellulose was 8:2, then stirred and filtered, 30 ml of glycerol is added. Then heated for 10 minutes while stirring, poured into plastic molds, then flattened and dried by leaving for 24 hours.

2.5 Characterizations

2.5.1 Biodegradation test

The biodegradation test is used to determine how quickly a biodegradable plastic is broken down by microorganisms in an environment. The medium used is soil because there are many types of microorganisms in the soil that support the degradation process to be carried out. The procedure is to bury the plastic and record the decrease in the mass of the plastic in a few days.

2.5.2 Absorption test

Bioplastic film is cut with a size of 1 x 1 cm, then weighed with a digital balance and then put the sample in a container that has contained distilled water at a temperature of 23°C for 24 hours, after which it is removed and cleaned with a dry cloth, the water resistance is calculated by the equation 1:

$$\text{Air (\%)} = \frac{W-W_0}{W_0} \times 100\% \quad (1)$$

A = water absorption (%)
W_0 = initial test weight (gram)
W = test weight after immersion (gram)

2.5.3 Thickness test

The thickness test was performed by measuring the thickness of the bioplastics using a Screw micrometre. The bioplastic film was measured at five different points, namely each corner and the center of the bioplastic. The thickness value is obtained from the average measurement results (equation 2). This test was performed three times.

$$\text{Thickness} = \frac{T1+T2+T3+T4+T5}{5} \quad (2)$$

2.5.4 Elongation test

Elongation test or percentage elongation is performed to calculate the additional length of the bioplastic sheet when the bioplastic sheet breaks. The test was performed three times. Percent elongation is calculated using the following equation 3:

$$\varepsilon = \frac{\Delta l}{lo} \quad (3)$$

ε = strain (%)
Δl = length gain (cm)
l_0 = initial length (cm)

3. Results and Discussion

The results of making bioplastics from the combination of banana peel starch and sweet potato starch with a composition ratio of starch: cellulose as much as 8: 2 then the ratio of starch: distilled water 1: 20 and 10ml glycerol as plasticizer can be seen in Figure 1.

3.1 Biodegradable test

The biodegradable test aims to measure the degradation of bioplastic can be degraded in the soil by a microorganism [17]. In this study, the biodegradable test was carried out on bioplastics for 7 days by comparing the mass before and after the test.

Table 1. Biodegradability test result for 7 days.

Bioplastic	Weight (gram)		Percent of Degrade (%)
	Before	After	
(a) 1:2	0.63	0	100
(b) 1:1	0.65	0	100
(c) 2:1	0.46	0	100

Based on the results of the biodegradable test contained in Table 1, the three bioplastic samples decreased in mass from the initial mass to the final mass and the three samples degraded by 100%. The level of biodegradability of bioplastics buried in the soil decreases in mass with increasing time, this is because starch and glycerol have OH groups that play a role in initiating hydrolysis reactions so that they can adsorb water from the soil which causes the polymer from starch to be decomposed into small pieces until the bioplastic fully decomposed in the soil.

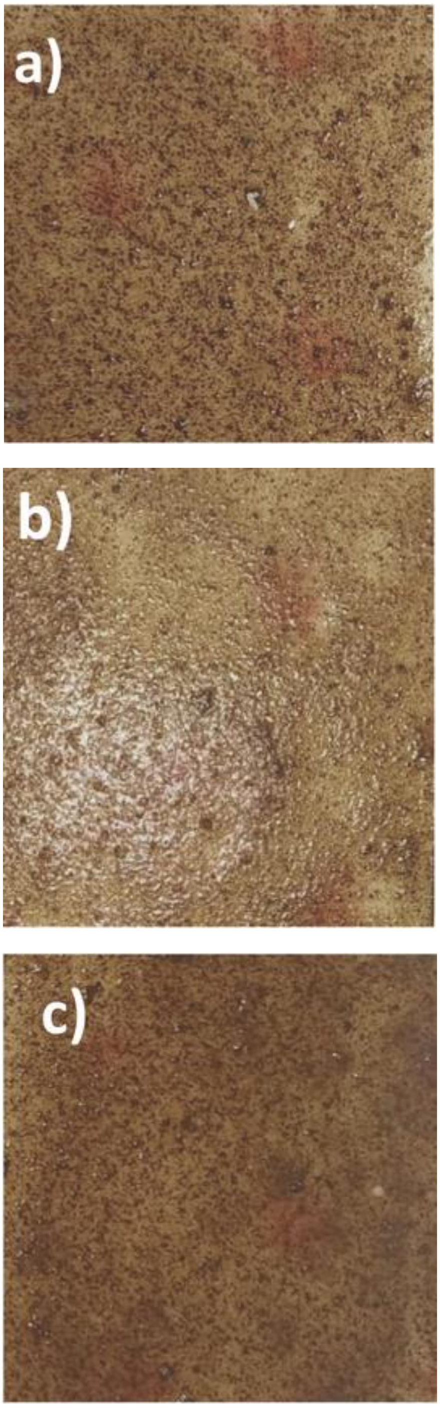

Figure 1. Bioplastics with the composition ratio of banana peel starch and sweet potato starch sequentially (a) 1:2 (b) 1:1 (c) 2:1

3.2 Absorption test

The water absorption test assesses the resistance of bioplastics to water contact, indicating their ability to absorb moisture. This parameter reflects the bioplastic's capacity to absorb water from its surroundings. Bioplastics with densely packed particles and greater thickness typically exhibit slower rates of water transmission. The results of the water absorption test for the bioplastics can be observed in the following table, which compares the initial and final mass measured during the test.

Table 2. Absorption test of bioplastic.

Bioplastic	Weight (gram)		Percent of Degrade (%)
	Before	After	
(a) 1:2	0.64	1.11	73.43%
(b) 1:1	0.54	1.06	96.29%
(c) 2:1	0.46	1.75	280.43%

The ability of water absorption in bioplastic samples is influenced by the nature of each starch which is hydrophilic. In addition, glycerol has water-soluble properties so that the polymer bonds formed have a great ability to bind to water molecules. Another factor that affects the percent water absorption is soaking time. When the bioplastic sample is soaked, water solvent molecules will diffuse into the bioplastic polymer. Thus, the longer the bioplastic soaking time, the more the percentage of water absorption will increase because more water will diffuse into the bioplastic sample.

The lower the ability of bioplastics to absorb water, the better the ability of bioplastics to be used as packaging. If bioplastics have a high-water binding ability so that the percentage of water absorption is also high, it will be easier for microorganisms to grow and decompose bioplastics which will interfere with the material packaged with bioplastics. According to SNI (Indonesian National Standard), the water absorption of bioplastics is 21.5% at 25°C and 69.09% at 100°C. In this study, percentage of water absorption in the three bioplastic samples based on Table 2 was 73.43% - 280.43% at room temperature depends on the composition.

3.3 Thickness test

The bioplastic thickness test was carried out using the microcal Messmer method, namely the thickness value will be obtained from the average of the bioplastic measurement results at five different points with three repetitions for each sample. Thickness measurements were taken at each corner and the center of the bioplastic sheet. The thickness of bioplastics is measured with the help of a calliper. The results of the bioplastic thickness test that have been made can be seen in the following table.

Table 3. Thickness test of bioplastic.

Bioplastic	Repetition (mm)			Mean (mm)
	1	2	3	
(a) 1:2	0.1	0.1	0.1	0.1
(b) 1:1	0.3	0.5	0.3	0.36
(c) 2:1	0.1	0.2	0.2	0.17

Based on the data in Table 3, the highest thickness value is in the bioplastic sample with a composition of 1: 1 with 5 grams of sweet potato starch and 5 grams of banana peel starch, which is 0.36 mm. The thickness value is influenced by the number of solids in the bioplastic solution, the more the number of solids in the solution, the thicker the bioplastic formed [20]. In addition, the uneven distribution of the constituent components of bioplastics can also affect the measurement. In the process of making bioplastics, the constituent components are not well dispersed so that the solution is not homogeneous and the distance between the component molecules becomes irregular. This will affect the thickness of the bioplastic during the moulding process.

3.4 Elongation Test

Table 4. Elongation test of bioplastic.

Bioplastic	Length (mm)		Elongation (%)
	Before	After	
(a) 1:2	20.5	48.7	137.56%
(b) 1:1	20.5	40.7	98.53%
(c) 2:1	20.3	39.3	93.59%

Based on the data in Table 4, the highest elongation percentage was obtained in bioplastics with a composition of (a) 1:2, 5 grams of plantain peel starch and 10 grams of sweet potato starch, which reached at 137.56%. Meanwhile, as the composition of sweet potato starch decreases and the composition of plantain peel starch increases in bioplastic samples, the percentage of elongation decreases. This can be seen in bioplastics with a composition of (b) 1:1 and (c) 2:1, which reached elongation at 98.53% and 93.59%, respectively.

Based on SNI 7188.7: 2016, the percentage of elongation of bioplastics is around 21 - 220%. The percentage of elongation in the three bioplastic samples produced in this study was 93.59% - 137.56%, which has shown results according to the bioplastic elongation criteria [21].

4. Conclusion

The addition of glycerol as a plasticizer significantly impacts various mechanical properties of bioplastics, including biodegradation rate, water absorption, thickness, and elongation. According to the biodegradability data, all three bioplastic samples exhibited complete degradation (100%). However, the water absorption levels in these samples did not meet the SNI standards. The sample composed of 5 grams of sweet potato starch and 5 grams of banana peel starch had the highest thickness, measuring 0.36 mm. Meanwhile, all three samples met the SNI standards for elongation, showing values between 93.59% and 137.56%. Increasing the proportion of sweet potato starch can enhance the elongation value, indicating greater flexibility in the bioplastics. This improvement can be attributed to the beneficial properties of banana peel and sweet potato starch, which contribute to maximizing the heat resistance of the biodegradable plastic film formed. Glycerol is an effective plasticizer choice. It enhances the mechanical and physical properties of plastics while providing protection against microbial degradation.

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