Development of Biodegradable Plastic from Various Banana Peels

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ABSTRACT

Banana peel, a commonly discarded organic waste, holds potential as a raw material for biodegradable plastic production due to its pectin content. This study investigates the effect of extraction temperature on pectin yield from two banana peel variants—kepok and plantain—and evaluates the physical properties of the resulting bioplastics. Pectin was extracted at temperatures of 70°C, 80°C, and 90°C, and used to produce bioplastics with sorbitol as a plasticizer and chitosan as an additive. The pectin yields increased with temperature, ranging from 1.77% to 4.40% in kepok peels and 4.60% to 8.10% in plantain peels. The highest bioplastic thickness (0.0031 cm) was observed in plasticized plantain-based samples, while the lowest (0.0025 cm) was found in non-plasticized variants. Tensile strength varied significantly: 3.732–5.318 MPa for plasticized kepok, 0.270–0.638 MPa for non-plasticized kepok, 1.946–2.934 MPa for plasticized plantain, and 0.170–1.263 MPa for non-plasticized plantain. Elongation at break ranged from 2.616–3.360% for plasticized kepok, 3.46–7.30% for plasticized plantain, 0.152–0.424% for non-plasticized kepok, and 0.096–0.728% for non-plasticized plantain. Water absorption was lower in plasticized bioplastics—61.41% (kepok) and 58.62% (plantain)—compared to non-plasticized ones, which showed 84.13% and 85.82%, respectively. While banana peel-derived bioplastics demonstrate potential, their mechanical and physical properties still fall short of standard requirements.

1. Introduction

Biodegradable plastic is plastic that microorganisms can break down. This plastic contains several components, such as lignin, starch, and cellulose. The biodegradation process is where plastic breaks down through decomposer activity. Then, the minerals and water produced from biodegradation will be processed by plants to help them carry out photosynthesis [1]–[7].

Biodegradable plastics are generally made by adding plasticizers to improve the quality of the bioplastics produced from glycerol and sorbitol. Where glycerol has the advantage of increasing the flexibility and elasticity of bioplastics, sorbitol can increase the tensile strength and elongation values of bioplastics and remain stable against enzymes, acids, and high temperatures. Bioplastics can also be used as an innovation created to reduce the problem of plastic waste, which can be easily decomposed, so that it does not cause waste to accumulate [4], [8], [9].

Biodegradable plastic can be made from banana peel waste [2], [9], [10], [11], [12]. Currently, banana peels cannot be further processed, so the presence of banana peel waste in the environment can pollute the environment. In this way, banana peels can be used as the raw material for biodegradable plastic because they contain starch. Biodegradable plastics made from starch still require adding additives such as plasticizers to improve the plastic produced. In the research that will be carried out, the plasticizers used are glycerol and sorbitol [13].

Banana peels are often found in the surrounding environment and have not been utilized. Therefore, it is necessary to study the use of waste. Banana peels can be used in making bioplastics because they contain starch. [13]. Results of previous research [14], explains that the variety of banana affects the starch content of the peel; here are some of the starch contents of banana peel: Kepok bananas (*Musa paradisiaca L*) 27.70%, Ambon bananas (*Musa paradisiaca var. sapientum* (*L.*) *Kuntze*) 29.37%, Horn bananas (*Musa paradisiaca*) 29.60%, and king bananas (*Musa paradisiaca var. Raja*) 30.66%. This study chose kepok (*Musa paradisiaca L*) and king banana peels (*Musa paradisiaca var. Raja*) because they are high in starch content. Previous research on biodegradable plastic made from banana peel flour with glycerol and sorbitol plasticizers produced elongation at break values that met SNI [15], [16], [17].

Based on previous research, it used only one variety of banana peel, namely the kepok banana. In this study, two varieties of bananas will be compared, namely kepok and raja bananas. This study aims to determine the parameters of bioplastic characteristics, including strength, tensile strength, and water resistance in kepok (*Musa paradisiaca L*) and raja banana peels (*Musa paradisiaca var. Raja*).

2. Research Methodology

3.1. Materials

The raw materials in this research include banana peels (kepok bananas and plantains), distilled water, 96% ethanol (P.A., Merck, Germany), PP indicator, chitosan, 3% citric acid (Merck, Germany), 0.5 M HCl (P.A., Merck, Germany), and sorbitol.

3.2. Procedures

1) Preparation of Raw Materials

Banana peels were washed until clean. Then, banana peels are cut into small pieces. The sample was dried in the oven at 60ºC. Using a blender to get the banana peel essence, the banana peel was crushed.

2) Pectin Extraction Process

Put the banana peel powder 300 g into a beaker, add 2 L of HCl, then heat it at 80ºC for 60 minutes to form a sour slurry. Then, the sour pulp was filtered using filter paper to obtain the pectin filtrate. The resulting pectin filtrate was then added with 96% ethanol in a ratio of 1:1.5, then precipitated for 24 hours to form sour pectin. The sour pectin produced was added to 96% ethanol and then filtered again. This process was carried out several times until the ethanol from the washing was clear and did not change color when added with the PP indicator. The pectin was dried using an oven at 40ºC for 7 hours to obtain dry pectin [18].

3) Making Bioplastics

Five grams of extracted pectin were dissolved using 100 mL of distilled water and were heated at 60ºC. Next, 1.5 grams of chitosan were dissolved with 5 mL of 3% citric acid and stirred until homogeneous. After that, the chitosan solution was added to the pectin solution and stirred until homogeneous. Then add 3 mL of sorbitol (for non-plasticizer samples, sorbitol does not need to be added) and heat until it reaches a temperature of 80ºC; maintain this temperature for 10 minutes. Then, the mixture was placed into a mold/baking pan and dried at 40-50ºC.

4) Result Analysis

a) Thickness

The resulting bioplastic was measured using a micrometer with an accuracy of 0.001 mm.

b) Tensile Strength Test

The tensile strength test was carried out in this research using an Electronic Universal Testing Machine. The way it works is that the bioplastic will be pulled from two directions, resulting in an increase in length and a reduction in diameter. The tensile strength test can be calculated using the formula:

$$TS = \frac{F_{max}}{A_0} \tag{1}$$

Notes: TS is tensile-strength, F_{max} is maximum force, and A_0 is the initial surface area of the sample.

c) Elongation Test (%)

The elongation test, or percent elongation, is a test to compare bioplastics when broken and before being pulled. The elongation test can be calculated using the formula:

$$e(\%) = \left[\frac{(L_1 - L_0)}{L_0}\right] \times 100\% \tag{2}$$

Notes: L_1 is the final length of the sample, and L_0 is the initial length of the sample.

d) Water Uptake Test

The bioplastic was cut into 3 cm x 3 cm pieces, weighed as W_0, and then placed in a petri dish filled with 15 milliliters of distilled water for 10 minutes. The water attached to the sample is dried with tissue and weighed as W_1. The formula for calculating water resistance is as follows [19]:

$$A(\%) = \frac{W_1 - W_0}{W_0} \times 100\% \tag{3}$$

Notes: A is water absorption (%), W_0 is the initial weight sample (g), and W_1 is the sample weight after immersion (g).

3. Results and Discussion

3.1. Effect of Temperature on the Yield Levels of Pectin Produced

The process of making bioplastics requires the main ingredient, namely starch. In this research, the starch used was kepok banana peel and plantain peel, and extraction was carried out to obtain the starch. This research shows that the higher the extraction temperature, the greater the pectin yield produced. It can be seen in Fig.1.

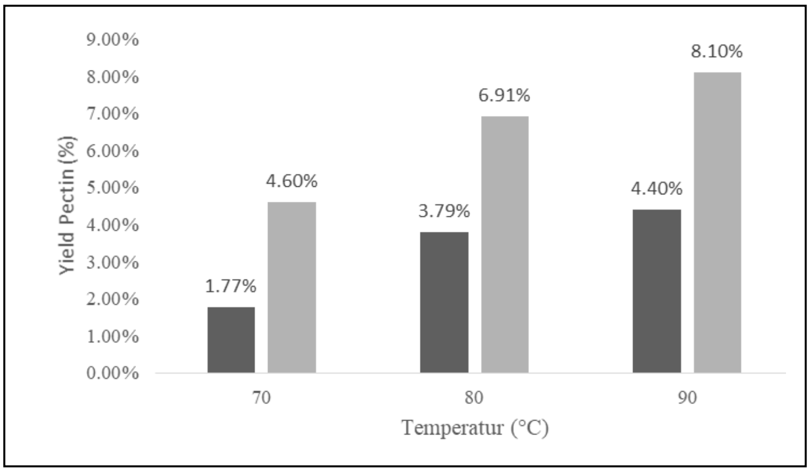

Fig. 1. Effect of temperature on pectin yield levels

Based on Fig.1., the yield of pectin produced by kapok banana peel and plantain peel at a temperature of 70ºC is 1.77% and 4.60%, at a temperature of 80ºC it is 3.97% and 6.91%, while at a temperature of 90ºC, it is 4.40 % and 8.10%. From the results of the data analysis, it can be concluded that the highest percentage is 8.10% at a temperature of 90ºC, namely in the plantain peel variant [20]. This trend aligns with prior studies showing that elevated temperatures enhance pectin extraction by promoting cell wall breakdown and protopectin solubilization [21], [22].

Plantain peel consistently produced higher yields than kapok, likely due to differences in peel composition and structure. Previous research reported that plantain peels have more soluble dietary fiber, including pectin, than other banana varieties [23]. The 8.10% yield aligns with typical values from other fruit peels, such as mango or citrus [24], [25].

3.2. Effect of banana peel type on the thickness test

This study found that the thickness of bioplastic was in the range of 0.0025-0.0031 cm. Bioplastic thickness measurements in this study were carried out at 3 points for each bioplastic for each variation.

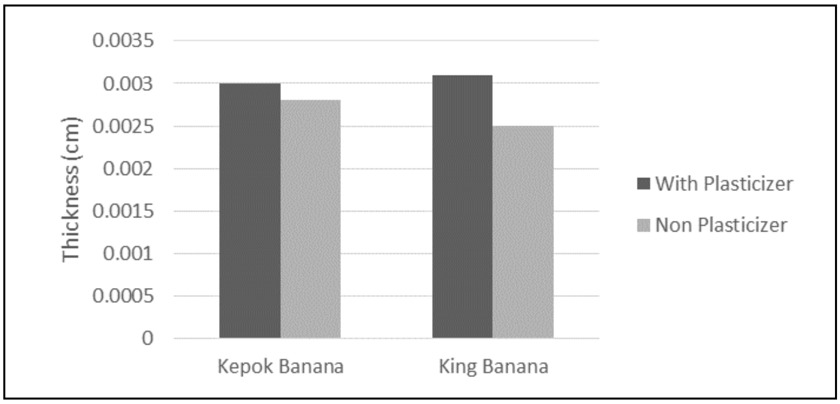

Fig. 2. Thickness test result

Fig. 2 illustrates the effect of plasticizer addition on the thickness of bioplastics derived from plantain peel. The maximum thickness recorded was 0.0031 cm with plasticizer, while the minimum, 0.0025 cm, was observed in bioplastics without plasticizer. These results indicate that plasticizer addition influences the bioplastic's physical structure, increasing its thickness due to enhanced polymer chain mobility and flexibility during film formation [26], [27].

Plasticizers such as glycerol are commonly used to improve film workability and reduce brittleness. However, their inclusion can also lead to structural expansion and higher moisture retention, thereby increasing thickness [28]. Among the samples tested, only the non-plasticized plantain peel bioplastic met the thickness requirement of the Japanese Industrial Standard (JIS) [29], which specifies a maximum thickness of 0.0025 cm for biodegradable films [5].

3.3. Average Tensile Strength of Bioplastics with Various Variations

The addition of plasticizers will affect the tensile strength of bioplastics, thereby reducing the tensile strength of bioplastics. This happens because plasticizers form hydrogen bonds, which cause a reduction in intermolecular bonds in the polymer matrix [16].

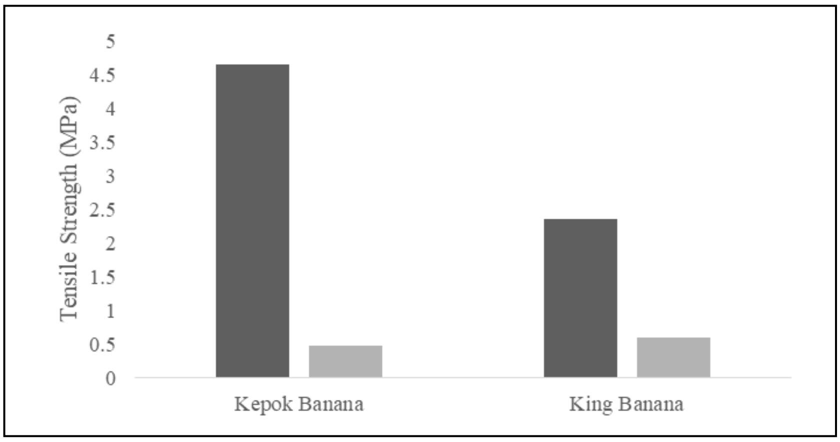

Fig. 3. Tensile strength of bioplastics with various variations

This research showed that the tensile strength of kepok banana peel bioplastic with plasticizers was 3.732-5.318 MPa, averaging 4.6546 MPa. In non-plasticizer Kepok banana peel bioplastics, it is in the range of 0.270-0.638 MPa with an average of 0.4802 MPa. Plantain peel bioplastics with plasticizers range from 1.946-2.934 MPa, averaging 2.3556 MPa. In non-plasticizer plantain skin, sorbitol ranges from 0.170-1.263 MPa with an average of 0.5932 MPa. According to the Indonesian

National Standard (SNI), it is known that the tensile strength of plastic is in the range of 24.7-302 MPa. When compared with SNI, the bioplastic results obtained are not appropriate [7], [3], [16], [30]. This study found that differences in tensile strength values were caused by differences in sample thickness, test preparation, the delay between making bioplastics and testing, and the storage time of bioplastics before testing.

3.4. Bioplastic Elongation Test with Various Variations

This research shows that adding plasticizers produces better elongation than non-plasticizer bioplastics. Thus, plasticizers can increase the flexibility of bioplastics but can reduce the tensile strength of the resulting bioplastics. The elongation test results of bioplastics on kepok banana skin were obtained in the range 2.616-3.360% with an average of 3%, and bioplastics on king banana skins were in the range 3.46-7.30% with an average of 5.4100%. The non-plasticizer bioplastic for kepok banana peel is 0.152-0.424% with an average of 0.28%, and for king banana peel, it is 0.096-0.728% with an average of 0.36%. According to SNI plastic standards, the elongation test ranges between 21% and 220%. Based on these standards, the research results do not meet the standards [1].

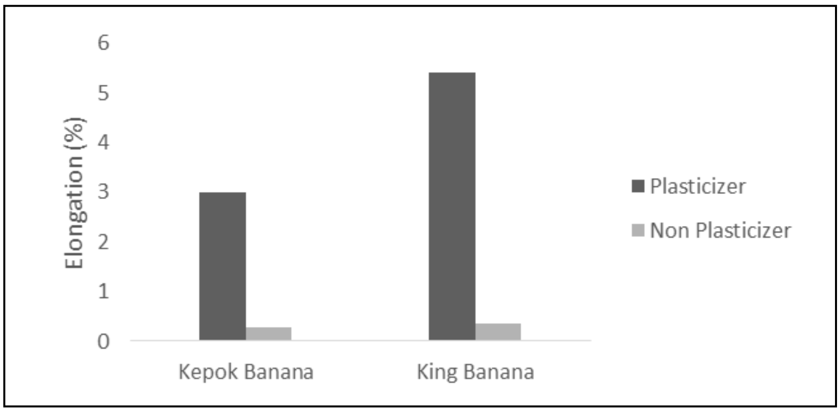

Fig. 4. Bioplastic elongation test with various variations

3.5. Water Absorbance Test

The water resistance test in this study aims to determine how many bioplastics can hold or absorb water, and this test also influences the rate at which bioplastics decompose; the greater the water resistance value, the longer the decomposition process will take.

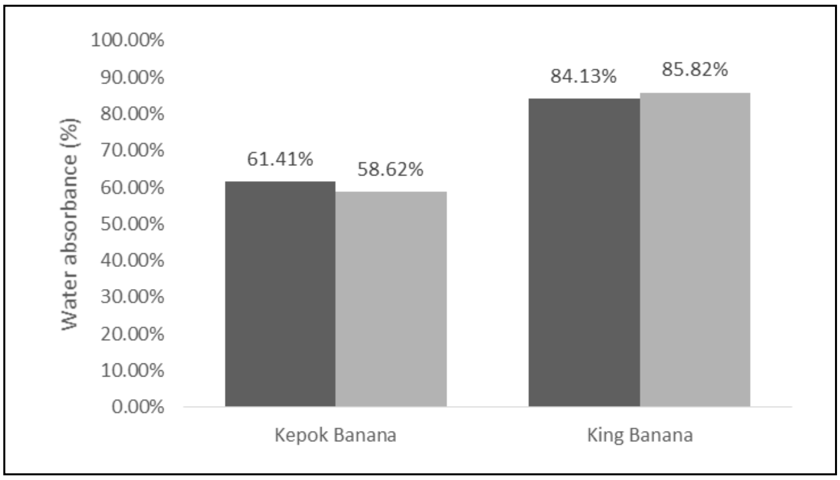

Fig. 5. Water absorbance test results

Fig. 5 shows that the water resistance of bioplastics made from kepok and plantain banana peels varies significantly with the addition of plasticizer. With plasticizer, water resistance dropped to 61.41% and 58.62%, respectively. In contrast, non-plasticized bioplastics showed improved resistance, with values of 84.13% (kepok) and 85.82% (plantain). These results demonstrate that plasticizer addition reduces the hydrophobicity of the bioplastic matrix, making it more susceptible to moisture absorption [26], [31].

The highest value achieved—85.82% for non-plasticized plantain peel bioplastic—still falls short of the Indonesian National Standard (SNI), which requires a minimum water resistance of 99% for biodegradable packaging materials [1]. This indicates that while plantain peel offers promising biopolymer characteristics, further formulation improvements are needed.

Plasticizers like glycerol disrupt internal hydrogen bonding between polymer chains, increasing free volume and water permeability [27]. Therefore, eliminating or optimizing the concentration of plasticizers, or blending with more hydrophobic agents such as beeswax or starch derivatives, could enhance water resistance. Future research should explore surface coatings or cross-linking methods to improve barrier properties [28], [32].

4. Conclusion

Based on the research that has been carried out, it can be concluded that the highest pectin yield is produced at a temperature of 90°C from plantain peel starch of 8.10%. The optimum bioplastic thickness, tensile strength, elongation, and water absorbance are for the king banana with values 0.0031 cm, 4.6546 MPa, 5.4100%, 0.36%, and 84.13%, respectively. Even though the result does not comply with SNI standards, banana peels are worth considering as a bioplastic material.

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