

Cellulose Impact on Bioplastic Performance: A Study on Mechanical Strength, Physical Properties, and Degradation of Water Hyacinth and Kepok Banana Peel-derived Materials

Faiza Armalia Putri^(1,a), Aditya Rianjanu^(1,b) and Wahyu Solafide Sipahutar^{(1,c)*}

⁽¹⁾Department of Materials Engineering, Institut Teknologi Sumatera, Lampung Selatan, 35365,
Email : ^(a)faiza.119360002@student.itera.ac.id, ^(b)aditya.rianjanu@mt.itera.ac.id,
^(c*)wahyu.sipahutar@mt.itera.ac.id

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Abstract. *Plastics, primarily made of synthetic polymers, are difficult to degrade by microbes, resulting in waste management challenges. Bioplastics are a viable alternative to conventional plastics' environmental problems. They are crucial for the circular economy transformation and sustainability goals. To address this issue, researchers investigated the formation of bioplastics from kepok banana peels (*Musa acuminata*) and water hyacinth (*Eichhornia crassipes*). This study investigates the mechanical properties, degradation rate, water absorption, and functional groups of these bioplastics. Different cellulose concentrations (0%, 4%, 8%, 12%, and 16%) are used throughout production process. The results show that cellulose content has a significant influence on the mechanical characteristics, degradation rate, and water absorption of bioplastics. Bioplastics with 2% cellulose had the best mechanical properties with a tensile strength of 2.551 MPa. On other hand, containing 4% cellulose degrade the fastest, losing 63.181% of their mass. This high degradation rate corresponds to the maximum amount of water absorption, which reaches 54.93%. Furthermore, the FTIR study shows that no novel functional groups were detected in the bioplastics. In conclusion, the used of kepok banana peel starch and water hyacinth to produce bioplastics shows potential as a solution to the problems faced by traditional plastics. This research shows that changing the cellulose content in bioplastics can lead to changes in mechanical qualities, breakdown rate, and water absorption. Further research in this area could pave the way for more ecologically friendly and sustainable alternatives to existing plastics.*

Keywords: *Bioplastic, Banana peel starch, Water hyacinth, Cellulose, FTIR*

INTRODUCTION

The growing demand for polymers is intimately related to the ongoing improvement of industrial technologies and the significant rise in the world population [1]. For its lightweight, water resilience, and affordability, synthetic polymer plastic is frequently utilized. However, its microorganism-resistant breakdown is an environmental problem. Recent research has

focused on biodegradable polymers to overcome this issue [2].

Bioplastics are a viable alternative to conventional plastics' environmental problems. They are crucial for the circular economy transformation and sustainability [3]. Bioplastics can minimize fossil fuel usage, create new recycling pathways, and employ less hazardous ingredients [4]. Bioplastics can also reduce uncontrolled dumping and dangerous chemical emissions from non-biodegradable plastics [5][6].

Bioplastic is a practical approach to investigating alternative sources of raw materials for plastic production. These alternative materials can be sourced from plants, particularly starch and cellulose. Bioplastics are made of vegetable starch, a potential component for developing sustainable resources well known for its high properties and low cost production. Starch is a natural polymer that has several industrial uses. Starch can be changed to improve its functionality for industrial applications. Starch, which is abundantly present in numerous plant components, including banana peels, tubers, seeds, and plant stems, provides a viable option [7]. Banana peels, for example, contain up to 27.70% starch, making them an ideal raw material for the manufacturing of bioplastics [8]. Aside from starch, bioplastics may be made from other plant substances such as cellulose, proteins, collagen, and casein. Cellulose is an effective bioplastic manufacturing material, a significant component of green plant cell walls. Water hyacinth was chosen as the cellulose source in this investigation due to its comparatively high cellulose content of around 64.51% [9]. A previous study using water hyacinth and banana peels as raw materials for ecologically friendly straws resulted in a 65% disintegration rate within four days, satisfying SNI (Indonesian National Standards) criteria [10].

The enzymatic degradation of water hyacinth was explored by Zhao X et al. [11]. This research has potential implications for comprehending the breakdown of materials originating from water hyacinth. Furthermore, the mechanical properties of thermoplastic starch bio nanocomposites reinforced with water hyacinth nanofiber cellulose were investigated by Asrofi et al. [12]. This study provided insights into the mechanical strength characteristics of materials obtained from water hyacinths [12]. In addition, Ungprasoot et al. conducted a study on the utilization of water

hyacinth, for the synthesis of biopolymers and biodegradation. This research might provide valuable information on the physical characteristics and degradation patterns of materials obtained from water hyacinth [13]. Bioplastics were created in this study utilizing starch from banana peels and cellulose from water hyacinth as the primary raw components. Glycerol and PVA plasticizers were also included in the production process. The study involved various tests, including degradability, water absorption, tensile strength, and FT-IR analysis, to evaluate whether the bioplastics met the standards set by the Indonesian National Standards.

Using banana peels and water hyacinth as alternative polymer materials serves an important economic purpose and can transform agricultural by-products into environmentally friendly bioplastic products. This approach offers a sustainable solution to meet the growing demand for plastics while simultaneously reducing the environmental impact associated with traditional petroleum-based plastics.

MATERIALS AND METHODS

The raw materials employed in this study consisted of kepok banana peel starch and water hyacinth powder, while the chemicals utilized included distilled water, NaOH, glycerol, and polyvinyl alcohol (PVA). The process of extracting starch from banana peels commenced with the washing of banana peels, followed by cutting the washed banana skins into small pieces. Next, the banana peels were mixed with 1 liter of water and pulverized using a blending machine. After blending, the mixture was filtered using a sieve to yield a filtrate (water and precipitate from the refinement). Subsequently, the resulting filtrate was left for 24 hours at room temperature, and the starch precipitate was dried in an oven at 200°C for 2 hours. The

dried starch was then milled and passed through a 100-mesh sieve. For the water hyacinth stems, they were dried until free of water content and then mashed using a crushing machine. The delignification solution was prepared by homogenizing 25 g of NaOH dissolved in 500 mL of distilled water in a 500 mL beaker, using a hot plate and magnetic stirrer at 330 rpm for 1 hour at room temperature, resulting in a 5% NaOH concentration. Subsequently, 20 g of water hyacinth was soaked in the NaOH solution on a hot plate and magnetic stirrer at 220 rpm for 2 hours at 100°C. The resulting fibers were washed with running water until they reached a neutral pH, then dried in an oven at 50°C for 3 hours. After drying, the fibers were crushed using a grinding machine and sieved through a 100-mesh sieve. The fabrication of bioplastic films based on banana peel starch with different water hyacinth cellulose variations, namely 0% (V1), 4% (0.12 g, V2), 8% (0.24 g, V3), 12% (0.36 g, V4), and 16% (0.48 g, V5) was conducted. Additionally, 60 mL of distilled water, 3 g of PVA, and 1.2 mL of glycerol were mixed in a 100 mL beaker. The 60 mL of distilled water was heated on a hotplate to 80°C, followed by homogenizing 3 g of PVA with distilled water on the hot plate at 80°C for 10 minutes and 900 rpm. Once homogeneous, the banana peel starch, water hyacinth cellulose, and 1.2 mL of glycerol were added to the mixture and stirred for 10 minutes at 80°C with a speed of 250 rpm. The solution was poured into a stainless-steel mold coated with Teflon paper and wax, measuring 15 cm x 23 cm, and then placed in a preheated oven at 70°C for 1 hour. Subsequently, a bioplastic film was released from the mold.

Biodegradable Testing

The objective of the biodegradation test was to assess the extent of decomposition undertaken by microorganisms in the soil on bioplastic samples. In accordance with the National Standardization Agency of

Indonesia (SNI 7188:7:2016, biodegradable standard), the biodegradation test was conducted using the soil burial test technique. The bioplastic specimen, with dimensions of 2 cm x 5 cm, was initially weighed and thereafter submerged in the soil to a depth of 2 cm for a duration of 7 days. The disparity between the original and final masses of the bioplastic was documented as the mass of the deteriorated sample.

Moisture Absorption Test

The water absorption test's objective was to assess the bioplastic's capacity to endure the hydrophilic environment. The water absorption testing procedure was conducted in accordance with ASTM D5229. The original mass of a sample measuring 3cm x 3cm was obtained by weighing. Subsequently, the specimen was immersed in water for one minute to determine the extent of water absorption. Subsequently, the surface of the specimen was desiccated using a tissue, and a further weighing was conducted to determine the overall mass acquired.

FTIR Test

The FTIR spectrophotometer (IR Prestige, Shimadzu) was used to conduct Fourier transform infrared spectroscopy investigations on untreated and treated fibers. At atmospheric conditions, the spectra were collected with a scan rate of 32 scans per minute and a resolution of 4 cm⁻¹ within the wavenumber range of 4000 cm⁻¹ to 500 cm⁻¹. The microstructure of the natural fibers was evaluated using the transmittance curve of Fourier Transform Infrared Spectroscopy (FTIR).

Tensile Test

The optimization of bioplastics was performed by mechanical testing, following the ISO 527 standard methodology. The testing was conducted using a Universal Testing Machine fitted with a 10 kN load cell. Individually produced film was used to

cut rectangular pieces of 3 x 4 cm. The grip separation was initially established at 50mm, while the preload speed was set at 50 mm/min. The mechanical testing results yielded the values of tensile strength (TS), elongation (Strain), and Young Modulus (YM).

RESULT AND DISCUSSION

Figure 1. shows that bioplastic films made from kepok banana peel starch and water hyacinth cellulose produce a brownish bioplastic film, and the color is produced by the enzyme polyphenol oxidase. Then, each variation in this bioplastic film research has a thickness of 0.20 mm.

Biodegradable analysis

Physical conditions and weight were analyzed on bioplastic films made from kepok banana peels reinforced with cellulose from water hyacinth, which were subjected to soil testing. On the first day, the bioplastic film showed no physical changes. After one week, the bioplastic film was reevaluated, and it was observed that wrinkles had developed on the cut edges of the film.

Bioplastic film samples containing starch without the addition of cellulose will degrade much faster than those with cellulose reinforcement [14]. The presence of cellulose, with its crystalline parts consisting of straight and long chains with strong hydrogen bonds, contributes to slowing down the degradation process [15]. Moreover, the incorporation of cellulose nanocrystals and nanofibers has demonstrated the ability to enhance the barrier characteristics of starch-based films, indicating the possibility of improving the features of bioplastics derived from banana peels [16]. The results of this analysis will be further discussed in the FTIR test.

Soil biodegradability tests are essential for assessing the extent of bioplastic degradation in the environment and

estimating the time it takes for bioplastics to break down. In this study, the soil burial test method was employed, ensuring stable soil temperature and humidity conditions [17]. The pH parameter of the soil used was 7.86, with a soil temperature maintained at 25°C.

The degradation of bioplastic films at variations V1, V2, V3, V4, and V5 resulted in degradation values of 36.88%, 63.18%, 24.326%, 18.47%, and 1.72%, respectively. The highest degradation value was observed in variation 2, where 4% (0.12 g) cellulose was added, leading to a mass loss value of 63.181% on the seventh day. According to SNI 7188:7:2016, a bioplastic sample's degradation percentage should be > 60% within seven days to meet the National Standardization Agency of Indonesia (SNI) biodegradable standards. Therefore, it can be concluded that samples with this variation comply with the SNI biodegradable standards.

Moisture Absorption Analysis

The water absorption capacity test was conducted using 20 ml of distilled water with a soaking time of 20 seconds. The result of the moisture absorption test of bioplastic displayed in Figure 3 and Figure 4 showed the treatment process and the result of the moisture absorption test.



Figure 1. Bioplastic film

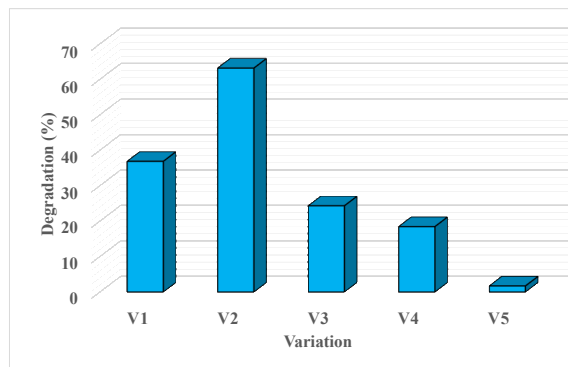


Figure 2. Bioplastics degradation rate (%)

There is a correlation between biodegradability testing and water absorption testing, wherein a higher cellulose content in the sample leads to increased hydrophobicity. The water absorption values for V1, V2, V3, V4, and V5 were found to be 46.04%, 54.93%, 51.51%, 50.80%, and 36.38%, respectively. Variation 2 exhibited the highest hydrophilic property, with a water absorption value of 54.93%. This observation aligns with the biodegradability test results, where variation 2 showed the highest degradation value compared to the other four samples. Consequently, adding cellulose can reduce the hydrophilic nature of bioplastic films, and the excessive use of glycerol can also increase the hydrophilicity of bioplastic films [18], [19]. Both glycerol and PVA contain hydroxyl groups (-OH) capable of forming hydrogen bonds. Glycerol reduces the internal hydrogen bonds of starch and increases the distance between molecules, thus reducing water absorption and increasing the hydrophobicity of bioplastics. Bioplastics with strong intermolecular bonds tend to be more hydrophobic, hindering water molecules from entering and interacting with the polymer structure. On the other hand, bioplastics with weaker bonds or hydrophilic groups tend to be more hydrophilic, as they easily interact with water [20].

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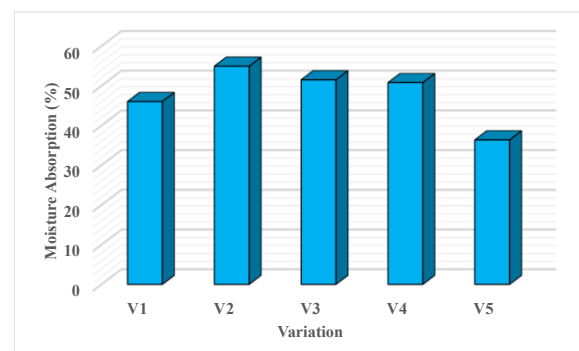


Figure 3. Moisture Absorption rate (%)

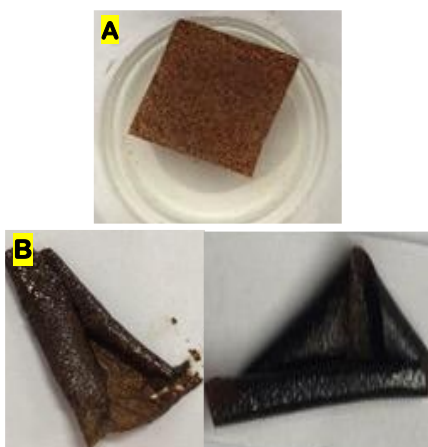


Figure 4. a) Bioplastics immersed in water
b) The result of bioplastics after water absorption testing

FTIR analysis

The spectrum of bioplastic films V1 and V5 exhibited wave numbers of 3667 cm^{-1} and 3272 cm^{-1} , respectively as shown in figure 5. O-H hydroxyl groups are attributed to starch as a raw material for bioplastic films. The abundance of O-H groups allows it to form bonds with water. The wave number 2922 cm^{-1} indicates the C-H spectrum of alkanes derived from glycerol and PVA, both derivatives of alkanes, and these compounds possess water-soluble properties. The presence of the C-O ester group at wave number 1259 cm^{-1}

demonstrates the typical characteristics of starch. The C-O ester bond is hydrophilic and can facilitate degradation [21]. The appearance of the C=C group at 797 and 1610 cm^{-1} indicates the presence of lignin compounds derived from the starch and cellulose used. Lignin is hydrophobic and can act as a UV barrier and an antimicrobial agent. The C-N functional groups at wave numbers 1021 and 1028 cm^{-1} indicate the presence of protein, which is hydrophilic. In the bioplastic films based on Figures 8 and 9, the FTIR spectra of bioplastics V1 and V5 showed only a decrease in the transmission value and shifts in functional groups. No new functional group peaks emerged. The shift in peak frequency in the FTIR spectrum is dependent on the molecular mass. If the peak shifts towards the higher wavenumber side, it indicates a decrease in the molecule's mass because the vibrational frequency is inversely proportional. The shift in the position of the maximum peak in the FTIR spectrum may be due to a change in the relative contribution of two overlapping bands rather than a gradual shift in the frequency of one band caused by specific chemical bonds influenced by molecular interactions [22], [23].

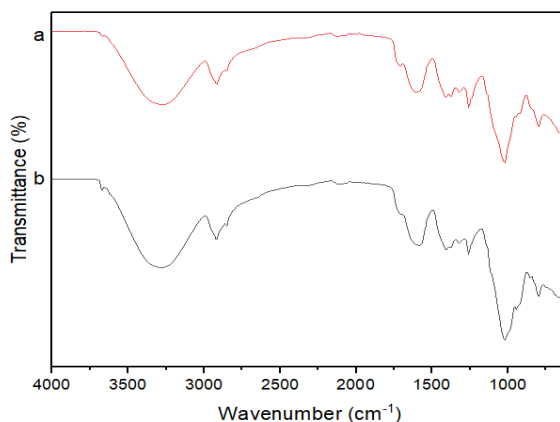


Figure 5. FTIR (a) Variation 5 (16% Cellulose) (b) Variation 1 (0% Cellulose)

Tensile properties

The mechanical properties were evaluated using a Universal Testing Machine tensile tester, following the ISO 527 standards, with a tensile speed of 100 mm/minute. The sample size was 10mm x 100mm, with an initial gauge length (L0) of 5 cm and a thickness of 0.2mm. The result mechanical properties of bioplastic displayed in Figure 6 and the details of tensile properties are shown in Table 1.

The results of the tensile test strengths for V1 (2.241 MPa), V2 (2.413 Mpa), V3 (2.524 Mpa), V4 (2.551 Mpa), and V5 (1.758 MPa). The filler and additives used during the production of bioplastic films greatly influence their tensile strength. In the case of samples V1, V2, V3, and V4, the tensile strength values increased, whereas sample V5 exhibited decreased tensile

strength due to an imbalance in the glycerol material. Glycerol is frequently employed as a plasticizer in the production of bioplastics. This process reduces intermolecular forces and increases the mobility of polymer chains, thereby enhancing the plastic's flexibility and brittleness [24-25]. The results of the tensile test demonstrate that the addition of cellulose can enhance the tensile strength of bioplastic films in specific variations. Cellulose is very crystalline, hence adding it to starch-based films can boost their crystallinity. Tensile strength and stiffness improve with crystallinity [14]. This observation underscores the importance of choosing appropriate materials and compositions to optimize the mechanical properties of bioplastics for different applications.

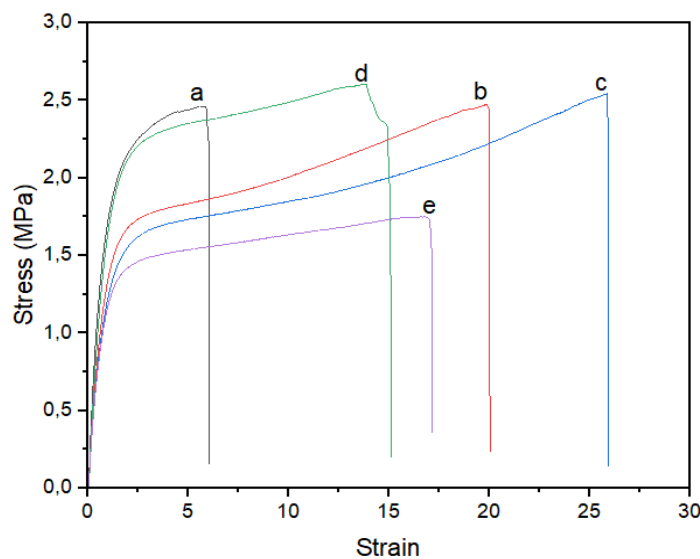


Figure 6. Tensile Test (a) Variation 1 (0% Cellulose) (b) Variation 2 (4% Cellulose) (c) Variation 3 (8% Cellulose) (d) Variation 4 (12% Cellulose) (e) Variation 5 (16% Cellulose)

Table 1. Tensile stress – strain bioplastic

Variation	UTS(MPa)	Yield Strength	Strain
V1	2,241 ± 0,220	0,885 ± 0,122	5,369 ± 0,675
V2	2,413 ± 0,63	1,080 ± 0,024	19,859 ± 0,170
V3	2,524 ± 0,021	0,905 ± 0,050	27,157 ± 1,227
V4	2,551 ± 0,056	1,135 ± 0,075	14,038 ± 1,063
V5	1,758 ± 0,009	0,780 ± 0,025	15,134 ± 2,032

CONCLUSION

Based on the research results, the degradation value of the bioplastic film in variation 2 with the addition of 4% cellulose yields 63.18% and meets SNI 7188:7 2016 in terms of soil degradation. In line with the rate of degradation in the degradation test, the results of the water resistance test carried out for 20 seconds resulted in variation 2 with the addition of 4% cellulose having a high hydrophilic value of 54.93%, and the more cellulose content, the more hydrophobic. The tensile strength produced in this study increased with the addition of cellulose, with the highest tensile strength value of 2.55 MPa, in variation 4 with the addition of 12% cellulose. In this study, the FTIR testing of bioplastic films was carried out to determine the functional groups present in the bioplastic films, resulting in no new functional groups appearing. To summarise, the incorporation of cellulose into bioplastic films can improve their mechanical characteristics by virtue of their elevated tensile strength, rigidity, and ability to resist water absorption. Potential for future engineering applications, bioplastic water hyacinth and kepok banana are environmentally friendly materials that are readily available and inexpensive.

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