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Research Article

Quality Evaluation of Bioplastic from Glutinous Rice Starch Reinforced with Bamboo Leaf Powder

Pengujian Kualitas Bioplastik dari Pati Beras Ketan Berpenguat Serbuk Daun Bambu

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Abstract

Plastics are widely used in various aspects of life due to their variety of superior properties. However, they contribute a negative impact on the environment, which leads to the search for an alternative solution such as the production of bioplastics as biodegradable plastics. Therefore, this study aims to evaluate the psycho-mechanic quality of bioplastic from glutinous rice starch reinforced with bamboo leaf powder. The bioplastic synthesis process was carried out using 0, 1, 3, 5, and 7% (w/w) variations of bamboo leaf powder on glutinous rice starch, respectively. The results showed that the best bioplastic composition was the addition of 3% (w/w) bamboo leaf powder to glutinous rice starch. This indicated that the addition of bamboo leaf powder in bioplastics can enhance the thickness, hardness, and tensile strength significantly. Meanwhile, the value of density, water vapor transmission rate, and elongation showed a slight increase, and the bioplastic also degraded more than 70% for 7 days.

Keywords: bioplastic; bamboo leaf powder; glutinous rice starch; psycho-mechanic properties

Abstrak

Plastik menawarkan berbagai sifat unggul sehingga banyak digunakan dalam berbagai aspek kehidupan. Namun, beberapa plastik berdampak negatif terhadap lingkungan. Bioplastik dapat menjadi solusi alternatif sebagai plastik yang mudah teruarai secara alami. Tujuan penelitian ini yaitu untuk mengetahui kualitas fisik-mekanik komposit bioplastik pati ketan berpenguat serbuk daun bambu dengan mempertimbangkan komposisi terbaik. Pati ketan yang mengandung amilopektin tinggi berperan sebagai matriks dalam produksi bioplastik. Sedangkan serbuk daun bambu merupakan sumber biosilika yang digunakan sebagai bahan pengisi. Penelitian ini dilakukan proses sintesis bioplastik dengan variasi pati daun bambu pada pati ketan masing-masing 0, 1, 3, 5 dan 7% (b/b). Hasil penelitian menunjukkan bahwa komposisi bioplastik terbaik adalah penambahan serbuk daun bambu 3% (b/b) pada pati ketan. Kesimpulannya, penambahan serbuk daun bambu sebagai bahan pengisi pada bioplastik pati ketan mampu meningkatkan ketebalan, kekerasan dan kekuatan tarik secara signifikan. Bioplastik juga mengalami degradasi secara alami lebih dari 70% selama 7 hari.

***Kata kunci**: bioplastik; serbuk daun bambu; tepung ketan; sifat fisik-mekanik.*

1. Introduction

The use of plastics cannot be avoided by human life because of their variety of superior properties. Generally, plastics are light, strong, durable, corrosion-resistant, flexible, inert, not easily broken, easy to obtain, color, as well as shape, and can be widely applied in various temperature ranges [1]. There is currently a significant increase in plastics production annually due to their wide application in various aspects of life.

Plastics provide millions of benefits but they also have various disadvantages that affect the environment. The burning of plastics can produce toxic gases, namely dioxins [2]. This is because several plastics are also not easy to recycle and are being disposed of into the environment both landfill and ocean. Based on data from the Ministry of Environment and Forestry of the Republic of Indonesia [3], approximately 6,300 million tons of plastic waste has been generated globally per year with an estimated 79% in landfills or accumulated in the environment. They take years to decompose by the activities of organisms and can cause environmental damage [4]. One of the alternative solutions to overcome this problem is the production of bioplastic as biodegradable plastics.

Bioplastics are organic-based plastics that can be decomposed by microorganisms into carbon dioxide in aerobic processes or methane in anaerobic processes in a relatively short time [2]. They are polymers composite made from renewable sources such as polysaccharides, proteins, lipids, or current substances derived by several microorganisms [5]. Bioplastics have properties that refer to the conventional ones, therefore, they can replace the plastic function.

The bamboo leaf is one of the agricultural wastes, which is only burned or used as compost materials [6]. Bamboo is a source of biosilica [7], with a silica content of about 17-23%, higher than the 9.3-13.5% in rice husks [6]. According to Warsiki *et al*. [8], the physical and mechanical properties of bioplastic composites can be improved by using silica as a reinforcement. Therefore, bamboo leaf powder is a source of biosilica that can be used as a filler for bioplastics.

In Indonesia, glutinous rice starch (*Oryza sativa glutinosa*) is widely found. and can be obtained at low prices. White glutinous rice starch contains 99% amylopectin and 1-2% amylose [9], which affect the stability of bioplastics and compactness, respectively [10]. The high amylopectin levels can facilitate the starch gelatinization process and cause a lot of space that can be filled by the other biopolymer to bind [8]. In bioplastic production, the glutinous rice starch containing high amylopectin acts as a matrix.

Several investigations related to the development of bioplastics from organic materials have been carried out. However, no information on the use of bamboo leaf containing biosilica as a filler and glutinous rice starch with high amylopectin as a matrix in bioplastics production. Therefore, this study was conducted to determine the effect of using glutinous rice starch reinforced with bamboo leaf powder on the psycho-mechanic characteristics and biodegradability of bioplastic composite by considering the best composition.

2. Research Methods

2.1 Materials

The glutinous rice was obtained from a local market in Yogyakarta, Indonesia. It was sieved to reach a uniform size in 40 mesh. The bamboo leaf waste was provided on plantation land in Rembang, Central Java, Indonesia. They were cleaned, milled, and sieved to powder form in size 100 mesh. Aquadest and glycerol from food-grade, UniChem Candi, Indonesia were purposed for bioplastic production.

2.2 Methods

This study was carried out in a schematic diagram as depicted in Figure 1. Concisely, the methods involved several main steps, namely experiment preparation, bioplastic production, physical characteristics evaluation, and mechanical properties evaluation. The psycho-mechanic characteristics were used to predict the best composition of bioplastic composite from glutinous rice starch reinforced with bamboo leaf powder.

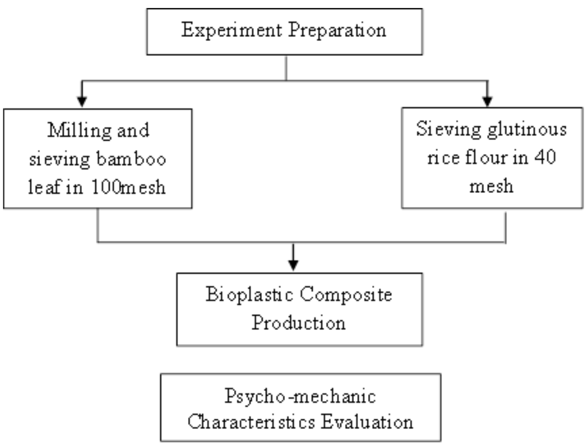

Figure 1. The schematic diagram of the research

2.3 Bioplastics Composite Production

The bioplastic composites were produced by adding bamboo leaf powder in glutinous rice starch under various composition ratios, namely 0, 1, 3, 5, and 7 % (w/w), respectively. They were dispersed in 100 ml aquadest. The process was carried out on a hot plate at around 90°C temperature and 436 rpm stirring speed using a magnetic stirrer for 10 minutes. Approximatly 30% plasticizer was added by volume of glycerol for each weight of glutinous rice starch, successively and the solution was stirred again until homogeneous. The molding process was carried out using a 25x25cm tray and dried at 50°C for 24 hours. Subsequently, the bioplastic composites that had been removed from the mold were evaluated for their physical and mechanical characteristics [13,18].

2.4 Physical Characteristics Evaluation

The physical characteristics analyzed were thickness, moisture content, hardness, density, and water vapor transmission rate. The thickness of the bioplastic composite was measured by a micrometer with an accuracy of approximately 0.0001 mm. The sample was cut at a size of 2×2 cm^2 and tested at 10 different points. The thickness bioplastic was determined using equation 1 [13].

$$\text{Thickness} = \frac{\text{Sum of measured value}}{10} \quad \text{........(1)}$$

The hardness tests are used to evaluate response under compressive load. Generally, the hardness of most plastic materials is measured using a durometer scale of Shore D. Testing was carried out at 5 different points on the sample. The hardness value of the bioplastic is expressed as the average of the measurement results [12].

The density value can be determined by the mass and volume ratio of the sample. The mass (m) of the sample was weighed using an analytical balance with an accuracy of 0.0001 g. The volume of the sample was calculated based on the area (A) and thickness (d) value of the bioplastic [13].

The moisture content is the amount percentage of water in a material. Meanwhile, the moisture content of bioplastic was measured by gravimetric analysis for 24 hours at 105°C using a drying oven [14]. It can be calculated based on initial and final weight data during drying as expressed in equation 2 [13].

$$\text{Moisture Content} = \frac{W_1 - W_2}{W_1} x\ 100\ \% \quad \text{........(2)}$$

The water vapor transmission rate (WVTR) test is used to measure the permeability of bioplastic under specific conditions of temperature and relative humidity [15]. The samples were cut at a size of 2×2 cm^2 and conditioned into a desiccator filled with distilled water with humidity (RH) of 80%. The WVTR was analyzed by weighing the samples every 2 hours for 24 hours. The WVTR value of the bioplastic was obtained by comparing the specimen weight (W) to the area of specimen (A) and 24 hours of time (t) as stated in equation 3.

$$\text{WVTR}\ (\text{g/m}^2) = \frac{W}{A\ x\ t} \quad \text{..................(3)}$$

2.5 Mechanical Characteristics Evaluation

The mechanical characteristic test for bioplastics-based glutinous rice starch reinforced with bamboo leaf powder was carried out by measuring the tensile and elongation.

Tensile strength is the amount of maximum force as the ability of the material to hold the strain before breakage [12]. The instrument used for testing tensile strength was Universal Testing Machine (Shimadzu, Japan). Furthermore, the specimen was elongated with a certain load and speed before breakage. The maximum force required to break the specimen is recorded as F. The value of tensile strength (τ) was obtained from the ratio of maximum force (N) to the cross-sectional area of the specimen (width x thickness) mm^2. The tensile strength was quantified by equation 4.

$$\tau\ (MPa) = \frac{F_{max}}{A} \quad \text{..................(4)}$$

Elongation is an extension in length of the specimen to break under tension. It was expressed as a percentage of the length before breaking when stretched. The elongation measurement is carried out simultaneously with the tensile test. The percentage of elongation was obtained using equation 5.

$$E\ (\%) = \frac{\Delta L}{L_0} \quad \text{......................(5)}$$

2.6 Biodegradability Evaluation

The biodegradable was evaluated using a decomposition test by burial in the ground [16]. The sample was cut at a size of 4×4 cm^2 and buried in the soil at a 10 cm depth. The weight loss was measured by weighing the sample daily for 7 days. The biodegradation of bioplastics was obtained using equation 6 for weight loss.

$$\text{Biodegradibility} = \frac{W - W_0}{W_0} x\ 100\% \quad \text{..........(6)}$$

3. Results and Discussion

This study aims to evaluate the quality of bioplastic composite from glutinous rice starch reinforced with bamboo leaf powder, especially psycho-mechanic characteristics. The experimental results showed the effect of using bamboo leaf powder on the quality of bioplastic. It was also discovered that glutinous rice starch can be an alternative raw material for making bioplastics due to the high amylopectin that acts as a matrix in bioplastic. Meanwhile, bamboo leaf powder is a source of biosilica used as filler.

3.1 Physical Characteristics Bioplastic

The physical characteristics of bioplastic, namely thickness, moisture content, hardness, density, and water vapor transmission rate were used to evaluate the quality. The results showed that the addition of bamboo leaf powder affects the thickness, hardness, and density of the bioplastic as presented in Table 1.

The higher amount of bamboo leaf powder caused an improvement in the thickness, density, and hardness value of the bioplastic. Table 1 revealed that the highest thickness of the bioplastic, which is 0.3419 mm was obtained using 7% bamboo leaf powder. Previous studies have stated that thickness can influence the characteristics of the composite [17], while bamboo leaf powder is used as an additive that contains high biosilica [18]. Silica is an amorphous molecule with a relatively large particle size, which can affect the thickness of the bioplastic [13]. The results showed that the percentage concentration of added filler obtained different thicknesses [19,23]. Hence, the higher the filler concentration, the more thickness the bioplastic will produce. This showed that thickness is one of the characteristics of bioplastics that impact its physical and mechanical properties [19].

Table 1. Effect of bamboo leaf powder amount on the thickness, hardness, and density of the bioplastic

Bioplastic Sample	Amount of Bamboo Leaf Powder (w/w) %	Thickness (mm)	Hardness (Shore D)	Density (g/cm^3)
A	0	0.2167	11	1.2615
B	1	0.2486	12	1.3812
C	3	0.2810	17	1.3889
D	5	0.3180	20	1.4203
E	7	0.3419	21	1.4611

In line with the result of thickness, Table 1 informs that the high addition of biosilica in bioplastics can enhance the value of hardness. The highest hardness value was 21 Shore D in addition to 7% bamboo leaf powder content. The hardness value also was influenced by the thickness of bioplastics. Consequently, the higher bioplastic thickness causes an increase in the hardness value, which shows the response of the material under compressive load [12].

The density values in polymer indicate the compactness of the composite materials. Density is one of the requirements to determine the quality of packaging bioplastics. Based on Table 1, the density of bioplastics was significantly affected by the increasing concentration of bamboo leaf powder. In this study, bioplastics that was not added bamboo leaf powder had a relatively low-density value of 1.2615 g/cm^3.

The density of bioplastic composites increased the higher the volume fraction of nanosilica was added [8]. Moreover, the high-density value is also related to the thickness of the bioplastic. Density increases with increasing thickness. Oluwasina *et al*. [13] stated that thickness influences the density value due to the presence of additive particles in bioplastics.

The low percentage of moisture content in bioplastics as a packaging material has a longer shelf life and can protect against spoilage due to microbial activity [20]. Bioplastic is often expected to have relatively low moisture content. In this study, the lowest value was recorded at 10.3% with the addition of 7% bamboo leaf powder. Oluwasina et al. [13] explained that amorphous silica can enhance the moisture content of bioplastics compared to other additives. However, the percentage of moisture content in the bioplastics decreased with further addition of silica concentration as revealed in Figure 2. Since the bamboo leaf powder contains biosilica which tends to be hydrophobic [8], little amount of moisture content was trapped in the bioplastic. Furthermore, the hydrophobic material decreases the solubility [20].

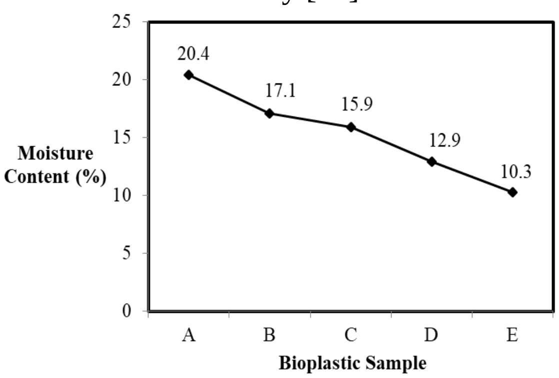

Figure 2. The percentage of bioplastic moisture content (wet basis) from glutinous rice starch reinforced with bamboo leaf powder

The WVTR of bioplastic composite from glutinous rice starch reinforced with different concentrations of bamboo leaf powder is depicted in Figure 3. The results showed that the WVTR value gradually reduced with increasing bamboo leaf powder content in the range of 9.421-15.124 g/m^2. Figure 3 revealed that the highest WVTR value was 15.124 g/m^2 in the control treatment without bamboo leaf powder. Meanwhile, the lowest value was 9.421 g/m2 in the treatment with 7% bamboo leaf powder content. These results indicate that bamboo leaf powder containing biosilica had a positive influence on the WVTR value of bioplastics-based glutinous rice starch.

Several studies have reported that the addition of a small filler in the polymer matrix can reduce WVTR value significantly [11]. The biosilica as filler tends to be hydrophobic and improves the moisture barrier properties of bioplastics. This is because it creates tortuous pathways to block the moisture diffusion pathways [13]. Kavoosi et al. [22] discovered that the water vapor diffusion process in biofilm depends on the hydrophilic-hydrophobic properties of their components and the degree of cross-linking. The biosilica will fill the pores in the amylopectin structure of the composite matrix glutinous rice starch, which makes a compact crosslinking structure. It was also reported that the hydrogen bonds between the oxygen atoms of biosilica and glutinous rice starch matrix in bioplastics composites can reduce the permeability to water vapor [17]. Furthermore, the thickness of the bioplastic affects the permeability to water vapor. This showed that the thicker the bioplastic film, the lower the WVTR value [8].

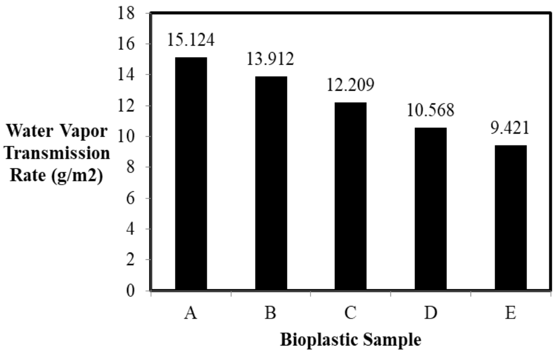

Figure 3. The water vapor transmission rate of bioplastic composite from glutinous rice starch reinforced with bamboo leaf powder

3.2 Mechanical Characteristics of Bioplastic

The mechanical characteristic test for bioplastics-based glutinous rice starch reinforced with bamboo leaf powder was carried out by measuring the tensile and elongation value. It is expected that the addition of filler in bioplastics composites significantly increases the mechanical strength especially tensile strength and elongation value [20]. The effect of bamboo leaf powder content on tensile strength in glutinous rice starch bioplastics is depicted in Figure 4.

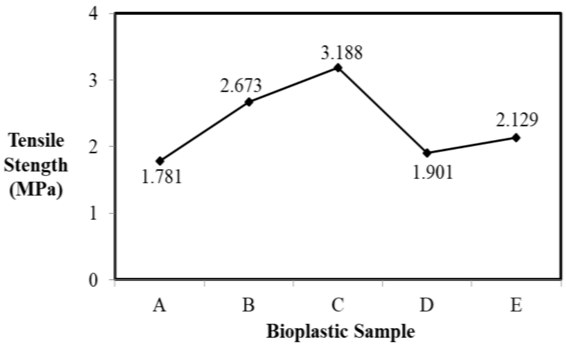

Figure 4. The effect of bamboo leaf powder content on tensile strength in glutinous rice starch bioplastics

Figure 4 informs that increasing content of bamboo leaf powder as a source of biosilica added to bioplastics in certain limits causes higher tensile strength values. In this study, the tensile strength increased to a maximum value of 3.188 MPa with the addition of 3% bamboo leaf powder. However, the value of tensile strength decreased when bamboo leaf powder content of more than 3% was added.

The higher addition of bamboo leaf powder as a source of biosilica increases the particle interaction, which makes the material stronger. Torabi and Nafchi [11] confirmed that nanosilica as a filler can enhance the mechanical performance of bioplastic due to their interaction with hydroxyl groups and other hydrogen or Van der Wall's bonds of starch to improve molecular strength. A previous report stated that the interactions of hydrogen generate molecular interactions that are getting stronger and harder to break because the process requires a lot of energy [23].

The amylose content of glutinous rice starch also affects the compactness of polymer networks in bioplastics to increase the mechanical properties [24]. However, there is a certain limit that the addition of filler cannot improve the mechanical properties of the composite. Generally, when the filler added exceeded a certain limit, it can create large agglomerates on the filler particles. This causes the reduction of interaction between the filler and the matrix in bioplastic composite [8]. Based on the results, the highest tensile strength of bioplastic was 3.188 MPa and did not meet the SNI 7188.7:2016 standard for moderate properties (10-100 MPa).

Elongation at the break of material shows an extreme extension in length of the specimen to break under tension associated with the initial length [20]. In most cases, elongation has a contrasting relation with tensile strength [11]. The influence of bamboo leaf powder content on elongation percentage in glutinous rice starch bioplastics is shown in Figure 5.

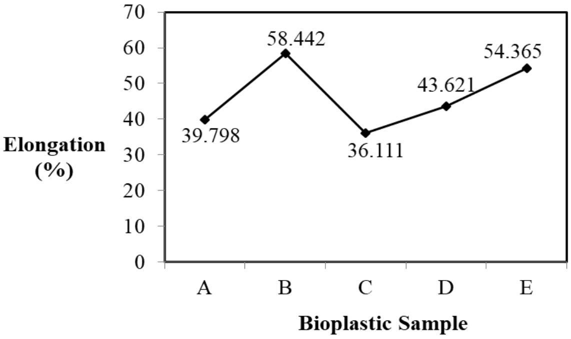

Figure 5. The effect of bamboo leaf powder content on elongation percentage in glutinous rice starch bioplastics

The addition of bamboo leaf powder in 0, 1, 3, 5, and 7% (w/w) significantly increased the tensile strength with a slight improvement in elongation. The higher value of elongation at break in bioplastic indicates it is more deformable [12]. The results also showed that the elongation percentage of bioplastic in various ratios of glutinous rice starch and bamboo leaf powder was around 39.798-58.442% and met the plastic standard of SNI 7188.7:2016 (21 - 220%) [25].

3.3 Biodegradability of Bioplastic

Biodegradability evaluation for plastics was carried out to ensure proper degradation in the environment [26]. Biodegradation of bioplastics is determined by the weight loss mass during the soil burial process at a certain time due to the activity of microorganisms. Generally, starch is a food source for microorganisms.

These microorganisms can damage the molecular structure of bioplastics, leading to the degradation and production of carbon dioxide [27]. Furthermore, microorganism enzymes can also break down polymer chains into monomers, which produce various organic compounds that are safe for the environment. The biodegradability of bioplastics from glutinous rice starch reinforced with bamboo leaf powder is revealed in Figure 6.

Based on Figure 6, the percentage of bioplastic biodegradation of glutinous rice starch at various concentrations of bamboo leaf powder was 70% and was not significantly different for 7 days of soil burial. This value has met the standard of biodegradability of bioplastics based on SNI 7188.7:2016. According to the Indonesian National Standard, the biodegradation value of bioplastics must be more than 60% during the 7-day testing process. Therefore, bioplastics from glutinous rice starch reinforced with bamboo leaf powder can be used as biodegradable plastic.

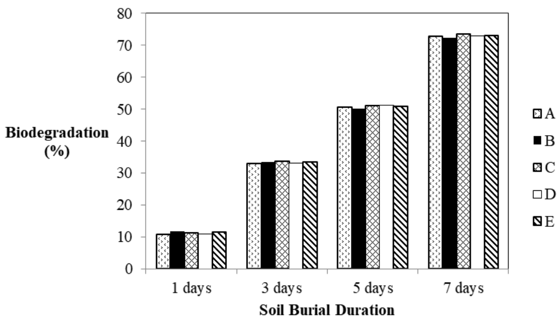

Figure 6. Biodegradability of bioplastics from glutinous rice starch reinforced with bamboo leaf powder

4. Conclusion

The results showed that the addition of bamboo leaf powder can improve the physical and mechanical properties of bioplastics. The addition of bamboo leaf powder to a reinforced bioplastic composite of glutinous rice starch enhanced the thickness and tensile strength significantly. Meanwhile, the value of density, elongation, and water vapor transmission rate showed a slight increase.

More than 70% of the bioplastics also degraded for 7 days. The best treatment was obtained on composite bioplastic with 3% bamboo leaf powder. However, the highest tensile strength value of 3.188 MPa of bioplastic had not reached the SNI standard for moderate properties, which ranged from 10 to 100 MPa.

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