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Physical Properties of Biofoam from Cassava Starch: An Environmentally Friendly Alternative to Conventional Styrofoam

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ABSTRACT

A study has been conducted on the manufacture of biofoam from cassava starch extract with the addition of peanut shell powder. There were 3 samples made in this study by heating using an oven (120°C, 140°C, 160°C) with the addition of magnesium stearate and ZnO. The quality characteristics of the synthesized biofoam were tested through water absorption tests, water content tests, leakage tests and biodegradable tests. The results of the water absorption test analysis obtained the percentage of each sample of 17.409%, 12.081%, and 4.049%. From these results, the temperature of 160°C which meets the SNI standard is 11.8682%. In the water content test, the percentage of each sample was 30.290%, 15.884%, and 9.615%. From these results, it has met the SNI standard of 26.12% except at a temperature of 120°C. In the leakage test, the results were obtained in the form of leaking samples on days 1, 2, and 4. In the biodegradable test, the percentage of each sample decomposed was 96%, 97%, and 100%, in the seventh week. Based on the biodegradable test, all samples can decompose well in a relatively fast time span and meet SNI, which is 100% for 60 days.

Keywords: Biofoam, Cassava starch, Peanut skin, Absorption capasity, Water content

1. INTRODUCTION

Single-use packaging like styrofoam is widely used due to its insulation properties, light weight, and temperature resistance [1],[2]. However, styrofoam waste poses environmental risks because it breaks into microplastics that pollute the air [3]. Recycling is possible but styrofoam contains styrene, a harmful compound linked to cancer and digestive irritation, especially when in contact with hot food [4].

To address these issues, bio-based polymers such as biofoam made from natural starch have been developed as safer, eco-friendly alternatives to Styrofoam [1],[5]. Indonesia's abundant agricultural resources, including various starch-rich crops, provide an excellent source for biofoam production[6]. Starch is renewable, biodegradable, cheap, and widely available, making it ideal for this purpose [7].

Peanut shells, usually considered waste, contain cellulose fiber, lignin, and hemicellulose, making them a potential natural filler to reinforce eco-friendly biofoam [8]. Starch-based biofoam has been widely developed using sweet potato, potato, corn, and cassava starch with added cellulose fibers to improve mechanical properties and water resistance [1],[3],[9],[10]. However, starch-based biofoam tends to absorb water due to the hydrophilic nature of cellulose. Therefore, adding water-resistant, biodegradable fiber fillers is necessary. ZnO is used as a binder to strengthen the biofoam structure[10].

This study uses cassava starch and peanut shell fibers with ZnO binder to produce biofoam that is strong, water-resistant, and biodegradable. The goal is to reduce water absorption, improve durability, and ensure complete biodegradation through testing.

2. MATERIALS AND METHODS

This study was conducted at the Laboratory Building of Universitas Singaperbangsa Karawang. The biofoam production process involved three main steps: extracting cassava starch, processing peanut shells into powder, and manufacturing the biofoam. The resulting biofoam samples underwent several tests, including water absorption, moisture content, leakage resistance, and biodegradability tests. The collected data were analyzed using the Analysis of Variance (ANOVA) method to determine the effect of different variables on the physical properties of the biofoam.

2.1 Materials

The materials used in this study consisted of cassava as a source of starch, peanut shells collected from plantations in Purworejo, Central Java, as well as zinc oxide (ZnO), distilled water, and magnesium stearate.

2.2 Experimental procedure

2.2.1 Preparation of Cassava starch

The cassava was first prepared and thoroughly cleaned. It was then grated using a grater. After grating, water was added, and the mixture was squeezed to separate the starch from the pulp. The extracted starch was allowed to settle for 12 hours to permit sedimentation of the starch particles. Once settled, the excess water on top was carefully removed, and the starch was dried in an oven for 4 hours at 80°C. Finally, the dried starch was ground and sieved to obtain fine, lump-free cassava starch powder.

2.2.2 Preparation of Peanut Shell Powder

The peanut shells were first cleaned with water and then ground using a blender. The resulting mixture was filtered using a strainer. The filtered peanut shell material was dried in an oven at 100°C for 3 hours to reduce its moisture content. Finally, the dried peanut shells were sieved to obtain a fine powder.

2.2.3 Biofoam Production Using the Baking Process Method

All materials were first placed into a beaker, consisting of 2 g of peanut shell powder, 20 g of cassava starch, 1.2 g of magnesium stearate, and 3 g of ZnO. The dry ingredients were stirred with a spatula for 2 minutes while 25 ml of water was gradually added until a homogeneous mixture was obtained. The mixture was then transferred to a petri dish that had been coated with magnesium stearate and heated in an oven at 120°C, 140°C, and 160°C for 1 hour each.

2.2.4 Physical Properties Testing of Biofoam

2.2.4.1 Water Absorption Test

The water absorption test was carried out to evaluate the resistance of biofoam to water by measuring weight changes caused by water uptake. The absorbed water was expressed as a percentage of the total initial mass. The test was conducted according to SNI 14-0499-2008 [11]. Samples (2 × 2 cm) were weighed, immersed in 40 ml of water for 1 minute, and reweighed after immersion.

$$\text{Water Absorption (\%)} = \frac{\text{Final Mass-Initial Mass}}{\text{Initial Mass}} \times 100\% \qquad (1)$$

2.2.4.2 Moisture Content Test

The moisture content of biofoam was measured to assess product quality and durability. Samples with high moisture content were considered less stable, while controlled moisture extended shelf life. The test followed SNI 1971:2011 [12]. Samples (2 × 2 cm) were weighed, dried in an oven at 105°C for 10 minutes, cooled for 5 minutes, and reweighed. The procedure was repeated until a constant weight was achieved.

2.2.4.3 Leakage Test

The leakage test was performed to assess the integrity and liquid resistance of biofoam, which is important for water-containing food packaging. Samples (2 × 2 cm) were tested by applying water drops on the surface. The time until water seeped to the bottom was recorded. Additional drops were applied if water had not fully penetrated. The procedure was repeated for all samples[13].

2.2.4.4 Biodegradability Test

The biodegradability of biofoam was evaluated by burying samples (2 × 2 cm) in soil to determine the rate of natural decomposition. The test followed SNI 7188.7:2016 [14]. Samples were weighed and buried at a depth of 15–20 cm. They were monitored and reweighed every 7 days for 7 weeks (49 days) to assess the degree of degradation.

$$\text{Biodegradability (\%)} = \frac{(W0 - W1)}{W0} \qquad (2)$$

With: W0: Initial Weight
W1: Final Weight

3. RESULTS AND DISCUSSION

3.1 Water Absorption Test

One way to measure the characteristics of biofoam is through a water absorption test. This measurement is conducted to meet the Indonesian National Standard (SNI). The water absorption test is performed to ensure the biofoam's resistance to water by calculating the change in weight caused by the amount of water absorbed by the biofoam.

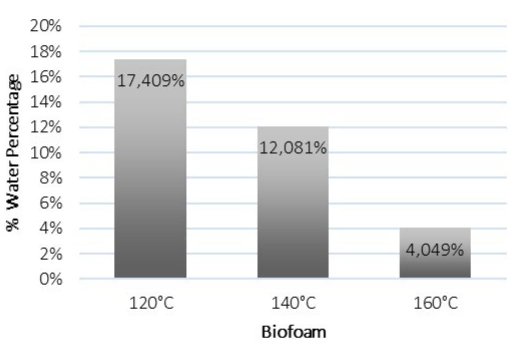

Figure 1. Water absorption test graph

The graph in Figure 1 shows that the best absorption sample is at a temperature of 160°C with a percentage of 4.049%. At 120°C and 140°C, the biofoam absorbed the most water, with percentages of 17.409% and 12.081%, respectively. This indicates that biofoam produced at these temperatures is less resistant to water. The ability of biofoam to absorb large amounts of water may shorten its lifespan if used as packaging in contact with water.

At 120°C and 140°C, the biofoam forms a structure with slightly open pores, resulting in higher water absorption at these temperatures. At 160°C, the water absorption is lower than at other temperatures. Higher temperatures increase the viscosity of starch, making it harder to form a porous structure. The biofoam's pores become fewer and smaller, reducing water absorption. Additionally, the moisture content in the biofoam mixture decreases at high temperatures, further reducing its water absorption capacity.

The ANOVA test yielded a significant value of 0.041. Since this value is less than the significance level ($p < 0.05$), temperature has a significant effect on the water absorption of the biofoam produced.

The addition of ZnO in the biofoam reduces water absorption compared to biofoam using PVA (Polyvinyl Alcohol) [10]. Starch-based biofoam tends to absorb large amounts of water due to its hydrophilic characteristics, which necessitates modifications by adding other materials such as fibers. These fibers can influence the biofoam's performance [15]. Biofoam can be made without fibers, using pure starch or a starch combination. However, fiber-free biofoam generally has mechanical weaknesses, such as brittleness and high water absorption. Therefore, fibers are often added to strengthen the biofoam structure [16]. In this study, ZnO was added to reduce water absorption. However, different temperature variations during biofoam production resulted in varying structures and water absorption capacities.

Research by Elyna et al. successfully isolated microcellulose from peanut shells, with microcellulose melting points at around 120°C

[17]. Bano et al. found microcellulose melting points near 250°C. A lower melting point indicates a higher amount of amorphous phase in microcellulose [18]. A high melting point shows resistance to high temperatures. At the biofoam production temperature of 120°C with added peanut shell fiber, water absorption increased. However, if the temperature exceeds 120°C or approaches the melting point, water absorption may decrease due to moisture evaporation and reduced interaction between cellulose and water. Maintaining the processing temperature below the melting point allows the biofoam to utilize the hydrophilic properties of cellulose in peanut shells to increase water absorption. Temperature variation during molding affects biofoam water absorption: the higher the molding temperature, the lower the water absorbed by the biofoam.

Based on the SNI standard of 11.8682%, the water absorption at 120°C and 140°C, with percentages of 17.409% and 12.081% respectively, exceeds the limit and does not meet the SNI standard. Meanwhile, water absorption at 160°C, with a percentage of 4.049%, is below the standard, indicating that biofoam produced at this temperature meets the SNI requirements.

3.2. Moisture Content Test

One method to characterize biofoam is by conducting moisture content testing. This measurement is carried out to meet the requirements of the Indonesian National Standard (SNI). The moisture content test aims to determine the amount of water contained in the biofoam and to assess its resistance to water. Biofoam with high moisture content tends to deteriorate quickly and has reduced water resistance. The moisture content test is conducted using an oven at 105°C for 10 minutes periodically until the weight results become constant.

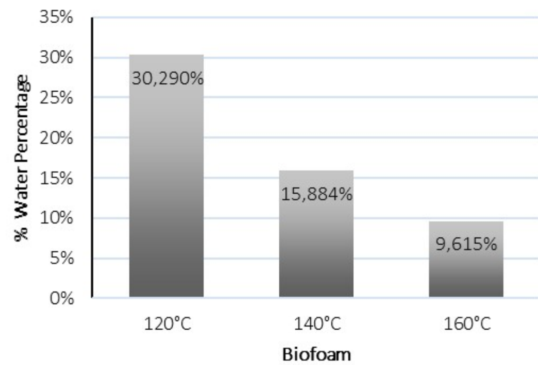

Figure 2. Moisture content test graph

The graph in Figure 2 shows differences in moisture content in biofoam produced at different temperatures. At 160°C, the biofoam has a relatively low moisture content of 9.615%, compared to 120°C and 140°C which have moisture contents of 30.290% and 15.884%, respectively. Increasing the temperature from 140°C to 160°C reduces the moisture content, indicating that higher heating helps to decrease the water content within the biofoam structure. During the biofoam production process, higher temperatures result in a drier structure that is less prone to absorbing water. Meanwhile, biofoam produced at 120°C has higher moisture content compared to other temperatures. This lower heating temperature makes it harder for the biofoam to release water trapped inside, thus causing the evaporation process to be less effective.

The ANOVA test showed a significant value of 0.047. Since this value is less than the significance criterion ($p < 0.05$), it indicates that temperature has a significant effect on the moisture content of the resulting biofoam.

High moisture content in the sample increases expansion ability, but excessive moisture can cause the biofoam to become too soft and fragile. This results in an unstable porous structure with thin walls and high water absorption[19]. Excessive moisture content in biofoam reduces its water resistance. Water in the biofoam production acts as a blowing agent that creates a porous structure, allowing the sample to expand [20]. The high moisture content is also influenced by the hydrophilic characteristics of peanut shell fibers. Additionally, biofoam made from starch is a natural material with hygroscopic properties, meaning it can absorb moisture from the environment, leading to higher moisture content [21]. This causes the moisture content of biofoam to be much higher compared to styrofoam, which contains only 1.11% moisture [22]. The moisture content in biofoam is also affected by the addition of peanut shell fibers and magnesium stearate, which is more hydrophobic compared to starch.

Based on the SNI standard, the maximum allowable moisture content is 26.12%. The test results show that biofoam produced at 140°C and 160°C, with moisture contents of 15.884% and 9.615% respectively, meet the SNI standard. However, biofoam produced at 120°C, with a moisture content of 30.290%, exceeds the limit and therefore does not meet the SNI standard.

3.3. Leakage Test

One way to characterize biofoam is by conducting a leakage test. This test is carried out to ensure the durability and integrity of the biofoam, as biofoam is likely to be used as packaging for food products containing water.

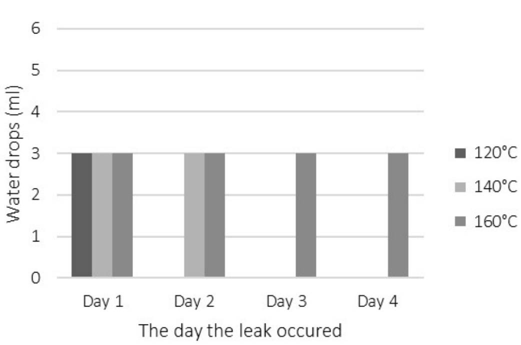

Figure 3. Leake test graph

Figure 3 shows that different manufacturing temperatures affect the durability time of biofoam. The leakage test on cassava starch biofoam indicates a relationship between the manufacturing temperature and resistance to leakage. Leakage testing was conducted simultaneously across all temperature variations. At 160°C, the test showed the best result, with the biofoam resisting water leakage of 3 ml per day for 4 days. At 120°C, biofoam started leaking 3 ml of water on the first day. At 140°C, leakage occurred on the second day, with 3 ml of water leaking per day for 2 days.

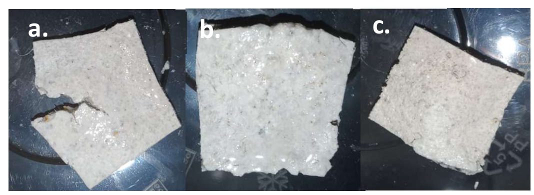

Figure 4. After leakage test a.) 120°C, b.) 140°C, c.) 160°C

Figure 4 shows that at each temperature, exposure to water caused the biofoam structure to crack and soften. Biofoam made at 120°C showed leakage after one day, indicating a less dense structure that is more easily penetrated by water. Increasing the manufacturing temperature to 140°C produced biofoam that was more resistant, with leakage occurring only after two days. The most significant result was observed at 160°C, where biofoam could resist leakage for up to four days. This indicates that higher temperatures produce a denser biofoam structure that is less vulnerable to water penetration, likely due to more complete starch gelatinization and fewer voids in the biofoam matrix. Increasing the manufacturing temperature can enhance the water leakage resistance of cassava starch biofoam, making it more suitable for applications requiring longer liquid protection.

The ANOVA test yielded a significance value of 0.007. Since this value is less than the significance criterion ($p < 0.05$), it indicates that temperature has a significant effect on biofoam leakage resistance.

Peanut shells contain cellulose (35.7%), hemicellulose (18.7%), and lignin (30.2%) [23]. The cellulose content in biofoam can impart hydrophobic properties, helping to prevent water from penetrating the biofoam. The ability of biofoam to resist water is also influenced by additives such as magnesium stearate, which forms a water-resistant film around the biofoam. Additionally, the thickness of the biofoam plays an important role in its water resistance [24].

3.4. Biodegradability Test

Another method to characterize biofoam is by conducting a biodegradability test. This test is carried out to meet the Indonesian National Standard (SNI). The biodegradability test involves burying the samples in soil to determine how easily biofoam decomposes. The test is conducted periodically over 49 days (7 weeks), starting from day 7.

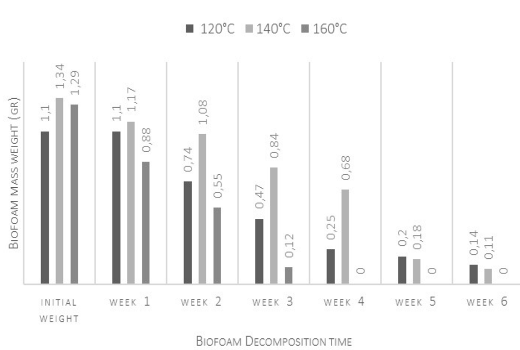

Figure 5. Biodegradability test graph

Figure 5 shows that drying temperature affects biodegradability properties. At week 7, the highest decomposition rate was observed in the biofoam made at 160°C, reaching 100%, followed by 140°C at 97%, and the lowest at 120°C with 96%. Therefore, higher temperature increases the biodegradability of the product. Likewise, longer drying time also increases biodegradability.

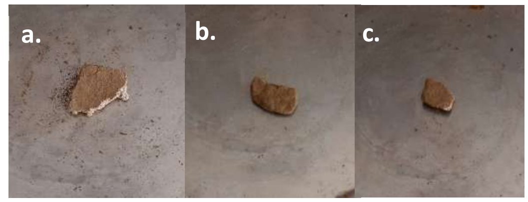

Figure 6. After biodegradability test a.) 120°C, b.) 140°C, c.) 160°C

Figure 6 shows the final results after the biodegradability test, indicating that the biofoam decomposed in the soil. The decomposed biofoam exhibited damage and a darker color compared to before testing. This is because starch-based biofoam interacts with water and microorganisms and is sensitive to physicochemical factors [25].

The ANOVA test showed a significance value of 0.011. Since this value is less than the significance criterion ($p < 0.05$), it indicates that temperature affects the biodegradability of biofoam.

According to research by Ruscahyani et al. [27], biofoam samples initially increase in weight and change shape due to water absorption in the soil. Subsequently, the samples lose weight due to microbial activity decomposing the material. Higher manufacturing temperatures make it easier for microorganisms to decompose the biofoam, resulting in weight loss [26] . Adding fibers to the biofoam also accelerates its natural decomposition [27]. Yudhanto [28] showed that cellulose in biofoam acts as an active filler (biofiller) that enhances material degradation in soil. The hydrophilic nature of cellulose facilitates interaction with water and microbes, accelerating the natural decomposition process[28]. Thus, adding peanut shell fibers can speed up the degradation of biofoam in soil.

According to the SNI standard, 100% biodegradation must occur within 60 days. The test results indicate that all temperature variants in this study meet the applicable SNI standard.

4. CONCLUSION

Biofoam made from cassava starch and peanut shell fibers absorbs water easily due to its hydrophilic nature. Adding ZnO helps reduce pore size, lowering water absorption by acting as a binder. The peanut shell fibers compact the structure, making the biofoam stronger and denser. This natural biofoam also biodegrades quickly in the environment. At a molding temperature of 160°C, biofoam performs best, with smaller pores, lower water absorption, and reduced moisture content due to better evaporation. Its dense structure minimizes water leakage and improves biodegradability, breaking down faster in soil. ANOVA results confirm that temperature significantly affects water absorption, moisture, leakage, and biodegradability. Biofoam produced at all tested temperatures decomposes naturally, with environmental humidity, temperature, and microorganisms influencing the biodegradation rate.

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CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Zulaikha Al-Qordhiyah: Conceptualization, methodology, investigation, data curation, writing-original draft.
Vera Pangni Fahriani: Supervision, writing-review & editing, validation
Fitri Yuliasari: Supervision, writing-review & editing
Fayzah Ahmad: Supervision, writing-review & editing
Angelita Sendi Sinaga: Supervision, writing-review & editing

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