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Effect of the Ratio of Shrimp Waste Powder (*Fenneropenaeus merguiensis de Man*) to Glycerol on the Characteristics of Yam Starch-Derived Bioplastics

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Abstract: Yam starch-based bioplastics generally exhibit low mechanical properties. However, the addition of shrimp waste powder has been shown to improve the tensile strength and elongation of yam starch bioplastics, with the enhancement occurring within an optimal range. Glycerol, on the other hand, is known to affect bioplastic properties in a dose-dependent manner. This study was conducted to investigate the effects of shrimp waste powder and glycerol ratios on the characteristics of yam starch-derived bioplastics. A Completely Randomized Design (CRD) was used, consisting of five treatment levels with three replications. The treatment levels were shrimp waste powder to glycerol ratios of 0:3, 0.5:2.5, 1:2, 1.5:1.5, and 2:1. The results showed that the shrimp waste powder to glycerol ratio significantly affected the tensile strength, elongation, thickness and water vapor transmission rate (WVTR) of the bioplastics, but had no significant effect on water absorption. The biodegradability of bioplastic in soil ranged from 144 to 149 days. The best treatment was 1:2 ratio of shrimp waste powder to glycerol, which resulted in a tensile strength of 19.26 N/mm^2, elongation of 84.09%, thickness of 0.35 mm, water absorption of 30.79%, WVTR of 20.80 $g/m^2.h$ and a faster decomposition rate compared to synthetic plastics.

Keywords: Bioplastics; Glycerol; Shrimp waste powder

Introduction

Plastic waste is one of the most abundant forms of waste in the world today and has become a serious global environmental issue. Plastics are widely used in daily life due to their many advantages—they are strong, lightweight, cost-effective, and durable. However, most plastics currently in use are synthetic polymers derived from petroleum, which is not easily broken down by natural processes. As plastic consumption continues to grow, the resulting environmental pollution also increases (Nogueira et al., 2025).

Bioplastics are an environmentally friendly alternative to conventional plastics. They function like regular plastic but are biodegradable—broken down by microorganisms into water, carbon dioxide, and other natural substances, without leaving behind toxic residues. Recognized globally for their potential, the bioplastics have been under development for decades. A key advantage of bioplastics is that they are made from renewable resources, such as crops and plantation products, which are readily available. Given Indonesia's

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vast agricultural and plantation sectors, the country has strong potential to become a leading producer of bioplastic raw materials (Nazarudin et al., 2023; Ulyarti et al., 2020). Although many types of tubers are grown in Indonesia (Dewanti et al., 2023; Latief et al., 2023; Lavlinesia et al., 2023; Rahmawati et al., 2023; Ulyarti, et al., 2023), yam is not widely utilized. Converting yam starch into bioplastics is one potential avenue for yam utilization. However, the low mechanical and barrier properties of yam starch-based bioplastics (Ulyarti et al., 2019) indicate the need for further improvement in their formulation.

Indonesia, as a maritime nation, is rich in fishery resources—particularly shrimp. *Fenneropenaeus merguiensis de Man*, commonly known as Jerbung shrimp, is an indigenous species found in Indonesian waters (Wiradana et al., 2020). While Jerbung shrimp farming generates significant economic value, it also produces substantial waste, including shrimp heads, shells, and tails. These by-products are valuable, containing approximately 14-30% dw chitin depend on the extraction method (Nirmal et al., 2020) and 34.9% protein (Putra et al., 2023). According to Yuan et al. (2020), shrimp shell waste protein itself is an excellent film material. Due to this composition, shrimp waste can be processed into shrimp waste powder, which holds great potential as a biomaterial for bioplastics. The hydrophobic nature of shrimp waste powder (Astuti, 2023) makes it an excellent additive for enhancing the mechanical and barrier properties of yam-based bioplastics (Widiyawati et al., 2024). However, the combination of these natural polymers often results in bioplastics that are rigid and brittle. To improve flexibility and mechanical performance, plasticizers such as glycerol are commonly incorporated into the formulation (Arham et al., 2016; Lim et al., 2020). The appropriate amount of plasticizer often depends on the type and proportion of polymer used (Arham et al., 2016; Fahrullah et al., 2023; Lim et al., 2020). However, it remains unclear whether the required amount of glycerol is more dependent on the starch content or the shrimp waste powder. Therefore, this study aims to evaluate the effect of the shrimp waste powder-to-glycerol ratio on the characteristics of the resulting bioplastics.

Method

The materials used in this study were shrimp waste, purple yam (*Dioscorea alata*), plasticizer (glycerol), distilled water, CH_3COOH, and NaOH. The tools used in the study were texture analyzer.

Research Design

This research was carried out using a Completely Randomized Design (CRD) with 5 ratios of shrimp waste powder to glycerol. Each ratio was repeated 4 times. The bioplastic in this study was prepared using formula as seen in Table 1.

Purple Yam Starch Extraction

The outer skin of the yam tuber is cleaned and then washed to remove the sap and remaining soil on the tuber, then cut and sliced with a thickness of 2 to 3 mm, then washed again to remove mucus and then drained. The sliced yam is soaked for 30 minutes in a 15% salt water solution, then washed again with clean water 3 times. Next, the yam is blended until smooth, the blended yam is then filtered using a 200mesh sieve. Then the suspension obtained is precipitated for 6 hours and then stored in a refrigerator at a temperature of 4°C. Furthermore, the sediment obtained is rinsed using distilled water in order to purify the starch. Then the starch is put into the oven to be dried for 6 hours at a temperature of 50°C. After the starch is dry, the starch is ground and sieved using a 60mesh sieve and then stored in an airtight container.

Shrimp Waste Powder Preparation

Shrimp waste powder was prepared using shrimp by-products (skin, legs, and tail) in good condition—characterized by a firm texture, fresh appearance, and the absence of unpleasant odor. The shrimp waste was thoroughly washed under running water to remove dirt and impurities, then homogenized and dried in an oven at 100 °C for 5 hours. After drying, the material was ground using a blender and sieved through a 60-mesh sieve.

A total of 90 g of the resulting powder was soaked in 450 ml 10% acetic acid (CH_3COOH) solution for 1 hour. The sample was then rinsed with water until a neutral pH was achieved. Subsequently, it was soaked in a 0.5 M sodium hydroxide (NaOH) solution and stirred on a hot plate at 65 °C for 2 hours. After cooling, the mixture was filtered and washed with distilled water until a neutral pH was reached. The neutralized powder was then dried in an oven at 100 °C for 4 hours and sieved again using a 60-mesh sieve.

Bioplastics Preparation

The first step in bioplastic preparation involved making a 5% acetic acid (CH_3COOH) solution. A volume of 5 mL of this solution was used to dissolve the shrimp waste powder, which was soaked in the acid for one hour. After soaking, distilled water and starch were added to the shrimp waste mixture and heated to 80 °C. Once the temperature reached 80 °C, glycerol was added and the heating and stirring was continued for another

20 minutes. The resulting film solution was then poured into a 20 × 20 cm flexible glass mold and dried in an oven at 50 °C for 24 hours. After drying, the mold was cooled to room temperature and the bioplastic was then carefully removed and stored in an airtight container. This process was repeated twice to produce two identical bioplastic films. The two films were then bonded using approximately 15 g of the film solution and dried again in the oven at 50 °C for about 5 hours. The final bioplastic sheet was then ready for further characterization.

Table 1. Bioplastic production formulation for 1 layer

Ratio	Shrimp waste powder (g)	Starch (g)	Glycerol (g)	CH_3COOH (ml)	Distilled Water (ml)
0:3	0	5	3	5	137
0.5:2.5	0.5	5	2.5	5	137
1:2	1	5	2	5	137
1.5:1.5	1.5	5	1.5	5	137
2:1	2	5	1	5	137

Tensile Strength

Tensile strength was measured using Texture Analyzer. Tensile strength was determined based on the maximum load when the film breaks. The equation for tensile strength is as follows:

$$\text{Tensile strength} = \frac{\text{Force (F)}}{\text{Film width}} \times 20 \tag{1}$$

Elongation

Elongation or percentage of elongation was measured using Texture Analyzer. Elongation is the percentage of elongation of the film at breaks. The equation for the percentage of elongation is as follows:

$$\%\ \text{Elongation} = \frac{A - B}{B} \times 100\% \tag{2}$$

Description:
A: Length at breaking (mm)
B: Initial Length (mm)

Thickness

The film thickness was measured using a micrometer screw with a tool accuracy of 0.01 mm. The film thickness was carried out five times at different position points and the average value was taken.

Water Absorption

The initial weight of bioplastics sample was recorded (W_0). Then the sample was dipped in distilled water for 20 minutes and then reweighed to obtain the final weight (W). The water absorption of the film was calculated using the following formula:

$$\text{Water absorption (\%)} = \frac{W - W_0}{W_0} \times 100\% \tag{3}$$

Information:
W_0: Initial weight of the sample
W: Weight of the sample after soaking

Water Vapor Transmission Rate/WVTR

A test tube containing 5 grams of Calcium Chloride (CaCl) was covered using a 6x6 cm film, then folded at the mouth of the test tube until tightly closed and the weight of the test tube was recorded. The tube was placed in a desiccator saturated with Sodium Chloride (NaCl) solution (RH 75%). Every 30 minutes the test tube was reweighed, the changes in the tube were then recorded and plotted as a function of time. The calculation of WVTR can use the following formula:

$$\text{WVTR} = \frac{\text{Slope}}{A} \tag{4}$$

Description:
WVTR: Water Vapor Transmission Rate g/m^2.hour
Slope : Linear function of weight gain and time (g/hour)
A : Film Area (m^2)

Cumulative Percentage of Bioplastic

Bioplastic degradation was defined as the time required for the film to degrade. Samples measuring 2cm x 2cm were placed in a container filled with soil, the film samples were left exposed to open air. Sample observations were carried out once a day until the film samples were completely degraded.

Data Analysis

The data were analyzed using Analysis of Variance (ANOVA) and followed by the Duncan New Multiple Range Test (DNMRT) whenever necessary.

Result and Discussion

Bioplastic is a biodegradable plastic or environmentally friendly plastic that can be decomposed by the activity of microorganisms. At present experiment, the bioplastic was prepared from purple yam starch with the addition of glycerol and shrimp waste powder. Bioplastics with several ratios of shrimp waste powder and glycerol were prepared using two-layer formulation, with a total material of 150 g each layer. The differences in color are visible among these bioplastics. The increasing amount of shrimp waste powder and decreasing the amount of glycerol produce increasingly darker colors, stronger, more elastic and decompose faster than the synthetic plastic. Bioplastics with several ratios of shrimp waste powder and glycerol can be seen in Figure 1.

Tensile Strength

The ratio of shrimp waste powder to glycerol has a significant effect on the tensile strength of bioplastics. The average tensile strength of the bioplastics ranges from 7.95 to 28.99 N/mm^2. The mechanical properties of bioplastics are influenced by the components that form the film, such as shrimp waste powder and glycerol. The tensile strength tends to increase with a higher proportion of shrimp waste powder and a lower proportion of glycerol. The addition of shrimp waste powder may enhance hydrogen bonding within the film, making it stronger and more resistant to breaking, as more energy is required to disrupt these bonds (Kedir et al., 2024).

The increasing amount of glycerol causes the tensile strength of bioplastics to decrease due to the plasticizer's ability to reduce the energy required for molecular movement. Plasticizers can disrupt the internal hydrogen bonds between molecules, thereby weakening the intermolecular attractive forces between adjacent polymer chains and reducing the breaking tensile strength (Lim & Hoag, 2013).

Elongation

Based on the results of the analysis of variance, the ratio of shrimp waste powder to glycerol has a highly significant effect at the $p < 0.01$ level. The average elongation value of the bioplastics ranges from 62.43 to 109.77%. This value is considered an improvement when compared to the elongation of typical chitosan-based plastics, which is usually below 40% (Brites et al., 2024).

(0 : 3) (0.5 : 2.5) (1 : 2) (1.5 : 1.5) (1 : 2)

Figure 1. Bioplastics prepared using several ratios of shrimp waste powder and glycerol

Table 2. Physical and mechanical properties of bioplastics with several ratios of shrimp waste powder and glycerol

Shrimp waste powder : glycerol ratio	Tensile strength (N/mm^2)	Elongation (%)	Thickness (mm)	Water absorption (%)	WVTR (g/mm^2.h)
0 : 3	7.95 ± 1.14^{a}	109.77 ± 3.90^{b}	0.31 ± 0.04^{a}	36.29 ± 8.82	28.66 ± 2.12^{c}
0.5 : 2.5	15.74 ± 2.75^{ab}	85.28 ± 24.95^{ab}	0.32 ± 0.04^{a}	35.27 ± 3.35	26,97 ± 2.18^{c}
1 : 2	19.26 ± 3.46^{bc}	84.09 ± 26.20^{ab}	0.35 ± 0.03^{ab}	30.79 ± 4.58	20.80 ± 0.92^{b}
1.5 : 1.5	27.88 ± 10.03^{c}	67.90 ± 2.43^{a}	0.39 ± 0.05^{bc}	29.02 ± 2.60	19.11 ± 1.49^{a}
2 : 1	28.99 ± 6.86^{c}	62.43 ± 0.30^{a}	0.44 ± 0.07^{c}	20.63 ± 9.84	16.18 ± 3.61^{a}

Note: Numbers followed by the same superscript in the same column are not significantly different at the 5% level according to the DnMRT.

Glycerol, as a plasticizer, imparts elastic properties to the plastic. Additionally, the increase in elongation values in bioplastics occurs because plasticizers reduce the intermolecular bonds between amylose and amylopectin, as well as the hydrogen bonds between starch molecules and the plasticizer.

Plastics with a higher number of C=C (carbon–carbon double) bonds tend to be more rigid and less stretchable, resulting in lower elongation values. This is due to the reduced distance between molecular bonds (Astuti, 2023). Therefore, with the addition of shrimp waste powder and a reduction in glycerol, the elongation value decreases, and vice versa.

However, the elongation of these bioplastics is considerably lower than the elongation values of synthetic polymers, such as low-density polyethylene (349%) and high-density polyethylene (213%) (Elhrari, 2018).

Thickness

As seen in Table 2, the highest thickness value is bioplastic with the treatment of shrimp waste powder and glycerol ratio 2:1 which is 0.44 mm while the lowest value is in the treatment of shrimp waste powder and glycerol ratio 0:3 which is 0.31 mm. Based on the analysis of variance, it shows that the bioplastic with the ratio of shrimp waste powder and glycerol has a very significant effect ($p < 0.01$) on the thickness. This show that the amount of shrimp waste powder that affect the total solids in the film solution leading to an increase in film thickness (Widiyawati et al., 2024).

Water Absorption

The higher the water absorption value, the lower the resistance level of the bioplastic and the bioplastic is quickly damaged. The water absorption value for bioplastics prepared using several ratios of shrimp waste powder and glycerol can be seen in Table 2. Ratio of shrimp waste powder and glycerol has no significant effect on water absorption of bioplastics. However, the addition of glycerol reduces water resistance due to hydrophilic nature of glycerol (Varshini et al., 2025). The thickness of the bioplastic also affects the level of water absorption as well as solubility in water (Ulyarti et al., 2021; Widiyawati et al., 2024).

Water Vapor Transmission Rate (WVTR)

The value of the water vapor transmission rate or water vapor transmission rate of a bioplastics packaging can be used to determine the shelf life of the product. Water vapor migration generally occurs in the hydrophilic part of the film. Thus, the ratio between the hydrophilic and hydrophobic parts of the film components will affect the value of the water vapor transmission rate of the film.

Table 2 shows that the water vapor transmission rate (WVTR) of bioplastics decreases with higher amount of shrimp waste powder and lower amount of glycerol. This is due to the hydrophobic nature of shrimp waste powder and the hydrophilic nature of glycerol.

The addition of plasticizers such as glycerol will also cause a decrease in internal hydrogen bonds and an increase in intermolecular distance which causes an increase in film permeability. In addition, a decrease in intermolecular interactions and an increase in molecular mobility will facilitate the migration of water vapor molecules.

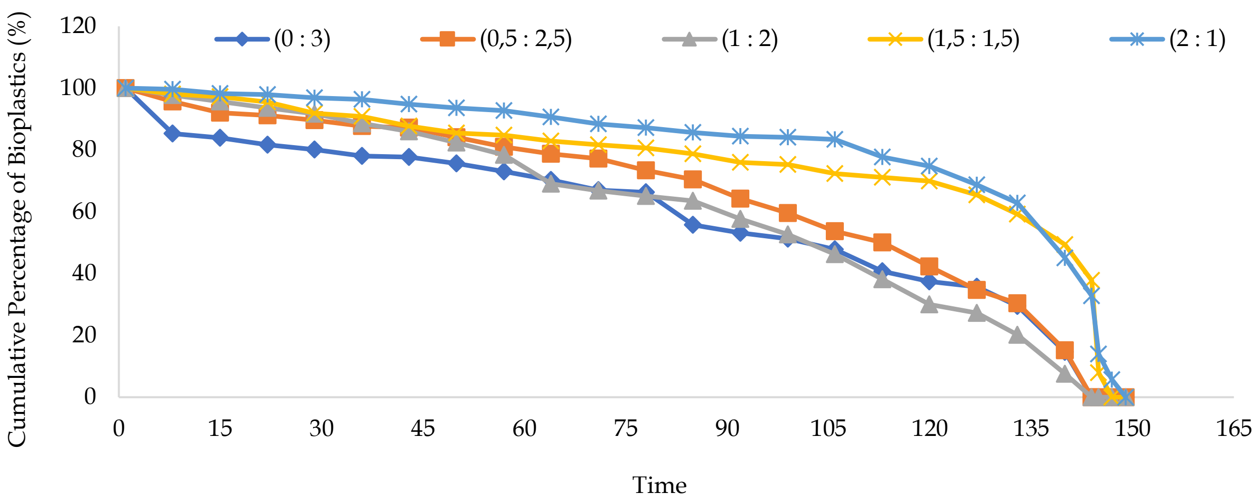

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Figure 2. Cumulative percentage of bioplastics prepared using several ratios of shrimp waste powder and glycerol during degradation in soil

Cumulative Percentage of Bioplastics

Biodegradation of bioplastics in soil is a multi-step process that involves the mineralization of the polymers by soil microorganism. This microorganism secretes extracellular enzymes that hydrolyze the polymers in bioplastics and utilize the products of hydrolysis as an energy source. Every compound in bioplastics has their unique effect on the growth of these organism (Prodana et al., 2025). The cumulative percentage of bioplastics is a parameter for bioplastics degradation in true soil which can be measured by determining the length of time for the bioplastic to completely decompose. The cumulative percentage of bioplastics in the present study can be seen in Figure 2.

Figure 2 shows that for the ratio of shrimp waste powder and glycerol 0:3; 0.5:2.5 and 1:2 experienced complete degradation on the 144th day. The length of time for complete degradation was increased to 147 days for ratio 1.5:1.5 and 149 days for 2:1. All bioplastic prepared in this study degraded faster than the synthetic plastic. This is in line with other study which report degradation within 4-5 months if buried in soil, while synthetic plastics generally take hundreds to thousands of years to degrade.

The biodegradation ability of bioplastic increases with higher amounts of glycerol and lower amounts of shrimp waste powder. This is because the initial step in the degradation process likely begins with the dissolution of bioplastic material in soil. Therefore, the more water soluble the bioplastic is, the easier it can dissolve and subsequently degrade.

Conclusion

Ratio of shrimp waste powder and glycerol affects the tensile strength, elongation, thickness and WVTR of the bioplastics, but does not affect the water absorption value. The biodegradability of bioplastic in soil was found to be in between 144 to 149 days. The best bioplastic is obtained in the ratio of shrimp waste and glycerol (1 : 2) with a tensile strength value of 19.26 N/mm^2, elongation 84.09%, thickness 0.35 mm, water absorption 30.79%, WVTR 20.80g/m^2.h and this bioplastic decomposes faster into the environment than synthetic plastic types.

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Author Contributions
Nazarudin contributes in the conceptualization and methodology of the research; Adisty Ramadhani contributes in the laboratory work and manuscript preparation; Mursyid contributes in the supervising the laboratory work; Ulyarti contributes in the writing, reviewing, editing and obtaining the research grant. All authors have read and approved the published version of the manuscript.

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Conflicts of Interest
Authors declare that no conflict of interest in this publication.

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