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The Effect of Differences in Mocaf Starch Weight and Glycerol Percentage on the Physical and Mechanical Properties of Bioplastics

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A B S T R A C T

The present study aims to analyse the effect of variations in the amount of Mocaf starch and glycerol concentration on the physical and mechanical characteristics of the bioplastics produced. The method employed in this study was casting. The experimental design employed in this study was a completely randomised two-factor design, namely the amount of starch (4, 5, 6 and 7 g) and glycerol concentration (20, 30, and 40% w/w based on starch). The data were analysed using analysis of variance (ANOVA) at a significance level of 5%; when significant differences were identified, Duncan's test was used for follow-up. The findings indicated that the quantity of mocaf starch and glycerol concentration exerted a substantial influence on the physical and mechanical properties of bioplastics. An increase in the amount of starch led to higher density, thickness, and, most significantly, tensile strength. Conversely, an increase in glycerol concentration did not affect density but increased thickness and elongation while decreasing tensile strength. The interaction of these two factors also had a significant effect on thickness, tensile strength, and elongation.

Contribution to Sustainable Development Goals (SDGs):
SDG 12 – Responsible Consumption and Production (Renewable-based bioplastics, sustainable materials_
SDG 9 – Industry, Innovation, and Infrastructure (Innovation in biodegradable materials)
SDG 13 – Climate Action (Reduction of fossil-based plastics)
SDG 2 – Zero Hunger (indirect) (Value addition to local cassava resources)

1. INTRODUCTION

1.1. Research Background

In 2023, global plastic production reached 413 million tonnes [1]. This is a concern, given that only 9% of the material is recycled, with the remainder disposed of in landfills or incinerated with no value. The primary issue at present is that the most prevalent form of plastic waste is synthetic, derived from petroleum, and is characterised by its resistance to decomposition. This has the potential to result in environmental contamination.

One alternative to conventional polymer-based plastics is biomass-based plastics, also known as bioplastics. Starch can be utilised as a raw material in the production of bioplastics. In addition to being readily biodegradable, starch-based raw materials are also renewable. A plethora of starch-based materials have been employed in the context of bioplastic production research, including tapioca starch [2], taro starch [3], [4], sago starch [5], [6], cilembu sweet potato starch, potato starch [7], [8], mocaf flour [9], cassava starch [10], and sweet potato starch [11], to name but a few.

1.2. Literature Review

In Indonesia, an up-and-coming local starch ingredient is Mocaf starch (modified cassava flour), produced by fermenting cassava with lactic acid bacteria. This starch is recognised as a carbohydrate source that can substitute for wheat flour in food products, as well as for rice and glutinous rice, and can also function as an additive [12], thus enabling its wider use as a raw material for bioplastics. This starch has advantages in terms of the availability of local resources and the potential added value of the food-agricultural industry.

The use of pure starch as a bioplastic matrix still faces technical challenges, as the resulting bioplastic tends to be brittle (dry or prone to cracking) and has poor water and water vapour barrier properties [13], [14]. To overcome these inherent weaknesses, the use of plasticisers such as glycerol is recommended to increase flexibility, reduce stiffness, and enhance elongation or extension of bioplastics. Conversely, the ratio or amount of starch will also affect the physical and mechanical properties of bioplastics. A study by (2019) found that the concentrations of cassava starch and glycerol greatly affect the film thickness, tensile strength, elongation, and water absorption of the bioplastics produced. Research using Mocaf starch as a matrix has been conducted by Rezekinta et al. (2023), but the optimal amount and concentration of starch have yet to be examined.

1.3. Research Objective

Therefore, it is important to conduct research on locally sourced starches such as mocaf, to specifically understand how the amount of mocaf starch and glycerol concentration affect the physical properties (thickness, water absorption, vapour permeability) and mechanical properties (tensile strength, elongation, modulus) of the resulting bioplastics. The purpose of this study is to analyse the effect of variations in the amount of Mocaf starch and glycerol concentration on the physical and mechanical characteristics of the resulting bioplastics.

2. MATERIALS AND METHODS

2.1. Materials and Equipment

The materials utilised in this study encompassed mocaf starch, glycerol (98% purity), and distilled water. The equipment employed for this study included a micrometre screw, a universal testing machine (UTM), an oven, a glass mould, a 250 ml beaker, a magnetic stirrer hotplate, a thermometer, and scales.

2.2. Research Procedure

The method used in this study was an experimental design with a completely randomised factorial Arrangement. The factors tested included the amount of starch (4, 5, 6, and 7 g) and the concentration of plasticiser (glycerol, 20, 30, and 40% w/w based on starch). The variables evaluated included thickness, density, tensile strength, and elongation, with each test conducted three times. Statistical analysis was conducted using analysis of variance (ANOVA) at the 5% significance level to identify differences in the mean results for each property and treatment. Subsequently, Duncan's test was employed to determine whether the means were significantly different. The statistical analysis was conducted using SPSS software, version 16.

2.3. Bioplastic Production

The production of bioplastic composites was based on a modified formulation [9]. The manufacturing process utilises mocaf starch in weights of 4, 5, 6, and 7 g, in conjunction with glycerol concentrations of 20%, 30%, and 40% (w/w). Mocaf starch is dispersed in distilled water at a ratio of 1:12. The mixture is stirred for 5 minutes. Then heated to a temperature of 85 °C. Next, glycerol was added according to the treatment (20, 30, and 40% (w/w)). The solution was stirred for an additional 3 minutes until it appeared homogeneous. The solution was then removed and left for approximately 1 minute to allow any air bubbles to dissipate. Subsequently, the substance was cast into a 15 x 15 cm glass mould. The bioplastic solution in the mould is dried at 40 °C for 24 hours, then left at room temperature for 3 days. Remove the bioplastic sheet from the mould and leave it in an open room until its weight is constant. Once the bioplastic is obtained, conduct a series of tests, such as physical properties: thickness test and density test, followed by mechanical properties, including tensile strength test and elongation test.

2.4. Analysis Procedures

2.4.1. Density Test [15]

Density (specific gravity) can be determined by measuring the sample's mass and volume. The equation is as follows:

$$\rho = \frac{m}{v} \quad (1)$$

Explan: ρ = density (g/cm^3)
m = mass of material (g)
v = volume of material (cm^3)

2.4.2. Thickness Test [16]

The thickness of the bioplastic film is measured with a micrometer screw gauge with an accuracy of up to 0.01 mm. The thickness of the bioplastic is determined by measuring five points and calculating the mean.

2.4.3. Tensile Strength Test and Elongation Test [15]

The tensile strength and elongation tests were conducted using a Universal Testing Machine (UTM). The dried film was then divided into segments measuring 10 cm in length and 2.5 cm in width. The extremities of the film sample were clamped to the testing machine. The experimenter initiated the procedure by pressing the designated start button. The machine was then engaged to pull the sample until it broke.

The formula for the tensile strength test is as follows:

$$\tau = \frac{F_{max}}{A} \qquad (2)$$

Explan: τ = tensile strength (MPa)
Fmax = maximum stress (N)
A = cross-sectional area (mm^2)

The formula for the elongation test is as follows:

$$\%E = \frac{\Delta L}{L_o} \qquad (3)$$

Explan: %E = Elongation (%)
ΔL = Increase in specimen length (mm)
L_0 = Initial specimen length (mm)

3. RESULT AND DISCUSSION

3.1. Physical Characteristics

3.1.1. Density

The results of the analysis of variance show that the amount of starch has a very significant effect ($p < 0.05$) on the density of bioplastics from mocaf starch. However, the concentration of glycerol and the interaction between the amount of starch and the concentration of glycerol do not have a significant effect ($p > 0.05$) on the density of bioplastics from mocaf starch. The density of the bioplastic produced ranged from 0.117 ± 0.023 to 0.168 ± 0.028 g/cm³, as shown in Table 1.

Table 1. Density values (g/cm³) of bioplastic from Mocaf starch

Amount of Starch	**Glycerol Concentration**			**Mean**
	G1 (20%)	**G2 (30%)**	**G3 (40%)**	
P1 (4 g)	0.133 ± 0.043	0.134 ± 0.020	0.117 ± 0.023	0.128 ± 0.010 b
P2 (5 g)	0.136 ± 0.024	0.131 ± 0.015	0.127 ± 0.022	0.131 ± 0.005 b
P3 (6 g)	0.162 ± 0.034	0.154 ± 0.011	0.147 ± 0.031	0.154 ± 0.007 ab
P4 (7 g)	0.168 ± 0.028	0.157 ± 0.009	0.164 ± 0.042	0.163 ± 0.023 a

Note: Different letters behind the mean values indicate significant differences at the 5% error level ($p < 0.05$)

Table 1 shows that the higher the amount of starch added, the greater the bioplastic's density. These results are supported by a study by Ref. [17], which found that the density of sweet potato starch-based bioplastics increases with increasing starch:glycerol ratio, reaching a maximum at 3.5:1 (1.66 g/cm³). The increase in density is due to a denser matrix with more polymer chains and more interactions between chains, resulting in a denser film structure [17].

3.1.2. Thickness

The analysis of variance results showed that the amount of starch and glycerol concentration had a very significant effect ($p<0.05$) on the thickness of mocaf starch bioplastic, as did the interaction between the two ($p<0.05$). The thickness of mocaf starch bioplastic ranged from 0.260 ± 0.013 to 0.709 ± 0.085 mm, as shown in Table 2.

Table 2. Thickness values (mm) of mocaf starch bioplastics

Amount of Starch	**Glycerol Concentration**		
	G1 (20%)	**G2 (30%)**	**G3 (40%)**
P1 (4 g)	0.260 ± 0.013 e	0.300 ± 0.038 de	0.340 ± 0.046 de
P2 (5 g)	0.353 ± 0.026 d	0.370 ± 0.015 d	0.470 ± 0.014 bc
P3 (6 g)	0.370 ± 0.010 d	0.385 ± 0.014 cd	0.505 ± 0.050 b
P4 (7 g)	0.667 ± 0.096 a	0.628 ± 0.061 a	0.709 ± 0.085 a

Note: Different letters behind the mean values indicate significant differences at the 5% error level ($p < 0.05$)

Table 2 shows that higher starch and glycerol concentrations are associated with an increase in bioplastic thickness. (2016) found that adding glycerol at a specific concentration can enhance the thickness of the AS film produced. The utilisation of greater quantities of starch results in an increased amount of dissolved solid mass, thereby causing an augmentation in the thickness of the bioplastic [18]. This may be due to the role of plasticisers in disrupting and restructuring the intermolecular polymer chain network, changing all free volumes, thereby resulting in a thicker film structure [19], [20], [21].

3.2. Mechanical Characteristics

3.2.1. Tensile Strength

The tensile strength test results can be seen in Table 3. The lowest tensile strength value was found in the 4 g starch sample with 40% glycerol concentration, which was 0.8469 ± 0.09 MPa, while the highest value was found in the 7 g starch sample with 20% glycerol concentration, which was 2.2462 ± 0.21 MPa. Based on the results of the analysis of variance, it is known that the amount of starch and glycerol concentration have a very significant effect ($p<0.05$) on the tensile strength of mocaf starch bioplastics, as well as the interaction between the two ($p<0.05$).

Table 3. Tensile strength (MPa) values of Mocaf starch bioplastics

Amount of Starch	Glycerol Concentration		
	G1 (20%)	G2 (30%)	G3 (40%)
P1 (4 g)	1.1338 ± 0.11 f	0.9425 ± 1.13 fg	0.8469 ± 0.09 g
P2 (5 g)	1.7312 ± 0.06 cde	1.6269 ± 0.12 de	1.5278 ± 0.16 e
P3 (6 g)	2.0712 ± 0.12 ab	1.9847 ± 0.10 abc	1.8632 ± 0.09 bcd
P4 (7 g)	2.2462 ± 0.21 a	2.0500 ± 0.13 ab	1.8451 ± 0.12 bcd

Note: Different letters behind the mean values indicate significant differences at the 5% error level ($p < 0.05$)

The results showed that the higher the starch concentration in the formulation, the higher the tensile strength. This is in line with the study by Ref. [20], which found that increasing cassava concentration led to a significant increase in the tensile strength of bioplastics. However, the opposite occurs with an increase in glycerol concentration, resulting in a decrease in the tensile strength of mocaf starch bioplastics. This finding is reinforced by Ref. [21], who reported an increase in the tensile strength of cassava starch from 1.90 MPa to 2.47 MPa with the addition of starch.

The high starch content in the formulation results in a greater content of matrix-forming solids, making the film structure denser and more compact. Starch, especially its amylose fraction, can form strong hydrogen bonds between polymer chains, thereby increasing resistance to tensile forces. Then, the decrease in tensile strength as glycerol concentration increases is due to glycerol acting as a plasticiser, weakening hydrogen bonds between starch molecules, making bioplastics more flexible but less strong [22], [23].

3.2.2. *Elongation*

The elongation test results are shown in Table 4. The lowest elongation value was observed in the treatment with 4 g of starch and 20% glycerol, at 4.803% ± 0.26, while the highest was observed in the treatment with 5 g of starch and 40% glycerol, at 13.533% ± 2.56. Based on the analysis of variance, it was found that the amount of starch and glycerol concentration had a very significant effect ($p<0.05$) on the elongation of mocaf starch bioplastic, as did the interaction between the two ($p<0.05$).

Table 4. Elongation (%) values of the mocaf starch bioplastic

Amount of Starch	Glycerol Concentration		
	G1 (20%)	G2 (30%)	G3 (40%)
P1 (4 g)	4.803 ± 0.26 f	8.532 ± 1.71 cde	12.013 ± 1.13 ab
P2 (5 g)	6.132 ± 1.32 ef	8.199 ± 0.80 cde	13.533 ± 2.56 a
P3 (6 g)	5.260 ± 0.87 f	9.468 ± 0.75 bcd	10.776 ± 0.62 bc
P4 (7 g)	4.919 ± 0.79 f	7.868 ± 0.52 de	8.763 ± 1.16 cde

Note: Different letters behind the mean values indicate significant differences at the 5% error level ($p < 0.05$)

As illustrated in Table 4, an increase in glycerol concentration exerts the most significant influence on the rise in elongation percentage. This finding is further substantiated by research reported in Ref. [11], which asserts that an increase in glycerol composition is directly proportional to an increase in elongation percentage. This increase in elongation percentage is caused by a decrease in intermolecular bonds between amylose, amylopectin, and the amylose-amylopectin starch matrix, facilitated by plasticisers; these bonds are therefore replaced by hydrogen bonds between starch molecules and plasticisers. Consequently, there is a decline in stiffness and an augmentation in film flexibility, thus facilitating enhanced chain mobility and rendering the film more elastic [24], [25].

4. CONCLUSION

The findings of the study suggest that the quantity of mocaf starch and glycerol concentration exerts a substantial influence on the physical and mechanical properties of bioplastics. It has been demonstrated that an increase in the starch content of a given material results in an increase in its density and thickness, as well as its tensile strength. Conversely, an increase in glycerol concentration does not affect density, but it increases thickness and elongation while decreasing tensile strength. The interaction between these two factors has been shown to affect thickness, tensile strength, and elongation significantly. Therefore, the optimal bioplastic formulation depends on the appropriate combination of starch content and glycerol concentration, determined by the intended use of the material.

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