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Research Article

# Biodegradable Plastic Synthesis from Sapodilla Fruit Starch (*Manilkara zapota*): Effects of Chitosan Ratio and Glycerol Concentration

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**Abstract**

The productivity of Majalengka sapodilla production has declined, posing significant challenges for sapodilla farmers. This issue is further compounded by the fluctuating availability of land for sapodilla cultivation. Given its nutritional composition, sapodilla fruit holds potential for development into a biodegradable product by utilizing its starch in conjunction with chitosan. The aim of developing this biodegradable product is to reduce the reliance on synthetic plastic for packaging processed foods. This study investigated the water, fat, and protein content in sapodilla fruit, as well as the characteristics of the resulting biodegradable material. The sapodilla starch content was found to be 9%, with a water content of 2%, a fat content of 0.5%, and a protein content of 12.44%. The biodegradable material exhibited a maximum thickness of 0.354 mm at a sapodilla starch to chitosan ratio of 30%:70% with 100% glycerol plasticizer. The maximum degradability percentage achieved was 85.7% at a starch to chitosan ratio of 60%:40% with 100% glycerol. From the degradability tests of sapodilla starch and chitosan biodegradable plastic with glycerol plasticizer, it can be concluded that the optimum degradability value is 88.2% for samples with a starch to chitosan ratio of 60%:40% and a glycerol volume of 100%. This indicates that increasing the volume of glycerol and starch enhances the biodegradable capability.

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## 1. Introduction

The advancement of food technology in Indonesia is progressing rapidly, resulting in the production of a diverse array of renewable food products. A significant proportion of these products necessitate packaging, which is frequently utilized for food items (Kaushani et al., 2022). Packaging materials derived from petrochemical polymers, commonly referred to as plastics, are the most extensively employed for this purpose. Over the past 25 years, the prevalence of plastic packaging materials can be attributed to their flexibility and malleability (Farrell et al., 2024).

Plastic is considered less safe for use in food packaging due to its composition of monomers, which are the fundamental units forming long-chain polymers. When food is wrapped in plastic, these monomers can migrate into the food and subsequently into the human body. As they are insoluble in water, they cannot be excreted through urine or feces. The accumulation of harmful chemicals from plastics may contribute to the development of cancer (Monclús et al., 2025).

Synthetic plastics are widely favored in various industries due to their advantageous properties such as flexibility, mechanical strength, and chemical stability. These characteristics make them suitable for a broad range of applications, from packaging to construction materials. However, the inherent stability of these plastics also results in significant environmental challenges, as they resist natural degradation processes and accumulate in ecosystems. Moreover, the reliance on petroleum as the primary raw material for synthetic plastics raises sustainability concerns, given the finite nature of fossil fuel reserves and the environmental impact of their extraction and processing (Azizi et al.,

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2024). In response, research has increasingly focused on developing biodegradable alternatives derived from renewable natural polymers that can reduce environmental burden and dependence on non-renewable resources (Samuel et al., 2024).

Among these alternatives, cellulose extracted from savoy and pulp from saguaro plants have shown promise as raw materials for biodegradable plastics. These natural polymers offer a renewable resource base and possess properties conducive to forming biodegradable films with desirable mechanical and barrier properties (Tian et al., 2022). Incorporating chitosan, a biopolymer known for its biodegradability and antimicrobial properties, into plastics derived from sapodilla fruit represents a novel approach to enhancing the functional characteristics of biodegradable plastics. This study aims to explore how varying the volume of chitosan affects the physical and chemical properties of such biodegradable plastics, potentially contributing to the optimization of eco-friendly materials that could replace conventional plastics in various applications.

## 2. Materials and Methods

### 2.1 *Materials*

The materials utilized in the preparation include savoy fruit, distilled water, glycerol, chitosan, and acetic acid. Sapodilla is sourced from the Majalengka region and West Java, with additional materials provided by the Laboratory of Diponegoro University. The equipment employed in the research comprises a blender, sieve, hot plate stirrer, oven, glass beaker, stirrer, and scales. The research variables concerning the production and characteristics of biodegradable soybean starch and chitosan plastics with glycerol as a plasticizer encompass the composition of raw materials and characteristics, analyzed using a completely randomized design system. Further details can be found in Table 1 and Table 2.

Table 1. Percentage of biodegradable plastics composition with glycerol 60%.

| Bioplastic sample | Starch (%w/w) | Chitosan (%w/w) |
|---|---|---|
| B1 | 30 | 70 |
| B2 | 40 | 60 |
| B3 | 50 | 50 |

Table 2. Percentage of biodegradable plastics composition with glycerol 80%.

| Bioplastic sample | Starch (%w/w) | Chitosan (%w/w) |
|---|---|---|
| B1 | 30 | 70 |
| B2 | 40 | 60 |
| B3 | 50 | 50 |

### 2.2 *Preparation of sapodilla starch*

The sapodilla fruit should be thoroughly washed and then peeled. Subsequently, slice the fruit into chips and grind it using a blender. Pass the ground material through a 60-mesh sieve and then strain it. Add water to the strained material and allow it to settle for 24 hours. Wash the residue until it appears white and then dry it in an oven at 60°C for one hour.

### 2.3 *Making biodegradable*

The raw materials, including sapodilla starch, distilled water, chitosan, glycerol, and acetic acid, are combined in ingredient ratios of 30:70, 40:60, and 50:50. These mixtures are then stirred using a stirring rod. Subsequently, the mixtures are placed in an oven, with the temperature and duration adjusted according to the specified variations.

### 2.4 *Biodegradation analysis*

The degradation process initiates with the absorption of water by the material, followed by a reduction in the material's oxidation, and subsequently, microbial activity occurs. Samples measuring 3 x 4.5 cm were placed in a desiccator and weighed to determine the initial mass. These samples were then buried in a box containing soil with a height of 25 cm for a duration of 14 days (Zhang et al., 1996). After 14 days, the samples were cleaned of any adhering soil and reweighed to determine the final mass. The loss in mass was calculated using equation (1)

$$lost\ weight\ (\%) = \frac{W_0 - W_i}{W_0} \times 100\% \quad (1)$$

### 2.5 *Water content Measurement*

The sample was cut into small pieces and then weighed 1 gram in a porcelain cup that had previously been weighed to determine the weight. The cup is placed in the oven for 5 hours at the temperature of 100°C –105°C then cooled in a desiccator until it reaches a constant weight (Peces et al., 2014). Weight loss will be calculated as a percentage of water content and calculated using equation (2).

$$WC\ (\%) = \frac{initial\ mass - constant\ mass}{initial\ mass} \times 100 \quad (2)$$

## 3. Results And Discussion

### 3.1 *Results of measuring the thickness of biodegradable plastic*

The thickness of biodegradable plastics in this study was measured with a caliper with an accuracy of 0.01

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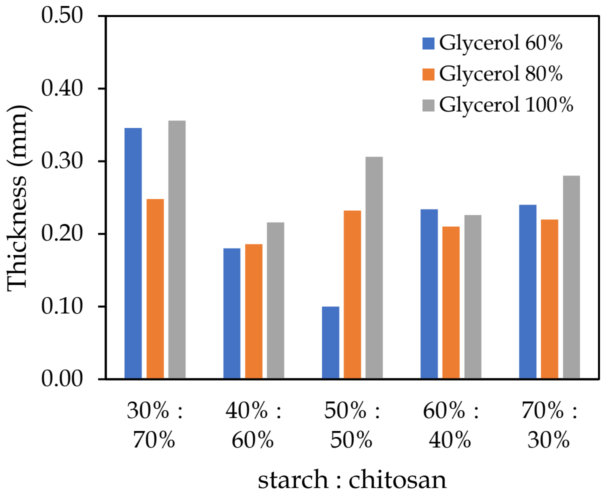


Figure 1. Thickness of biodegradable plastics.

mm. From the measurement of the thickness of biodegradable plastic, data was obtained as in Table 1.

Table 3 highlights significant variations in plastic thickness depending on the composition of the sapodilla starch-chitosan blend and the concentration of glycerol plasticizer used. The thickest plastic observed, measuring 0.356 mm, corresponds to the 30%:70% sapodilla starch to chitosan ratio with glycerol plasticizer. This suggests that a higher proportion of chitosan in the blend, combined with glycerol, contributes to a denser or more robust film structure, potentially due to stronger intermolecular interactions or enhanced polymer network formation. Conversely, the thinnest plastic, at 0.1 mm, is found in the 50%:50% sapodilla starch-chitosan blend with a higher glycerol concentration of 60%. This indicates that increasing glycerol content in an equal-ratio blend acts as a more effective plasticizer, reducing film thickness by increasing polymer chain mobility and flexibility.

The findings from the diversity analysis indicate that incorporating 80% glycerol in the production of biodegradable plastic significantly affects the resultant thickness, with the exception of the composition ratios of 60% starch to 40% chitosan and 70% starch to 30% chitosan (Figure 1). Notably, the addition of 60% glycerol with a composition ratio of 50% starch to 50% chitosan demonstrates that the thickness of the biodegradable plastic is likely influenced by the concentration of plasticizers and chitosan, as well as the increased total amount of dissolved solids in the film solution. Furthermore, the thickness of the plastic is affected by the total solids present in the solution and the thickness of the mold. With a consistent mold, a greater amount of total solids results in a thicker plastic formation.

### 3.2 *Degradability Test Results*

Biodegradation serves as a critical parameter for assessing the environmental friendliness of bioplastics. Soil is employed as the medium for this evaluation due to its abundance and diversity of microorganisms, which facilitate the degradation process (Wang et al., 2024). The assessment of degradation capability involves a seven-day burial period in soil, followed by the calculation of the percentage of mass reduction in the biodegradable plastic. The results of this degradation capability assessment are presented in Table 4.

Table 4 highlights the significant influence of glycerol content on the degradability of sapodilla starch-based biodegradable plastics, demonstrating how varying the chitosan-starch ratio and glycerol percentage alters the material's breakdown efficiency. The highest degradability, reaching 88.2%, was

Table 3. Thickness measurement results.

| glycerol (%) | starch : chitosan (%) | K1 (mm) | K2 (mm) | K3 (mm) | K4 (mm) | K5 (mm) | K average |
|---|---|---|---|---|---|---|---|
| 60% | 30 : 70 | 0.34 | 0.33 | 0.37 | 0.34 | 0.35 | 0.346 |
| | 40 : 60 | 0.20 | 0.18 | 0.19 | 0.18 | 0.19 | 0.18 |
| | 50 : 50 | 0.11 | 0.12 | 0.10 | 0.11 | 0.08 | 0.10 |
| | 60 : 40 | 0.21 | 0.22 | 0.24 | 0.23 | 0.24 | 0.234 |
| | 70 : 30 | 0.23 | 0.24 | 0.22 | 0.25 | 0.22 | 0.23 |
| 80% | 30 : 70 | 0.24 | 0.25 | 0.26 | 0.25 | 0.24 | 0.24 |
| | 40 : 60 | 0.19 | 0.20 | 0.19 | 0.16 | 0.19 | 0.186 |
| | 50 : 50 | 0.24 | 0.20 | 0.23 | 0.24 | 0.25 | 0.232 |
| | 60 : 40 | 0.23 | 0.24 | 0.23 | 0.21 | 0.22 | 0.226 |
| | 70 : 30 | 0.24 | 0.22 | 0.23 | 0.25 | 0.24 | 0.236 |
| 100% | 30 : 70 | 0.34 | 0.35 | 0.36 | 0.35 | 0.38 | 0.356 |
| | 40 : 60 | 0.21 | 0.19 | 0.22 | 0.16 | 0.15 | 0.216 |
| | 50 : 50 | 0.27 | 0.28 | 0.34 | 0.35 | 0.29 | 0.306 |
| | 60 : 40 | 0.19 | 0.21 | 0.22 | 0.21 | 0.22 | 0.21 |
| | 70 : 30 | 0.22 | 0.25 | 0.24 | 0.25 | 0.24 | 0.24 |

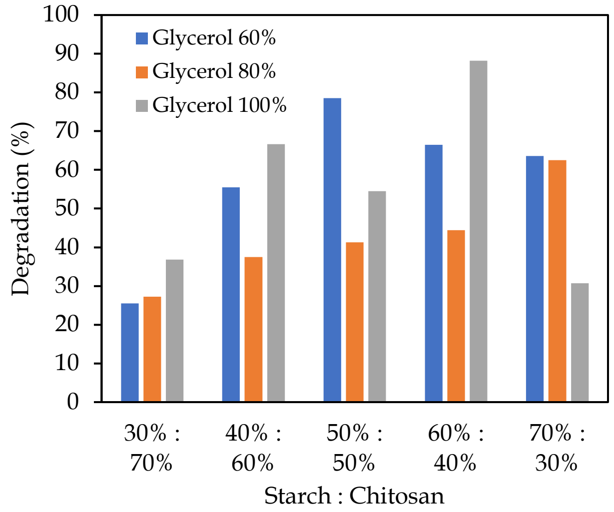


Figure 2. Degradation of the biodegradable plastics.

achieved with a formulation containing a 60% chitosan to 40% starch ratio combined with 100% glycerol. This suggests that a higher glycerol concentration, paired with a balanced chitosan-starch blend favoring chitosan, enhances the plastic's susceptibility to degradation, likely due to glycerol's plasticizing effect improving polymer chain mobility and water interaction.

Conversely, the lowest degradability of 25.5% was observed in a sample with a 30% chitosan to 70% starch ratio and only 60% glycerol, indicating that lower glycerol content and a starch-dominant composition reduce degradability. This outcome may be attributed to the reduced plasticizing effect and the structural characteristics of starch-rich blends, which could limit microbial or enzymatic access during degradation. Overall, these results emphasize the critical role of glycerol concentration and polymer composition in tailoring the environmental breakdown of biodegradable plastics based on sapodilla starch, providing valuable insights for optimizing formulation parameters to achieve desired degradation rates.

Figure 2 illustrates the degradation ability of biodegradable plastic composed of a 60% chitosan to 40% starch ratio, with 100% glycerol, achieving a degradation percentage of 88.2%. This study involves the production of plastics derived from banana peels, incorporating chitosan and glycerol as plasticizers. The burial method in soil indicates that decomposition requires a duration of seven days. Consequently, it can be concluded that the inclusion of glycerol in this study enhances the degradation rate of biodegradable plastic. An increased amount of glycerol facilitates easier degradation. Glycerol's hydrophilic properties influence the chain strength and the high interchain forces resulting from hydrogen bonds between hydroxyl groups in the chain, which enable bioplastics to interact readily with microbes (Santana et al., 2017).

### 3.3 *Sapodilla Starch Content*

Based on the findings of this study, it was determined that 20 grams of sapodilla yielded 9 grams, or 9%, of starch. In comparison, the study by Antarlina and Utomo (2010) reported a starch content of 9.44 grams from 15 grams of sapodilla, indicating that the starch yield in the present study was comparatively lower. The starch content in Sapotaceae is influenced by the optimal harvest age; deviations from this optimal age result in reduced starch content in the tubers. Additionally, the overall starch content is affected by the purity level of the starch during the extraction process, as the presence of impurities such as fiber and sand decreases the starch content per unit weight (Neeraj et al., 2021; Pramana et al., 2024).

Table 4. Testing the ability to degrade biodegradable plastic.

| Glycerol (%) | starch :chitosan (%) | $m_0$ (mg) | M (mg) | Degradation (%) |
|---|---|---|---|---|
| 60% | 30 : 70 | 215 | 160 | 25.5 |
| | 40 : 60 | 90 | 40 | 55.5 |
| | 50 : 50 | 190 | 41 | 78.5 |
| | 60 : 40 | 150 | 50 | 66.6 |
| | 70 : 30 | 110 | 40 | 63.6 |
| 80% | 30 : 70 | 110 | 80 | 27.2 |
| | 40 : 60 | 80 | 50 | 37.5 |
| | 50 : 50 | 145 | 85 | 41.3 |
| | 60 : 40 | 90 | 50 | 44.4 |
| | 70 : 30 | 160 | 60 | 62.5 |
| 100% | 30 : 70 | 95 | 60 | 36.8 |
| | 40 : 60 | 60 | 20 | 66.6 |
| | 50 : 50 | 110 | 50 | 54.5 |
| | 60 : 40 | 85 | 10 | 88.2 |
| | 70 : 30 | 130 | 90 | 30.7 |

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## 4. Conclusion

The findings from the research on the production and characterization of biodegradable plastics derived from sapodilla starch and chitosan, utilizing glycerol as a plasticizer, can be summarized as follows. The analysis of sapodilla starch revealed a starch content of 9%, water content of 2%, fat content of 0.5%, and protein content of 12.44%. The characterization of biodegradable plastics from sapodilla starch indicated a maximum thickness of 0.354 mm at a sapodilla starch to chitosan ratio of 30%:70% with 100% glycerol plasticizer. The highest degradability percentage was 85.7% at a starch to chitosan ratio of 60%:40% with 100% glycerol. The degradation test demonstrated an optimum degradability value of 88.2% for samples with a starch to chitosan ratio of 60%:40% and 100% glycerol. These results suggest that increasing the volume of glycerol and starch in the biodegradable plastic enhances its degradability, attributed to the hydrophilic nature of starch and glycerol.

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