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Characterization of Biodegradable Avocado Seed Starch Films Reinforced with Chitosan and Plasticized with Glycerol

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***Abstract:** Researchers have developed biodegradable bioplastics from renewably sourced natural materials in response to the environmental consequences of synthetic plastics. This study looks at how different amounts of glycerol and chitosan affect the properties of bioplastics made from avocado seed starch. This study evaluated the mechanical, hydrophilic, and degradation properties of tensile strength, elongation at break, thickness, water absorption, and structural stability over time. The results showed increased glycerol content improved flexibility and elongation but impaired tensile strength and water resistance. On the other hand, the increase of chitosan concentration contributes to a significant enhancement of tensile strength, water resistance, and stability. The mixture A3 (1 ml glycerol, 4.5 g chitosan) was thought to have good mechanical stiffness (16.560 ± 3.661 MPa) and water resistance. On the other hand, B1 (2 ml and 2.5 g) had better elasticity (elongation: 32.299 ± 8.910%). Upon performing degradation analysis, B-series samples exhibited a high hydrophilicity, which caused faster breakdown than A-series samples. Avocado seed starch plasticized by a combination of chitosan and glycerol shows promise as an environmentally friendly plastic, and this study shows a way toward fine-tuning both mechanical and hydrophilic properties to produce biodegradable bioplastics.*

***Keywords**: Bioplastics, Mechanical Properties, Plasticizer, Renewable Resources, Sustainable Material.*

INTRODUCTION

The increasing demand for sustainable and eco-friendly materials has recently motivated growing interest in biodegradable bioplastics as substitutes for synthetic plastics. Traditional plastics, mainly synthesized from fossil fuel feedstock, are one of the most concerning environmental pollutants because they are non-biodegradable and tend to persist in an ecosystem (Geyer et al., 2017; Muchtar et al., 2023). Because plastics derived from fossil fuels will contribute to the global plastic pollution crisis, bioplastics created from renewable natural polymers present a potential for reducing plastic waste and its consequent environmental impact.

Due to its biodegradability and compatibility with many additives, starch is a cost-effective and renewable natural polymer widely available for bioplastic production. However, native films made of starch are usually brittle, lack excellent mechanical properties, and are very sensitive to humidity, which limits the practical applicability of such materials (Christwardana et al., 2021; De Beukelaer at al., 2022; Hakiim & Sari, 2017; Muchtar et al., 2023). Some problems with starch bioplastics have been fixed by adding plasticizers (like glycerol) and structural reinforcing agents (like chitosan). This makes the starch bioplastics more flexible, strong, and water-resistant (Anugrahwati et al., 2022; Rhim et al., 2013).

Avocado (*Persea americana*) seeds are an underutilized agricultural by-product, rich in starch, which makes them an intriguing candidate for a sustainable feedstock in bioplastic production. Using avocado seed starch for bioplastics aligns with the principles of a circular economy, which aims to minimize agricultural waste and valorize otherwise discarded resources. The study by (Molavi et al., 2015; Onyeaka et al., 2022) found that starch extracted from avocado seeds can be used to make films like starch extracted from cassava, corn, and potatoes.

Chitosan is a naturally occurring biodegradable polysaccharide that treats chitin with an alkaline solution. It is known for killing microbes, making strong films, and being an excellent moisture barrier. Chitosan enhances the mechanical properties of the bioplastic and lowers its sensitivity to moisture through strong inter- and intramolecular hydrogen bonding when mixed with starch (Khan et al., 2010).

A common plasticizer called glycerol makes bioplastic more flexible by breaking up the intermolecular forces between starch and chitosan. This makes the plastic stretchy. Although glycerol is a hydrophilic molecule, excessive glycerol may reduce the tensile strength and enhance the water absorption (Abdullah, Putri, & Sugandi, 2019; Hernando et al., 2024; Renata Ferreira Santana et al., 2018). Therefore, the balance between the concentration of chitosan and glycerol is crucial in developing the optimal characteristics in biodegradable bioplastics.

While starch-based bioplastics have been widely studied in the literature, the combination of avocado seed starch, chitosan, and glycerol as a bioplastic has not been explored appreciably. Also, different amounts of chitosan and glycerol have not yet been studied to see how they change these bioplastics' mechanical properties, water resistance, and breakdown.

This study examined the mechanical and physical properties of bioplastics made from avocado seed starch that had been chitosan-reinforced and plasticized with glycerol. The study also examined how adding different amounts of glycerol (1 and 2 ml) and chitosan (2.5, 3.5, and 4.5 g) changed the bioplastics' thickness, tensile strength, and ability to soak up water. Finally, it examined bioplastic deterioration and long-term performance. To answer these objectives, this study provides one more step toward producing higher-quality biodegradable materials, contributing to decreased synthetic plastic consumption and environmental pollution.

RESEARCH METHODS

Materials and Tools

The equipment used in this study included a beaker glass, stirring rod, blender (crusher), oven, thermometer, 100-mesh sieve, molds, and a hot plate with a magnetic stirrer. The materials included avocado seed starch, distilled water (aquadest), sodium metabisulfite, chitosan, glycerol, and acetic acid. Figure 1 shows the steps to make a sample, such as getting the starch from avocado seeds, making bioplastics, and setting the test parameters. The sources of avocado seeds are local juice and "alpukat kocok" vendors around Karawang.

Methods

In Figure 1, the chitosan solution was made by mixing 2.5, 3.5, or 4.5 grams of chitosan with 200 mL of a 1% acetic acid solution and stirring until the mixture was smooth. Glycerol

(1 or 2 ml) was added as a plasticizer. The bioplastic samples formed were subjected to 6 tests with 3 repetitions, namely:

1) Tensile strength, elongation at break, and thickness measurement (ASTM D882-18)
   The Yogyakarta Rubber and Plastic Industry Standardization and Service Center tested bioplastic samples and determined the tensile strength (TS) in the following manner:

$$TS = \frac{F_{max}}{A} \qquad \text{(Eq.1)}$$

   where: TS = tensile strength (MPa), F_{max} = maximum force (N), and A = initial cross-sectional area (mm^2). The bioplastics' maximum stretchiness is measured by their elongation at break. For thickness measurement, all constant film thickness values were measured, and the corresponding film was adjusted accordingly.

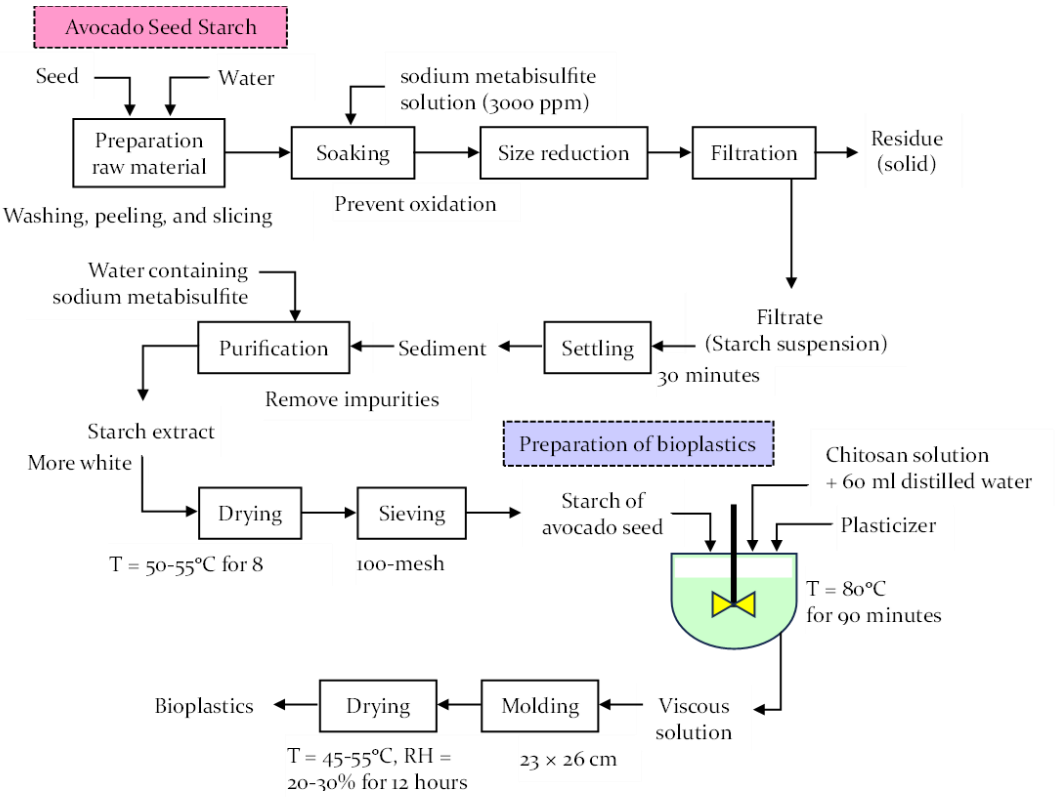

Figure 1. The process of making bioplastics from avocado seeds with a chitosan solution and glycerol plasticizer

2) Water uptake
   Bioplastic samples (2×2 cm) were weighed before (W0) and after immersion in distilled water for 10 seconds (W), and water uptake (WU) was computed as follows:

$$WU(\%) = \frac{W - W_0}{W_0} \times 100 \qquad \text{(Eq.2)}$$

3) Swelling test

Specimens (3×3 cm) were soaked in distilled water, and swelling (ST) was determined as:

$$ST(\%) = \frac{D_{final} - D_{initial}}{D_{initial}} \times 100 \qquad \text{(Eq.3)}$$

The variables $D_{initial}$ and D_{final} represent the sample dimensions before and after processing.

4) Biodegradability test
Sample bioplastics (5×5 cm) were buried in compost soil for 50 days and assessed every 48 h for physical changes and degradation time. This test did not involve any environmental controls such as pH, temperature, or moisture of compost.

RESULTS AND DISCUSSION

Physical Degradation and Structural Integrity

The mechanical analysis (Table 1) also evidences the compromise between flexibility and strength with changing glycerol and chitosan concentrations. A3 (16.560 ± 3.661 MPa) was found to possess the highest tensile strength due to its higher concentration of chitosan, which strengthens the rigidity of the polymer network. As (Olewnik-Kruszkowska et al., 2021; Węgrzynowska-Drzymalska et al., 2020; Yang et al., 2019) observed, the associated cross-linking between chitosan improves its tensile properties, and the interchain movement contributes to the increase in tensile strength and modulus. Ji et al., (2016); Pimsen et al., (2017) analyzed the starch-chitosan films. However, B1 had the lowest strength (8.303 ± 2.059 MPa). This mainly was because too much glycerol was added, which can disrupt polymer chain interactions of polymers and lower their tensile strength (Hidayati et al., 2021).

Table 1. Mechanical properties of bioplastics from seed avocado starch

Code Sample	Tensile Strength (MPa)	Elongation at Break (%)	Thickness (µm)
A1	14.589 ± 2.203	2.948 ± 1.652	180.933 ± 10.901
A2	14.987 ± 0.934	5.577 ± 1.727	220.333 ± 14.343
A3	16.560 ± 3.661	4.256 ± 3.563	237.067 ± 32.139
B1	8.303 ± 2.059	32.299 ± 8.910	155.067 ± 6.311
B2	13.317 ± 4.928	8.795 ± 4.894	218.667 ± 20.081
B3	15.737 ± 1.022	3.146 ± 0.912	224.267 ± 9.180

All of data in Table 1 has p-value < 0.05.

The B-series samples had the most substantial elongation, with the highest value (32.299 ± 8.910%) achieved by B1. As a hydrophilic plasticizer, glycerol made the chain more mobile and flexible, so the stiffness dropped. Study (Joseph et al., 2024; Nazree et al., 2021) also observed similar trends for starch-based bioplastics, where glycerol improved ductility but lowered strength.

Bioplastics were thicker in A3 and B2, indicating higher chitosan concentrations in bioplastics. Chitosan's higher molecular weight provides structural mass, affecting film thickness. The results of this study agree with those of (Hao et al., 2023; Joseph et al., 2024), who discovered that chitosan-starch composites had the higher thickness and better mechanical stability.

Bioplastic stability is affected by glycerol and chitosan, as shown in Figure 2: changes in how it looks after 10 and 50 days. Samples B1–B3 (2 ml glycerol) showed prominent degradation, while samples A1–A3 (1 ml glycerol) demonstrated better structural integrity.

In the B-series, the larger amount of glycerol takes on the function of a plasticizer, improving flexibility and reducing stability. Adding glycerol increases the polymer's free volume, which lets more water in and speeds up hydrolytic degradation. The study (Anugrahwati et al., 2022; Waluyo et al., 2024) focused on starch-chitosan bioplastics.

Additionally, (Lubis et al., 2018; Rhim et al., 2013; Santana et al., 2018) found that more plasticizer means weaker intermolecular forces, facilitating decomposition.

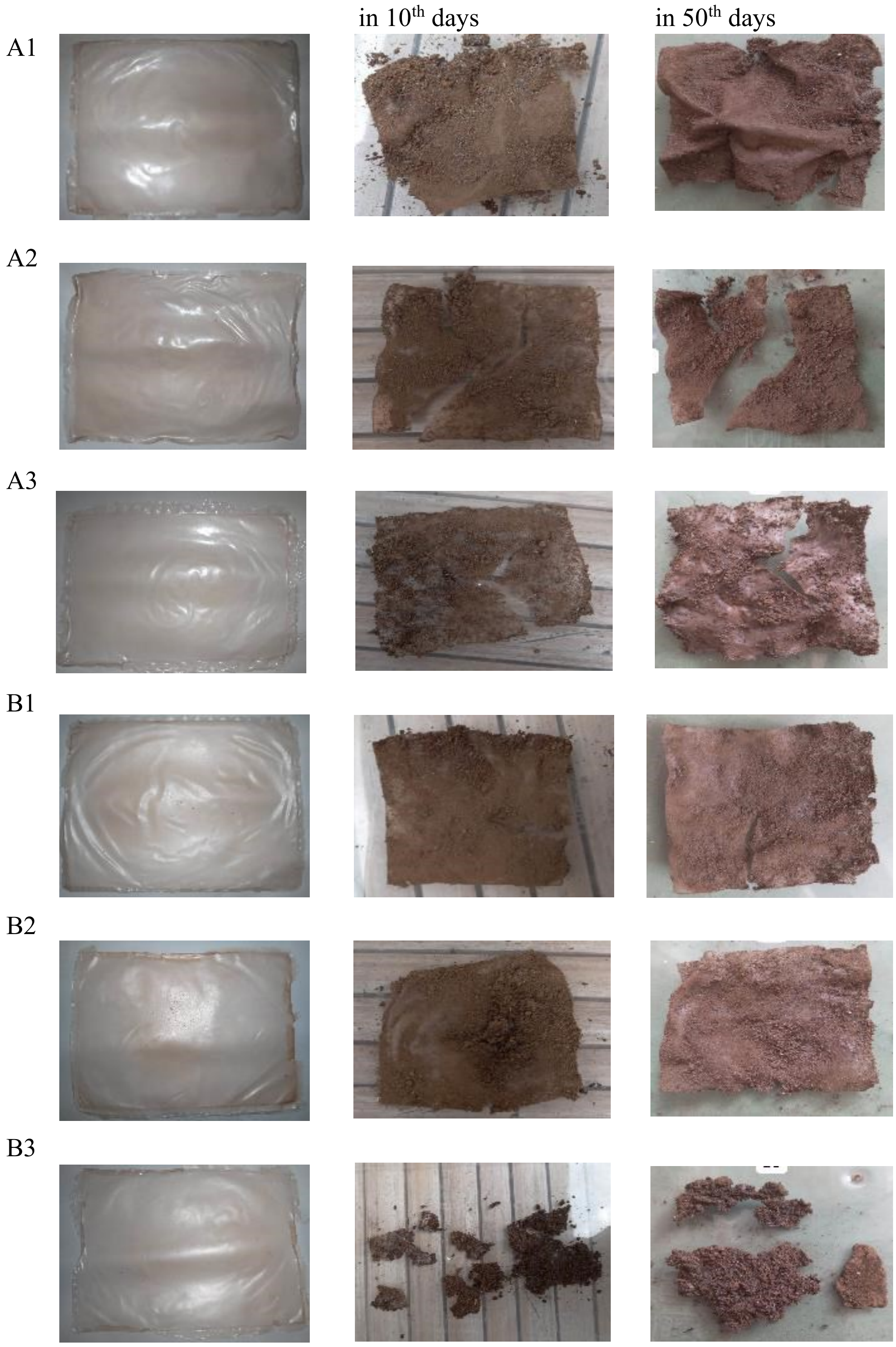

Figure 2. Bioplastics from avocado seed starch: product, as well as after the 10th and 50th days of biodegradation

Samples with higher chitosan content, especially A3, had a greater resistance to fragmentation (A-series). Chitosan can form hydrogen bonds that strengthen the polymer matrix. This makes it more resistant to water and gives it more mechanical stability (Mallakpour & Madani, 2015; Rhim et al., 2013; Xu et al., 2023).

Hydrophilic Behavior: Swelling Degree, Water Resistance, and Water Uptake

Water absorption and swelling characteristics (Figure 3) indicate the material's hydrophilicity. The increased glycerol content showed higher swelling in B-series samples. Glycerol is hydrophilic and increases swelling by drawing water into the polymer matrix. Study (Aitboulahsen et al., 2020; Hazrol et al., 2021; Rhim et al., 2013) corroborate this observation by mentioning the increased water permeability of plasticized films.

Glycerol content negatively affected water resistance. Since glycerol makes things more flexible, A3 had less and more chitosan than the others. This made the matrix denser because hydrogen bonds formed. Researchers (Luchese et al., 2018; Rodríguez-Núñez et al., 2012) also stated that the hydrophobicity of chitosan contributes to its water resistance when it is homogeneously mixed with starch films.

High glycerol and chitosan content in B3 contributed to a significant water uptake in this treatment. Even though glycerol makes it more hydrophilic, high chitosan content also makes it more hydrophilic because it has amine groups that attract water. Study of (Ajiya et al., 2018; Basiak et al., 2018; Shahrim et al., 2018) have shown similar behavior on glycerol-modified starch-based films.

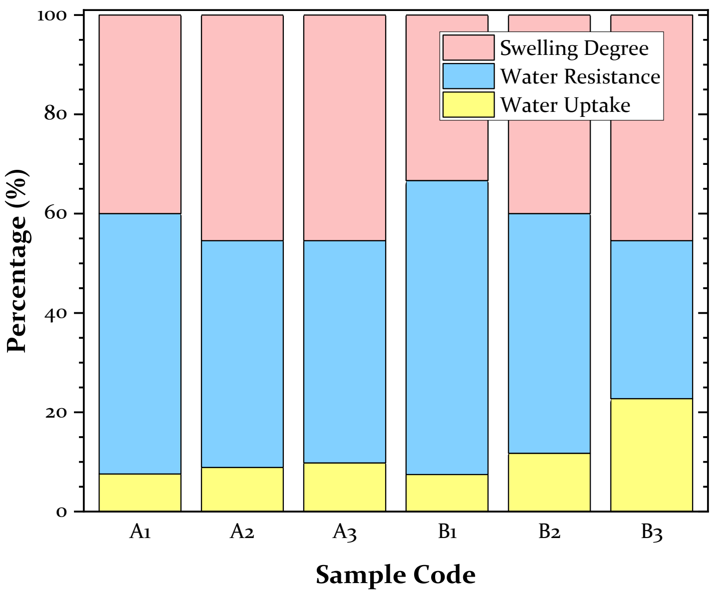

Figure 3. Hydrophilic behavior from bioplastics of avocado seed starch

Influence of Glycerol and Chitosan Content on Performance

The way that the amounts of glycerol and chitosan interact is significant for figuring out how well bioplastics work: [1]Adding glycerol makes the material longer and more flexible, but it also makes it less strong and resistant to water because it has more free space and is more hydrophilic. [2]Chitosan is cross-linked and hydrogen-bonded to the matrix, enhancing tensile strength, thickness, and water resistance. The decreases are in line with what has been written about starch-chitosan-glycerol systems. Researchers (Ji et al., 2016; Sangsuwan et al., 2014; Sayyahi et al., 2017) found that the best balance of plasticizer and chitosan led to good mechanical and hydrophobic properties.

CONCLUSIONS

This study's chitosan and glycerol concentrations significantly influenced avocado seed starch-based bioplastics' mechanical, hydrophilic, and degradation properties. As illustrated in A3, the combination of 1 ml glycerol and 4.5 g chitosan yielded the highest overall performance, leading to increased tensile strength, thickness, and water resistance, all attributed to the reinforcement effect. On the other hand, adding more glycerol made it more flexible and longer at break (B1: 2 ml glycerol, 2.5 g chitosan), but it also made it weaker in tension and more likely to absorb water, which made it break down faster. The difference in physicochemical properties shows that the chitosan and glycerol ratios could be optimized to make biodegradable bioplastics with good properties that can be used instead of regular plastics in similar situations. This indicates that chitosan–glycerol ratios can be controlled so that the biodegradable bioplastics would be applicable for food packages, and possibly, biomedical uses. However, additional research should be conducted to evaluate the environmental stability of these materials, especially the potential biodegradability under natural conditions, and to overcome the challenges associated with the scale-up and implementation in industrial applications.

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