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COMPARISON OF THE USE OF GLYCEROL AND SORBITOL AS PLASTICIZERS ON THE QUALITY OF BIOPLASTICS BASED ON CELLULOSE-CHITOSAN

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Abstract

The accumulation of plastic waste poses significant environmental and health problems. One effort to mitigate this issue is the development of bioplastics. Correspondingly, the primary materials used in this research were cellulose from teak (Tectona grandis) wood powder, chitosan, glycerol, and sorbitol. This study aimed to compare the effectiveness of glycerol and sorbitol as plasticizers. Glycerol is considered cost-effective, renewable, biodegradable, and environmentally friendly, while sorbitol, which is also non-toxic and naturally abundant, can enhance product durability by inhibiting water evaporation. Both materials exhibit good potential as plasticizers; therefore, their comparison is necessary. The research stages included extracting cellulose from teak wood powder, synthesizing cellulose-chitosan-glycerol and cellulose-chitosan-sorbitol bioplastics, and characterizing the resulting materials. The results exhibited the presence of functional groups such as –OH, C-H, and C-O, which were typical of cellulose, as well as N-H groups, characteristic of chitosan. The best quality for glycerol-based bioplastics was achieved with the addition of 0.5 mL of glycerol, yielding a tensile strength of 5.79 MPa, elongation of 10.3%, water absorption of 43.43%, and a degradation time of 17 days. For sorbitol-based bioplastics, the best quality was obtained with the addition of 1 mL of sorbitol, resulting in a tensile strength of 6.23 MPa, elongation of 13.7%, water absorption of 67.46%, and a degradation time of 14 days. Based on these results, sorbitol is more recommended than glycerol as a plasticizer in this study.

Keywords: *bioplastics; cellulose; chitosan; glycerol; sorbitol*

Introduction

Plastic is widely used in daily life for various purposes, including household items, packaging for electronics, and food or beverage containers. However, the increasing reliance on plastic has led to significant environmental and health challenges due to its resistance to decomposition. Plastic waste contributes to the pollution of water, air, and land (Maskun et al., 2022). Furthermore, it poses risks to human health, such as respiratory and lung diseases caused by the burning of plastic waste (Alfitri et al., 2020). To address these issues, bioplastics have emerged as a promising alternative due to their biodegradability and eco-friendly nature.

Bioplastics are produced from renewable materials and are easily decomposed by microorganisms (Maesaroh et al., 2021). A key raw material for bioplastic production is cellulose, an abundant and biodegradable natural polymer. Teak (*Tectona grandis*) wood powder, which contains approximately 60% cellulose (Mursalim et al., 2019), is considered a superior biomass resource to hemp fiber, palm oil, and rice straw, making it a promising candidate for bioplastic production. However, cellulose-based bioplastics tend to be fragile, necessitating the addition of other polymers, such as chitosan, to enhance their mechanical properties (Rojtica, 2021).

Chitosan, derived from chitin, is an eco-friendly and non-toxic material commonly used in bioplastic synthesis due to its flexibility, strength, and ability to form thin layers (Muhammad et al., 2021). Its hydrophobic and water-insoluble nature enhances bioplastics' durability and water resistance, making it a valuable additive. However, while chitosan improves tensile strength, it also results in a stiff texture, necessitating the inclusion of plasticizers to improve flexibility and elongation (Nanda & Azizati, 2018). The incorporation of chitosan into bioplastics thus aims to increase their strength and durability.

Plasticizers are critical in creating bioplastics with strong yet flexible structures capable of withstanding mechanical testing. Glycerol and sorbitol are commonly used plasticizers, each offering distinct advantages. Glycerol is cost-effective, renewable, biodegradable, and environmentally friendly (Sartika, 2017). Sorbitol, which is also non-toxic and naturally abundant, enhances product durability by inhibiting water evaporation (Asngad et al., 2020). While studies on the influence of plasticizers on bioplastic characteristics derived from various raw materials are abundant, direct comparisons between glycerol and sorbitol in bioplastics made from teak wood powder have not been thoroughly investigated. Therefore, the present research aimed to compare the effects of glycerol and sorbitol as plasticizers in bioplastics derived from teak wood powder cellulose, with the objective of identifying the optimal formulation for superior mechanical properties and eco-friendly characteristics.

Methodology

Materials

This research utilized teak wood powder and compost soil as primary materials, along with distilled water, a universal pH indicator, and filter paper for solution preparation and testing. Key chemical reagents, including 1M sodium hydroxide (NaOH), 5% sodium hypochlorite (NaOCl), 2N sulfuric acid (H_2SO_4), and 2% acetic acid (CH_3COOH), were employed to treat and modify the raw materials. Chitosan, glycerol, and sorbitol were incorporated as essential components to enhance the properties of the bioplastics, ensuring a sustainable and effective formulation.

Procedure

1. Cellulose Extraction
   50 grams of teak wood powder were soaked in 1 liter of 1M NaOH solution, heated at 70°C for 3 hours, and subsequently filtered and rinsed to remove residual NaOH. The sample was bleached with 800 mL of 5% NaOCl at 55°C for 1 hour, rinsed again, and treated with 60 mL of 2N H_2SO_4 at 70°C for 30 minutes. After rinsing to neutralize the pH, the sample was oven-dried, crushed, and sieved. The cellulose obtained was characterized using Fourier Transform Infrared Spectroscopy (FTIR) to analyze its composition (Gian et al., 2017; Isnaini, 2019).
2. Synthesis of Cellulose-Chitosan-Glycerol (S-K-G) Bioplastics
   1 gram of chitosan was dissolved in 80 mL of 2% acetic acid, stirred at 50°C for 30 minutes, and mixed with 1 gram of cellulose and varying amounts of glycerol (0.5 mL, 1 mL, 1.5 mL, and 2 mL). The mixture was stirred for 30 minutes at 80°C, poured into molds, and left to dry. After drying, the samples were tested for functional groups using FTIR, mechanical strength using a Universal Testing

Machine (UTM), and biodegradation and water absorption properties.

3. Synthesis of Cellulose-Chitosan-Sorbitol (S-K-S) Bioplastics
   1 gram of chitosan was dissolved in 80 mL of 2% acetic acid and stirred for 30 minutes at 50°C. Then, 1 gram of cellulose was added, followed by varying amounts of sorbitol (0.5 mL, 1 mL, 1.5 mL, and 2 mL). The mixture was stirred for 30 minutes at 80°C, poured into mold plates, and air-dried. The dried samples were analyzed using FTIR for functional groups and tested for mechanical strength using a UTM, as well as biodegradation and water absorption properties.
4. Bioplastics Testing
   a. Mechanical Strength Test
      The samples, cut into 2 × 10 cm pieces, were tested for tensile strength and elongation using a UTM to evaluate their mechanical properties, such as stress resistance and stretchability (Lailyningtyas et al., 2020).
   b. Biodegradation Test
      Cellulose-chitosan, cellulose-chitosan-glycerol, and cellulose-chitosan-sorbitol bioplastics, cut into 1 × 3 cm pieces of equal mass, were buried at the same depth in compost soil for one day. The degradation time of each sample was observed, and the biodegradation rate was calculated using the formula in Equation 1 (Amalia et al., 2019).

$$\%m = \frac{m_o - m_1}{m_o} \times 100\% \quad (1)$$

m = mass (g)
m_o = mass before degradation (g)
m_1 = mass after degradation (g)

   c. Water Absorption Test
      The bioplastic samples, cut into 2 × 2 cm pieces, were weighed to determine their initial mass (Wo) and then immersed in distilled water for 10 seconds. Afterward, the surface water was removed with tissue, and the final mass (W) was measured. The water absorption rate was calculated using Equation 2 (Tamiogy et al., 2019).

$$\text{Absorbed water} = \frac{W - W_o}{W_o} \times 100\% \quad (2)$$

W = final mass of the sample (wet condition) in grams (g)
Wo = initial mass of the sample (dry condition) in grams (g)

Results and Discussion

The cellulose extraction process began with a delignification stage using a 1M NaOH solution, which aimed to remove the lignin content. Dissolved lignin was indicated by the black color in the solution. Trisanti et al. (2018) stated that NaOH solution could damage the ester bonds in lignocellulose, which connect lignin and cellulose. The OH^- ions from NaOH bonded with the H^+ groups from lignin to form H_2O, while the Na^+ ions bonded with lignin to form sodium phenolate. Sodium phenolate has polar properties, making it easily soluble in water.

The next stage was the bleaching process using a 5% NaOCl solution. NaOCl in water produces hydroxyl ions and hypochlorous acid, which are strong oxidizing agents that can break the ether bonds in the lignin structure. This process could increase the degree of whiteness of the cellulose resulting from the bleaching process.

The final stage of the cellulose extraction process was acid hydrolysis using 2N H_2SO_4. Acid hydrolysis served to reduce the fiber size and remove any remaining hemicellulose content (Isnaini, 2019). The cellulose characterization test was carried out using FTIR, as shown in Figure 1.

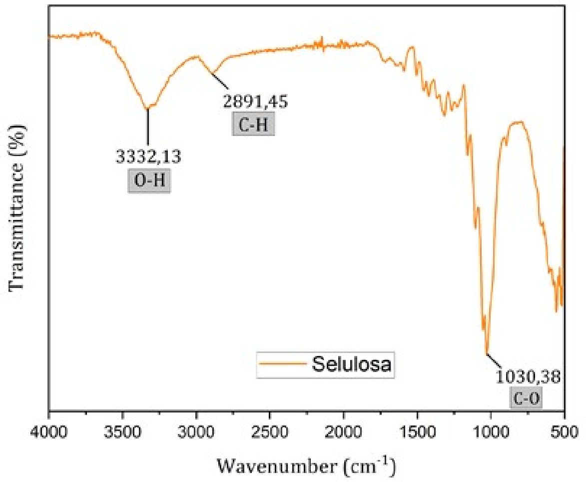

Figure 1. Cellulose FTIR Results

Based on Figure 1, the FTIR spectrum of cellulose revealed the absorption of –OH stretching groups in the range of 3200 cm^{-1} to 3550 cm^{-1}. In the spectrum of teak wood powder cellulose extraction, the –OH stretching group appeared at a wavelength of 3332.13 cm^{-1}. In previous research by Prameswari et al. (2020), the –OH group appeared at a wave number of 3332.24 cm^{-1}. C-H stretching vibrations were observed at 2891.45 cm^{-1} in this study, which was a key component of the cellulose structure. In previous research, C-H stretching vibrations appeared at 2907.32 cm^{-1}. The peak absorption at 1030.38 cm^{-1} indicated the presence of the C-O group in cellulose, which aligned with the findings of Prameswari et al. (2020).

The bioplastics obtained were then subjected to functional group testing using FTIR, as well as mechanical strength testing, biodegradation testing, and water absorption testing.

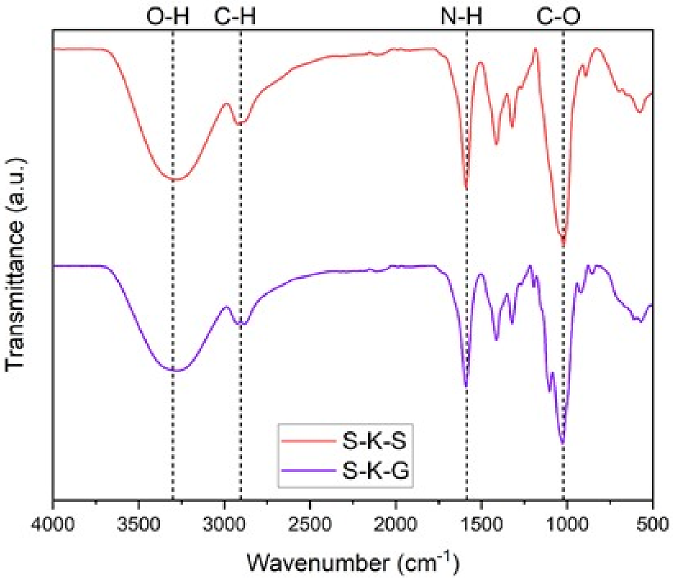

Figure 2. Bioplastics FTIR Results

Table 1. Bioplastic Absorption Results

No.	Functional Groups	Absorption Area (cm^{-1})	Wavenumber (cm^{-1})	
			S-K-G Bioplastics	***S-K-S Bioplastics***
1.	-OH	3200-3550	3273.09	3274.24
2.	C-H	2840-3100	2924.71	2923.16
3.	N-H	1580-1650	1590.18	1589.19
4.	C-O	1020-1075	1026.20	1019.98

Based on Table 1, the characterization results of S-K-G bioplastics revealed the presence of an –OH group, as indicated by the absorption wavenumber of 3273.09 cm^{-1}. The presence of the C-H stretching group was observed at the absorption wavenumber of 2924.71 cm^{-1}, demonstrating the presence of glycerol functional groups. Additionally, the absorption wavenumber of 1590.18 cm^{-1} indicated the presence of N-H amine groups from chitosan, while the C-O groups were identified at the wavenumber of 1026.20 cm^{-1}.

Similarly, Table 1 displayed the presence of an –OH group in S-K-S bioplastics, with an absorption wavenumber of 3274.24 cm^{-1}. The C-H stretching group was observed at the absorption wavenumber of 2929.66 cm^{-1}, confirming the presence of sorbitol functional groups. The absorption at a wavenumber of 1555.89 cm^{-1} indicated the presence of N-H amine groups from chitosan, while the C-O groups appeared at the wavenumber of 1024.54 cm^{-1}.

Table 2. Bioplastic Mechanical Strength Test Results

No.	Sample	Mechanical Strength Test Results	
		Tensile Strength Results (MPa)	**Elongation Results (%)**
1.	S-K-G 0.5	5.79	10.3
2.	S-K-G 1	2.01	20.0
3.	S-K-G 1.5	0.98	26.7
4.	S-K-G 2	0.28	44.7
5.	S-K-S 0.5	13.99	5.7
6.	S-K-S 1	6.23	13.7
7.	S-K-S 1.5	3.66	15.7
8.	S-K-S 2	2.54	18.7

The addition of plasticizers, including glycerol and sorbitol, resulted in a decrease in the tensile strength of the bioplastic. However, this addition also increased the elongation value of the bioplastics. Rojtica (2021) mentions that the addition of plasticizers is directly proportional to an increase in elongation value due to the ability of plasticizers to reduce intermolecular bonds in bioplastics, thereby increasing elasticity. According to *SNI* (Indonesian National Standard) 7188.7:2016, the tensile strength value of bioplastics ranges from 1–10 MPa, while the elongation value is 10–20% (Rojtica, 2021). Based on these results, the optimal mechanical strength for bioplastics with glycerol was achieved with 0.5 mL of glycerol, yielding a tensile strength of 5.79 MPa and an elongation of 10.3%. For bioplastics with sorbitol, the best results were obtained with 1 mL of sorbitol, yielding a tensile strength of 6.23 MPa and an elongation of 13.7%.

Table 3. Biodegradation Test Results for Bioplastics

No.	Sample	Time to Degrade 100%	*SNI* (Indonesian National Standard)
1.	S-K-G 0.5	17 days	100% in 60 days
2.	S-K-G 1	16 days	
3.	S-K-G 1.5	13 days	
4.	S-K-G 2	12 days	
5.	S-K-S 0.5	17 days	
6.	S-K-S 1	14 days	
7.	S-K-S 1.5	13 days	
8.	S-K-S 2	11 days	

The addition of plasticizer volume affected the biodegradation results: the more plasticizer added, the more easily the resulting bioplastic degraded. According to *SNI* (Indonesian National Standard) 7188.7:2016, a 100% biodegradation rate within 60 days was required (Rojtica, 2021). The results obtained in this study could meet the quality standards for bioplastics. Glycerol and sorbitol plasticizers, with their hydrophilic properties, enabled bioplastic production with their addition to degrade more easily in moist compost soil. Based on the research data, the fastest degradation time for bioplastics was 12 days with the addition of glycerol and 11 days with the addition of sorbitol.

Table 4. Bioplastics Water Absorption Test Results

No.	Sample	Water Absorption Test Results (%)
1.	S-K-G 0.5	43.43
2.	S-K-G 1	43.96
3.	S-K-G 1.5	44.20
4.	S-K-G 2	44.98
5.	S-K-S 0.5	64.67
6.	S-K-S 1	67.46
7.	S-K-S 1.5	68.06
8.	S-K-S 2	71.41

The water absorption capacity of bioplastics significantly affects their water resistance. A lower water absorption value indicates improved quality, as it suggests reduced water permeability, making the bioplastic more resistant to water. Conversely, a higher water absorption capacity correlates with greater levels of damage and solubility in water, accelerating the decomposition of the bioplastic. This situation is reversed for bioplastics with lower water absorption values, which decompose more slowly.

In this study, bioplastics with the best hydrophobicity—indicated by low water absorption—were obtained by adding 0.5 mL of glycerol or sorbitol. These results highlighted hydrophobicity's critical role in enhancing bioplastic water resistance.

Conclusion

The quality of bioplastics with the addition of glycerol and sorbitol plasticizers was evaluated based on mechanical strength (tensile strength and elongation), biodegradability, and water absorption. The optimal bioplastic quality with the addition of glycerol as a plasticizer was achieved with 0.5 mL of glycerol, yielding tensile strength of 5.79 MPa, elongation of 10.3%, water absorption of 43.43%, and complete degradation on the 17th day. For sorbitol as a plasticizer, the optimal quality was obtained with 1 mL of sorbitol, resulting in tensile strength of 6.23 MPa, elongation of

13.7%, water absorption of 67.46%, and complete degradation on the 14th day. The results indicated that bioplastics' mechanical strength and degradation performance improved more significantly with the addition of sorbitol compared to glycerol. Based on these findings, sorbitol is recommended as the preferred plasticizer over glycerol in this study.

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