Bioscientist: Jurnal Ilmiah Biologi
https://e-journal.undikma.ac.id/index.php/bioscientist

June 2026 Vol. 14, No. 2
e-ISSN: 2654-4571
pp. 589-599

Processing of Sugarcane Bagasse (*Saccharum officinarum* L.) for Bioplastic Production with the Addition of Glycerol and Chitosan

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Received: March 2026; Revised: April 2026; Accepted: May 2026; Published: June 2026

Abstract: This study aimed to analyze the effects of varying bagasse mass, as well as the roles of glycerol as a plasticizer and chitosan as a reinforcing agent, on the physical, mechanical, thermal, and morphological properties of bioplastics. The research was conducted through laboratory experiments using a completely randomized design (CRD). The mass of bagasse was varied at 2, 4, 6, 8, and 10 g, while the concentrations of glycerol and chitosan were kept constant across all treatments. The results showed that increasing the mass of bagasse tended to produce bioplastics with greater stiffness and brittleness, while also reducing surface homogeneity, as observed through SEM analysis. The addition of glycerol improved material flexibility, as indicated by an increase in elongation from 11.8% to 27.9%. Meanwhile, chitosan contributed to enhanced tensile strength, which increased from 0.4199 MPa to 1.4221 MPa. In addition, higher bagasse content improved thermal resistance, as demonstrated by DSC analysis. The highest biodegradation rate reached 73.95% in a sample with a specific composition during the testing period. FTIR analysis confirmed the presence of functional group interactions among cellulose, glycerol, and chitosan within the bioplastic matrix. These findings indicate that the combination of bagasse with glycerol and chitosan can produce bioplastics with a balanced combination of flexibility, mechanical strength, and biodegradability. This study contributes to the utilization of agricultural waste as a value-added raw material for bioplastic production and supports the development of sustainable, environmentally friendly materials.

Keywords: Bagasse; bioplastics; glycerol; chitosan; cellulose

How to Cite: Lubis, A. N. S., Hutasuhut, M. A., & Widiarti, L. (2026). Processing of Sugarcane Bagasse (Saccharum officinarum L.) for Bioplastic Production with the Addition of Glycerol and Chitosan. *Bioscientist: Jurnal Ilmiah Biologi*, *14*(2), 589–599. https://doi.org/10.33394/bioscientist.v14i2.20291

https://doi.org/10.33394/bioscientist.v14i2.20291

INTRODUCTION

Bioplastics are plastics derived from natural materials that can be degraded by microorganisms and are therefore considered more environmentally friendly than conventional petroleum-based plastics. To address the growing problem of plastic pollution, the development of biodegradable biopolymers as alternatives to synthetic polymers has become increasingly important (Nag et al., 2023; Westlake et al., 2023). Biodegradable plastics have emerged as promising substitutes for conventional plastics because they can be produced from renewable raw materials, particularly plant-derived compounds such as starch, cellulose, collagen, and casein (Nag et al., 2023; Kour et al., 2025). Among these biopolymers, cellulose is one of the most abundant natural polymers and can be obtained from various agricultural residues, including sugarcane bagasse generated by sugar mills (Cut Trisna Farida, 2024; Kour et al., 2025).

In Indonesia, sugarcane bagasse remains underutilized despite its high fiber content, which accounts for approximately 30% of the total weight of the sugarcane plant. Sugarcane bagasse contains 52.7% cellulose, 20% hemicellulose, and 24.2% lignin (Fadilla et al., 2023). This composition is consistent with previous reports indicating that bagasse is a lignocellulosic biomass rich in cellulose, hemicellulose, and lignin, making it a potential feedstock for value-added bioproducts (Alokika et al., 2021). According to Statistics Indonesia, sugarcane production increased continuously from 2022 to 2023, which indirectly increased the amount of bagasse waste generated nationally (BPS, 2024). If not properly managed, this waste may create environmental problems; however, it also has considerable potential to be converted into value-added raw material through biomass valorization (Alokika et al., 2021; Westlake et al., 2023).

The high cellulose content of sugarcane bagasse makes it a promising raw material for bioplastic production, as cellulose can reduce pore size and contribute to greater dimensional stability in the resulting material. Cellulose-based bioplastics have been widely recognized for their biodegradability, renewability, biocompatibility, and potential use in sustainable packaging applications (Kour et al., 2025). The utilization of sugarcane bagasse waste for bioplastic production not only supports the reduction of agricultural waste but also provides economic value through the development of sustainable and environmentally friendly products. However, to improve the properties of the resulting bioplastic, the incorporation of a plasticizer is required. One commonly used plasticizer is glycerol (Kalsum et al., 2020; Tarique et al., 2021).

Glycerol functions as a plasticizer, namely a substance added to a polymer matrix to improve the flexibility and elasticity of the material. Mechanistically, glycerol forms hydrogen-bonding interactions with hydroxyl groups along the polymer chains, thereby reducing intermolecular attraction between polymer chains (Tarique et al., 2021). This interaction increases the spacing between polymer chains and enhances chain mobility, resulting in a material that is more flexible and less brittle. However, this increase in flexibility is generally accompanied by a reduction in tensile strength due to the weakening of strong interactions among polymer chains (Setyaningrum et al., 2020; Tarique et al., 2021).

Chitosan is a biopolymer that can be used to enhance the mechanical strength of bioplastics. Mechanistically, chitosan can form additional hydrogen bonds with polymer matrices such as starch or cellulose, thereby strengthening the polymer network structure (Najih, 2018; Tan et al., 2022). These interactions produce a denser structure and improve cohesion among polymer chains, which contributes to increased tensile strength and material stability. Previous studies have also shown that chitosan incorporation can improve water resistance and support the development of biodegradable films with better mechanical performance (Tan et al., 2022; Chandra et al., 2024). In addition, chitosan is biodegradable, thereby supporting a more environmentally friendly degradation process for bioplastics (Kołodziejska et al., 2021).

Several studies on bioplastic production have been conducted. One study investigated the use of sugarcane bagasse and corn starch with varying glycerol concentrations and obtained a tensile strength of 0.00367 MPa (Kalsum et al., 2020). The use of glycerol as a plasticizer has been reported to improve flexibility and elasticity by increasing polymer chain mobility, although excessive glycerol loading may reduce tensile strength (Setyaningrum et al., 2020; Tarique et al., 2021). This trade-off indicates that plasticizer concentration must be optimized to obtain a balance between flexibility and mechanical integrity.

However, the addition of glycerol alone primarily improves flexibility and does not significantly enhance mechanical strength, particularly tensile strength (Kołodziejska et al., 2021; Tarique et al., 2021). To address this limitation, chitosan has been increasingly explored as a reinforcing agent. Chitosan is a natural biopolymer produced through the deacetylation of chitin; it is biodegradable and can improve the viscosity, water resistance, and mechanical strength of bioplastic films (Kustiyah et al., 2023; Tan et al., 2022; Chandra et al., 2024).

Although the potential of sugarcane bagasse and the role of chitosan are generally recognized, studies integrating sugarcane bagasse cellulose with specific combinations of glycerol and chitosan to achieve an optimal balance between flexibility and mechanical strength remain limited (Lisdawati, 2017). The scientific novelty of this study lies in the optimization of dual glycerol–chitosan concentrations in sugarcane bagasse cellulose-based bioplastics, with a specific focus on achieving an optimal balance between flexibility and mechanical performance. Unlike previous studies that generally used either a single plasticizer or a single reinforcing agent, this study integrates the synergistic roles of glycerol as a plasticizer and chitosan as a reinforcement within one material system.

Based on this background, this study aims to comprehensively analyze the characteristics of bioplastics through Differential Scanning Calorimetry (DSC), tensile strength testing, percent elongation testing, and biodegradation testing. The contribution of this study lies in the development of sugarcane bagasse cellulose-based bioplastics with the addition of chitosan and glycerol as a plasticizer, thereby producing a biodegradable material derived from sugarcane industrial waste with a balanced combination of mechanical strength, flexibility, and degradability.

METHOD

Research Design

This study was designed as a laboratory-based experimental study with a quantitative approach. The research aimed to prepare and characterize bioplastic films made from chitosan and cellulose extracted from sugarcane bagasse (*Saccharum officinarum* L.). The experimental treatment was the variation in sugarcane bagasse cellulose mass, namely 2, 4, 6, 8, and 10 g, while the chitosan and glycerol concentrations were kept constant. The effects of cellulose variation were evaluated based on the thermal, mechanical, and biodegradability properties of the resulting bioplastic films. The main parameters analyzed included glass transition temperature (Tg), melting temperature (Tm), decomposition temperature (Td), tensile strength, percent elongation, and mass loss during biodegradation.

Materials

Sugarcane bagasse (*Saccharum officinarum* L.) was obtained from a sugarcane juice vendor in Kerasaan I Village, Pematang Bandar District, Simalungun Regency, North Sumatra, Indonesia. The main materials used in this study included sugarcane bagasse, chitosan, glycerol, sodium hydroxide (NaOH), hydrochloric acid (HCl), acetic acid, and distilled water.

Preparation of Cellulose from Sugarcane Bagasse

Cellulose was extracted from sugarcane bagasse through several sequential stages. The bagasse was cut into small pieces of approximately 1 cm and washed thoroughly with distilled water to remove impurities and residual sugar. The cleaned sample was then sun-dried for 1 day and subsequently oven-dried at 90°C for 17 h until completely dry. The dried bagasse was ground and sieved using a 100-mesh sieve to obtain a uniform powder.

A total of 30 g of sugarcane bagasse powder was added to 500 mL of 15% NaOH solution, corresponding to a solid-to-liquid ratio of 1:16.7 (w/v). The mixture was heated at 110°C for 4 h to facilitate delignification. After the delignification process, the mixture was filtered to separate the filtrate from the residue. The residue was washed repeatedly with distilled water until a neutral pH of approximately 7 was reached, and then dried at 100°C.

The delignified residue was further subjected to hydrolysis by reacting it with 300 mL of 0.1 M HCl solution at a ratio of 1:10 (w/v). The hydrolysis process was carried out at 105°C for 1 h. After hydrolysis, the sample was washed again with distilled water until neutral pH was achieved and then dried. This procedure was adapted from Kustiyah et al. (2023).

Preparation of Bioplastic Films

Bioplastic films were prepared using a casting method. First, 3 g of chitosan was dissolved in 100 mL of 1% acetic acid solution (v/v) in a beaker. The solution was stirred using a magnetic stirrer at 500 rpm until the chitosan was completely dissolved and a homogeneous solution was formed.

Sugarcane bagasse cellulose was then added to the chitosan solution at different masses of 2, 4, 6, 8, and 10 g. The mixture was stirred again until a homogeneous suspension was obtained. Subsequently, 3 mL of glycerol was added as a plasticizer, equivalent to approximately 3% (v/v) of the total solution volume. The mixture was heated on a hotplate at 120°C for 2 h while being continuously stirred at 500 rpm. This heating process was intended to improve the interaction among chitosan, cellulose, and glycerol, thereby producing a more homogeneous bioplastic matrix.

After heating, the mixture was allowed to stand for approximately 5 min to remove air bubbles formed during stirring. The solution was then poured into a 20 × 20 cm mold and leveled to obtain a uniform film thickness. The mold was dried in an oven at 60°C for 24 h. After drying, the bioplastic film was cooled to room temperature and carefully peeled from the mold. This procedure was based on the method developed by Kustiyah et al. (2023), with several modifications.

Differential Scanning Calorimetry Analysis

The thermal properties of the bioplastic films were characterized using a Differential Scanning Calorimetry instrument, DSC-1 Mettler Toledo. The samples were first cut into appropriate sizes and weighed using a digital balance. The sample mass used for analysis ranged from approximately 5 to 10 mg. Each sample was placed in an aluminum pan and sealed tightly before analysis (Lusiana et al., 2019).

The DSC analysis was conducted under an inert gas atmosphere, such as nitrogen, with a gas flow rate of approximately 20–50 mL/min to prevent oxidation during heating. The samples were heated from approximately 30°C to 400°C at a constant heating rate of 10°C/min. During the heating process, enthalpy changes as a function of temperature were recorded to generate DSC thermograms. The thermogram data were analyzed to determine the main thermal parameters, including glass transition temperature (Tg), melting temperature (Tm), and decomposition temperature (Td), following the methodology described by Darni et al. (2022).

Tensile Strength Test

Tensile strength testing was performed according to SNI 06-1315-2006 using a Lloyd Texture Analyzer, with procedures modified from Brilianti et al. (2023). The bioplastic films were cut into standard test specimens with a length of approximately 100 mm, a width of 10 mm, and a thickness corresponding to the molded film. Both ends of each sample were clamped vertically in the grips of the testing instrument.

Before testing, the initial gauge length was measured and recorded. The load sensor was calibrated to zero to ensure accurate initial readings. During testing, the sample was stretched at a constant crosshead speed of approximately 10 mm/min until deformation occurred and the sample fractured. The maximum force sustained by the sample was recorded and used to calculate tensile strength based on the resulting stress–strain curve. Each test was carried out in at least three replicates, and the reported value represents the average of the measurements. The data were then analyzed to evaluate the mechanical properties of the bioplastic films (Khotimah et al., 2022).

Percent Elongation Test

Percent elongation at break was measured to evaluate the elasticity of the bioplastic films according to ASTM D882-12. The test was conducted using a Universal Testing Machine. Each sample was clamped at both ends using the testing grips, and the initial gauge length was measured and recorded before testing.

During the test, the sample was stretched continuously at a specified speed until it reached the maximum load and eventually fractured. The change in sample length during stretching was automatically recorded by the sensor system of the tensile testing machine. Percent elongation was calculated based on the ratio of the increase in length to the initial length of the sample, expressed as a percentage, using the following equation:

$$\%\varepsilon = \frac{\Delta l}{l_o} \times 100\%$$

Note: Δl is the change in sample length, l_0 is the initial sample length.

Biodegradability Test

The biodegradability of the bioplastic films was evaluated using the soil burial test to assess sample degradation under natural environmental conditions. The bioplastic samples were cut into standard dimensions and weighed to determine their initial mass. The samples were then buried in containers filled with soil with specified characteristics, such as soil type, for example humus soil or topsoil, soil pH, and organic matter content, which support microbial activity.

During the test, environmental conditions such as soil moisture and temperature were maintained relatively constant because these factors strongly influence microbial activity during degradation. Observations were conducted periodically, and the samples were retrieved on days 6 and 9 to determine their final mass after degradation by soil microorganisms. Before final weighing, the samples were cleaned of adhering soil particles and dried until a constant mass was obtained. The percentage of mass loss was calculated using the equation reported by Hasri et al. (2021), as follows:

$$\textbf{Mass loss}\ (\%) = \frac{\boldsymbol{W_i - W_f}}{\boldsymbol{W_i}} \times \mathbf{100}\%$$

Note: (W_i) is the initial mass of the sample, (W_f) is the final mass after degradation.

RESULTS AND DISCUSSION

Differential Scanning Calorimetry (DSC) Analysis

Differential Scanning Calorimetry (DSC) is a thermal analysis method used to identify the thermal properties of materials, including glass transition temperature (Tg), melting temperature (Tm), and decomposition temperature (Td). The analysis was conducted using a Mettler Toledo DSC-1 instrument, which generated thermogram curves representing changes in energy as a function of temperature. The samples were heated from 20 °C to 400 °C at a heating rate of 10 °C/min. The DSC results are presented in Table 1.

Table 1. DSC (Differential Scanning Calorimetry) test data

Sample Mass	Normalized Energy (J/g)	Tg (°C)	Tm (°C)	Td (°C)
2 g	314.89	162.99	162.17	168.52
10 g	297.03	159.71	167.67	181.64

As shown in Table 1, the 2 g sample exhibited a normalized energy value of 314.89 J/g, with Tg, Tm, and Td values of 162.99 °C, 162.17 °C, and 168.52 °C, respectively. In comparison, the 10 g sample showed a normalized energy value of 297.03 J/g, with Tg, Tm, and Td values of 159.71 °C, 167.67 °C, and 181.64 °C, respectively.

The melting temperature (Tm) corresponds to the endothermic peak in the DSC curve, indicating the melting process of the crystalline phase of the material. Based on Table 1, the Tm value increased in the 10 g sample compared with the 2 g sample, suggesting that cellulose addition enhanced the stability of the crystalline phase. This improvement may be attributed to hydrogen-bonding interactions among the hydroxyl groups of cellulose, which strengthen the material structure and require higher energy for melting (Etikaningrum et al., 2016).

These results indicate that increasing cellulose content up to 10 g in bioplastic production can improve the thermal stability of the resulting bioplastic, as evidenced by the increase in melting transition temperature, while slightly reducing the energy required for the transition process. Overall, higher cellulose content contributed to thermal reinforcement of the bioplastic structure.

Tensile Strength Test

The tensile strength test was conducted to determine the ability of the specimens to maintain their structural integrity under tensile stress. The results are presented in Table 2.

Table 2. Tensile strength test data

Sample	Sugarcane Bagasse Mass (g)	Tensile Strength (MPa)	SNI 7818:2014 Standard	JIS Z 1707 Standard
A	2	0.4199	Minimum 13.7 MPa	Minimum 0.39 MPa
B	4	0.5573	Minimum 13.7 MPa	Minimum 0.39 MPa
C	6	0.7033	Minimum 13.7 MPa	Minimum 0.39 MPa
D	8	1.3737	Minimum 13.7 MPa	Minimum 0.39 MPa
E	10	1.4221	Minimum 13.7 MPa	Minimum 0.39 MPa

The tensile strength values of the bioplastic samples were 0.4199 MPa for sample A, 0.5573 MPa for sample B, 0.7033 MPa for sample C, 1.3737 MPa for sample D, and 1.4221 MPa for sample E. The highest tensile strength was observed in sample E, with a value of 1.4221 MPa, whereas the lowest value was recorded in sample A, at 0.4199 MPa. These results indicate that tensile strength varied according to the concentration of sugarcane bagasse used. In general, higher sugarcane bagasse concentrations tended to produce higher tensile strength values. Sample A, containing 2 g of sugarcane bagasse, exhibited a tensile strength of 0.4199 MPa, while sample E, containing 10 g, reached 1.4221 MPa. This increase suggests that sugarcane bagasse addition contributed to the improvement of the material’s tensile strength.

When compared with SNI 7818:2014, which requires a minimum tensile strength of 13.7 MPa, all tested samples remained far below the specified standard. This indicates that the materials produced in this study have not yet met the minimum tensile strength requirement for certain applications based on SNI criteria. However, when compared with the Japanese Industrial Standard JIS Z 1707, which specifies a minimum tensile strength of 0.39 MPa, all samples—A, B, C, D, and E—exceeded the minimum requirement. Thus, although the bioplastic did not satisfy the SNI standard, it demonstrated sufficient tensile strength according to the JIS standard for applications requiring lower mechanical resistance.

The increase in tensile strength at higher cellulose content may be associated with improved interfacial strength resulting from strong hydrogen bonding among cellulose hydroxyl groups. Cellulose fibers can reduce pore volume within the plastic matrix, thereby producing a denser structure with greater resistance to tensile deformation (Fadilla et al., 2023). This finding is consistent with the study by Jumiati et al. (2023), which reported improved tensile strength following the addition of sugarcane bagasse cellulose.

These results imply that the sugarcane bagasse-based bioplastic produced in this study is more suitable for low-load mechanical applications, such as lightweight packaging, biodegradable shopping bags, or dry-product wrappers. However, it is less suitable for applications requiring high tensile strength, such as heavy-duty packaging or structural products. Further improvements are therefore required, including formulation optimization, enhanced mixture homogeneity, and the application of cross-linking techniques to improve mechanical performance so that the material can meet SNI requirements and expand its potential applications.

Percent Elongation Test

The percent elongation test was used to determine the change in specimen length during tensile testing. The elongation value was calculated by comparing the increase in length with the initial length of the specimen before testing. The results are shown in Table 3.

Table 3. Percent elongation test data

Sample	Sugarcane Bagasse Mass (g)	Elongation (%)	ASTM D882-12 (%)
A	2	11.8	Minimum 10
B	4	16.36	Minimum 10
C	6	18.68	Minimum 10
D	8	19.26	Minimum 10
E	10	27.9	Minimum 10

Note: Tensile analysis was performed in triplicate.

As presented in Table 3, the percent elongation values of the bioplastics were 11.8% for sample A, 16.36% for sample B, 18.68% for sample C, 19.26% for sample D, and 27.9% for sample E. The lowest elongation value was observed in sample A, whereas the highest value was obtained in sample E. Based on ASTM D882-12, the minimum required elongation value is 10%. All tested samples exceeded this minimum requirement. Sample A, with an elongation value of 11.8%, was slightly above the minimum threshold, while sample E, with an elongation value of 27.9%, exhibited substantially greater extensibility than the required standard. These findings indicate that all product variations, including those with the lowest bagasse concentration, met the minimum standard for percent elongation.

The data further show that the percent elongation of sugarcane bagasse-based bioplastic increased with increasing bagasse concentration. Higher concentrations resulted in improved elasticity of the material. Among all samples, sample E, containing 10 g of sugarcane bagasse, showed the highest percent elongation value of 27.9%, making it the most optimal formulation in terms of elasticity. In this context, optimality refers to the ability of the material to undergo deformation or elongation without failure, which is an important indicator of bioplastic flexibility.

These findings are in agreement with Hasan et al. (2022), who stated that percent elongation reflects the mechanical characteristics of bioplastics, particularly their ability to deform under tensile stress. An increase in elongation generally corresponds to greater material flexibility, allowing the bioplastic to better resist cracking or breaking during use.

Biodegradation Test

The biodegradation test was conducted to determine the ability of the bioplastic to decompose naturally in soil. This method was based on measuring sample mass loss after burial in soil for a specified period. The biodegradation results are presented in Table 4.

Table 4. Biodegradation test data

Sugarcane Bagasse Mass (g)	Initial Mass (g)	Final Mass (g)	Biodegradation (%)	SNI 7188.7:2016 (%)
2 g	0.0879	0.0699	20.47	>60
4 g	0.0966	0.0476	50.72	>60
6 g	0.1020	0.0452	55.68	>60
8 g	0.1026	0.0404	60.62	>60
10 g	0.1002	0.0567	73.95	>60

Based on Table 4, the biodegradation rate increased with increasing mass of sugarcane bagasse cellulose. The sample containing 2 g showed a biodegradation value of 20.47%, which increased to 50.72% at 4 g and 55.68% at 6 g. The biodegradation value further increased to 60.62% at 8 g and reached the highest value of 73.95% at 10 g. Thus, the highest biodegradation value was observed in the 10 g sample, while the lowest value occurred in the 2 g sample. When compared with SNI 7188.7:2016, which requires a biodegradation value greater than 60%, only the 8 g and 10 g samples met the standard.

These results demonstrate that the bioplastic was capable of biodegrading in soil, with the percentage of biodegradation increasing proportionally with cellulose content. Higher cellulose content enhanced the degradability of the material. Therefore, the 8 g and 10 g samples have potential for applications requiring readily degradable materials, such as lightweight biodegradable packaging, environmentally friendly shopping bags, dry-food wrappers, disposable trays or food containers, and agricultural applications such as biodegradable mulch.

The biodegradation rate of bioplastics is influenced by their constituent components, particularly cellulose and glycerin. Cellulose is hydrophilic and can enhance water absorption into the bioplastic matrix. This condition creates a favorable environment for microbial activity, thereby promoting material decomposition. In addition, glycerin acts as a plasticizer that increases both the hydrophilicity and flexibility of the material, facilitating water diffusion and microbial access into the bioplastic structure. Consequently, increased hydrophilicity plays an important role in accelerating the biodegradation process (Zaenab et al., 2023).

CONCLUSION

The incorporation of cellulose derived from sugarcane bagasse was shown to positively influence the properties of the bioplastic, particularly by improving thermal stability, mechanical strength, and biodegradation rate. Increasing the cellulose concentration up to 10 g enhanced the melting point and tensile strength of the material. This improvement was attributed to the formation of stronger hydrogen bonds and a reduction in pore volume within the plastic structure. Compared with the applicable standards, the tensile strength of the produced bioplastic exceeded the JIS Z 1707 standard but did not yet meet the requirements of SNI 7818:2014. In contrast, the biodegradation performance was highly favorable, as the samples containing 8 g and 10 g of cellulose met the SNI 7188.7:2016 standard. Based on these characteristics, sugarcane bagasse cellulose-based bioplastics are more suitable for applications that do not require high tensile resistance, such as lightweight packaging or environmentally friendly single-use products. This study also provides an important contribution to the development of sustainable materials by utilizing sugarcane bagasse waste as a cellulose source. This approach not only increases the added value of agro-industrial waste but also supports efforts to reduce the use of conventional plastics. Further development is required through optimization strategies, including the selection of more effective plasticizers and the application of cross-linking methods, to improve the tensile strength of the material. Through these approaches, the resulting bioplastic is expected to meet SNI requirements and demonstrate broader potential for commercial packaging applications.

RECOMMENDATION

Future research should focus on optimizing the type of plasticizer and applying cross-linking methods to improve tensile strength, thereby enabling the resulting bioplastic to meet SNI standards and expand its applicability for commercial packaging.

ACKNOWLEDGMENT

The authors would like to express their gratitude to all parties who contributed to this study and provided constructive suggestions and feedback during the preparation of this manuscript.

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