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Effect of Glycerol Concentration and Filler Addition on the Properties of Bioplastics Derived from Kepok Banana Corm Starch

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Abstract

The waste from kepok banana corms and stems has not been well utilized, even as banana production continues to rise, increasing the volume of such waste. In Indonesia, banana production in 2023 reached 9.75 million tons, up from 7.2 million tons the previous year, leading to a corresponding increase in banana waste. This research investigates the effects of glycerol and banana stem filler on the properties of bioplastics made from kepok banana corm starch, aiming to develop a sustainable alternative to conventional plastics. Starch was extracted from kepok banana corms through grinding, filtering, and drying at 80°C for 15 minutes. Cellulose filler was produced from banana stems using bleaching with NaOH and H_2O_2, followed by neutralization and drying to a constant weight. Bioplastics were then produced with filler concentrations of 0%, 2%, 4%, and 6% and glycerol volumes of 1-4 mL per 10 grams of starch, on mixing conducted at 70°C in distilled water. Characterizations and tests of the bioplastics included for cristallinity, functional groups, surface morphology, yield, density, water absorption, tensile strength, and elongation. Bioplastics with addition filler performed better than those without filler, with the 6% filler and 2 mL glycerol variation showing the most favorable properties, including a yield of 25.92%, density of 1.14 g/mL, water absorption of 0.24%, tensile strength of 5.49 MPa, elongation of 8%, and a homogeneous surface with well-distributed filler. These findings demonstrate the potential of kepok banana waste-based bioplastics as an environmentally friendly alternative.

Keywords: Banana corm, bioplastic, filler additive, kepok banana stem

1. Introduction

Banana corm has a relatively high starch content, with its starch resembling sago flour. Banana corm consists of 76% starch, 20% water, and the remainder consists of protein and vitamins (Sembiring et al., 2017). Starch-based plastics generally have characteristics that are rigid, brittle, and highly absorbent. To overcome these weaknesses, fillers need to be added. Banana stems are abundant in nature, containing 63%-64% cellulose, which has strong binding properties and is hydrophobic, making it suitable as a filler material (Othman et al., 2020).

Besides the addition of fillers, the inclusion of additives such as plasticizers is also necessary. The addition of plasticizers during the bioplastic manufacturing process disrupts the hydrogen bonds between adjacent polymers, thereby reducing the intermolecular tensile strength of the polymer chains, which in turn increases the mobility of the polymers (Narancic et al., 2020). Plasticizers can also reduce brittleness and improve flexibility (Hidayati et al., 2015).

Bioplastic is a type of plastic made from natural, renewable materials that can be decomposed by microorganisms (Ibrahim et al., 2021). The production of bioplastics from natural and environmentally friendly materials has been widely developed, particularly for starch-based bioplastics, such as those made from durian seeds (Wahidin et al., 2021), taro tubers (Shanmathy et al., 2021), and kepok banana corms (Berghuis, 2023). Bioplastics have advantages over

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conventional plastics made from non-renewable synthetic materials that are difficult to degrade (Fauziyah et al., 2021). Bio-based bioplastics are generally derived from renewable resources such as polysaccharides (cellulose, starch, pectin, chitin), proteins (gluten, casein, gelatin), lipids (animal and vegetable oils), or from materials produced by microorganisms (microalgae) (Ayu and Aisyah, 2020).

Polysaccharides, as the most abundant macromolecules in nature, are among the most suitable raw materials for bioplastics in the form of starch. In addition to being renewable and abundant, starch is also inexpensive, has beneficial thermoplastic properties, and is biodegradable (Shafqat et al., 2021).

According to research conducted by Humairi et al., 2023 on improving the physical properties of biodegradable film from kepok banana peel (Musa acuminata) with the addition of natural fillers using the solution casting method, the fillers used included sengon sawdust, sugarcane bagasse, and kraft paper as paper pulp. The filler composition was varied at 1%, 2%, 3%, and 4% for all types of fillers. The results showed that tensile strength values increased with the addition of fillers, although the values remained low. Therefore, further research on filler composition variations is necessary (Humairi et al., 2023).

Research by Shanmathy et al., (2021) studied the effect of glycerol addition on the tensile strength and elongation at break of bioplastics made from taro tuber starch. Using the casting method, the study varied starch solution concentrations (0.2 w/v, 0.3 w/v, and 0.4 w/v) with glycerol volumes (1% v, 2% v, and 3% v) and gelatinization temperatures (60°C, 70°C, and 80°C). The results showed that bioplastics made from taro tuber starch had a gelatinization temperature of 70°C, with the best results obtained for bioplastics with a 0.3 w/v starch concentration and 1% v glycerol addition. In general, the addition of glycerol caused a decrease in tensile strength and an increase in elongation at break (Shanmathy et al., 2021). This article aims to determine the optimal glycerol and cellulose concentrations to achieve desirable properties and characteristics in kepok banana corm starch-based bioplastics, which have the potential to replace conventional plastics.

Based on previous research, further studies are intended to explore the potential of the kepok banana corm as a starch source for the production of bioplastics, owing to its exceptionally high starch content. Additionally, prior research has revealed a high cellulose content in the stem of the kepok banana, which suggests its potential to enhance the physical properties of bioplastics. As a result, it has been selected as a filler in the development of bioplastics in this study.

2. Methodology

2.1. Materials

The primary materials used in this study can be seen in figures 1 and 2, which are kepok banana stems and corms sourced from banana plantations in Simalungun, North Sumatra, Indonesia. The chemicals used include sodium hydroxide (NaOH) 17.5%, sulfuric acid (H_2SO_4) 40%, hydrogen peroxide (H_2O_2) 7.2%, glycerol ($C_3H_8O_3$) 96%, and distilled water (H_2O). All chemicals were purchased from CV. Rudang Jaya, Medan, North Sumatra, Indonesia.

Figure 1. Kepok banana stems

Figure 2. Kepok banana corm

2.2. Starch Extraction Process

Starch extraction from kepok banana corms was carried out with modifications from the previous study by Shanmathy et al., (2021). A total of 100 grams of kepok banana corms

were washed with clean water and then drained. The corms were cut into cubes measuring (1x1x1) cm. The banana corm pieces were placed into a blender, followed by the addition of 200 mL of distilled water, and blended until smooth. The mixture was then filtered using a filter cloth and allowed to settle for 24 hours. The resulting starch sediment was washed by adding distilled water, stirred, and left to stand for 1 hour before the water was discarded. This process was repeated by adding distilled water to the starch sediment until a clean starch sediment was obtained. The clean starch sediment was then transferred into a watch glass and dried in an oven at 80ºC. The starch was dried until a constant weight was achieved. The starch yield was then calculated by comparing the dry weight of the starch with the initial weight of the kepok banana corms used.

2.3. Cellulose Isolation Process

Cellulose isolation from kepok banana stems was carried out with modifications from the previous study by (Syakri et al., 2021). The kepok banana stems were washed with clean water and chopped. The chopped banana stems were then blended until smooth and sifted using a 200-mesh sieve. A total of 10 grams of banana stem powder was dissolved in 17.5% NaOH and heated on a hot plate at 55°C for 2 hours. After that, the solution was mixed with 7.2% H_2O_2 and neutralized with 40% H_2SO_4 until the pH reached 7. The bleaching product was then filtered and rinsed with distilled water three times. The powder was then dried in an oven at 80°C until a constant weight was achieved. The cellulose yield was calculated by comparing the dry weight of the cellulose with the initial weight of the kepok banana stems used.

2.4. Bioplastic Manufacturing Process

Bioplastic production was carried out with modifications from the previous study by Shanmathy et al., (2021). A total of 10 grams of dry starch from kepok banana corms was weighed and 120 mL of distilled water was added into a beaker glass. The mixture was then added with fillers in predetermined variations (0%, 2%, 4%, 6% w) and stirred until homogeneous. Next, glycerol was added at volumes of 1 mL, 2 mL, 3 mL, and 4 mL. The solution was then heated on a hot plate to 70°C, while stirring with a magnetic stirrer until gelatinization occurred. The solution was poured into a mold of 25 cm x 25 cm x 1 mm and dried at room temperature for 24 hours. The resulting bioplastic was then analyzed. Bioplastic quality analysis was performed in accordance with SNI 7188.7:2016, which included testing for density, water absorption, yield, tensile strength, elongation, as well as characterization using FTIR, XRD, and surface morphology using SEM.

The selection of filler concentration variations (0%, 2%, 4%, and 6% w/w) and glycerol volumes (1 mL, 2 mL, 3 mL, and 4 mL) in this study was based on scientific considerations aimed at evaluating the influence of each component on the physical and mechanical properties of the bioplastic. The filler variations were chosen to determine the extent to which the addition of filler, such as cellulose extracted from banana stems, can improve the characteristics of the bioplastic, particularly in terms of mechanical strength, density, and surface morphology. The selected concentration range of 0–6% was considered appropriate because, within this range, the filler can generally be dispersed homogeneously without excessive agglomeration, which could otherwise reduce the quality of the bioplastic.

Furthermore, using incremental variations (2% intervals) facilitates the observation of trends in material properties in a systematic manner. Meanwhile, the addition of glycerol as a plasticizer aims to enhance the flexibility and elasticity of the bioplastic. The glycerol volume range of 1–4 mL represents commonly used values in starch-based bioplastic research. These variations were intended to identify the optimum volume that can improve the mechanical performance without making the bioplastic overly soft, sticky, or difficult to dry. Through this combination of variations, the study aims to obtain a bioplastic formulation with a balanced set of physical and mechanical properties.

3. Results and Discussion

3.1. Raw Material Yield

The starch yield obtained was 12.8%, which is higher than the values reported in previous studies, as shown in Table 1. The cellulose yield was 15.7%, where a higher yield typically indicates a more efficient isolation process. For comparison, a similar study by Merais et al. (2022) reported a cellulose yield of 22.58% from the pseudostem of the klutuk banana. The starch extracted from the corm of the Kepok banana and the isolated cellulose from the stem are presented in Figures 3 and 4, respectively.

Table 1. Starch yield in various types banana weevil

Weevil Variety of Banana	Yield (%)	Researcher
Kepok	12,56	(Syakri et al., 2022)
Raja	12,3	
Mahuli	10,20	
Susu	10,70	
Ambon	11,63	
Kepok	12,80	This research

Figure 3. Starch from kepok banana corm

Figure 4. Cellulose from kepok banana stems

The amount of cellulose obtained is influenced by the concentration of NaOH, temperature, and bleaching time. A low NaOH concentration will result in a low cellulose yield, while a high NaOH concentration can also decrease the cellulose yield. Additionally, the temperature must be kept below 100°C to prevent water from evaporating, which could lead to an increase in NaOH concentration. Both the concentration and the bleaching time affect the cellulose yield. The crystallinity of cellulose decreases as the concentration of H_2O_2 increases. Moreover, a bleaching time of less than 1.5 hours results in cellulose with low brightness, whereas if the bleaching time exceeds 1.5 hours, the brightness tends to remain constant (Cifriadi et al., 2017).

3.2. Crystallinity Characteristic of Fillers

X-ray Diffraction (XRD) was used to measure the crystallinity percentage of the filler, which is cellulose derived from the Kepok banana stem. In this study, XRD characterization was conducted on three samples: untreated banana stem powder, banana stem powder subjected to delignification using 4% NaOH, and banana stem powder treated with 17.5% NaOH. The crystallinity percentage was calculated using Equation 1.

$$C = 100\% \frac{I_{crystal}}{I_{crystal} + I_{amorphous}} \qquad (1)$$

The crystalline intensity and amorphous intensity values were obtained using Origin v.8.3 software, by analyzing the intensity of each peak produced. The crystallinity percentage was then calculated using Excel. The XRD diffractogram results for the filler in this study are shown in Fig. 5. Figure 5 shows the XRD result interpretation of the tested samples: C523 (banana stem powder without treatment), C524 (banana stem powder that underwent delignification with 4% NaOH), and C525 (banana stem powder treated with 17.5% NaOH).

The diffraction patterns were measured between 2 Theta (2θ)= 10,01° to 89,990° using Cu as a anode material. In the diffractogram, peaks indicate the crystalline phase, while amorphous areas are represented by valleys preceding the crystalline peaks (Fauziyah et al., 2021). The crystallinity percentage was calculated using Origin v.8.3 software to measure the intensity of the crystalline and amorphous phases. The results show a crystallinity of 88.524% for C523, 96.318% for C524, and 97.780% for C525. This indicates that the NaOH concentration in the delignification process affects the resulting cellulose crystallinity, with higher NaOH concentrations leading to increased crystallinity. These findings align with Budtova and Patrick's (2016) study, which states that a lower NaOH concentration yields lower cellulose output.

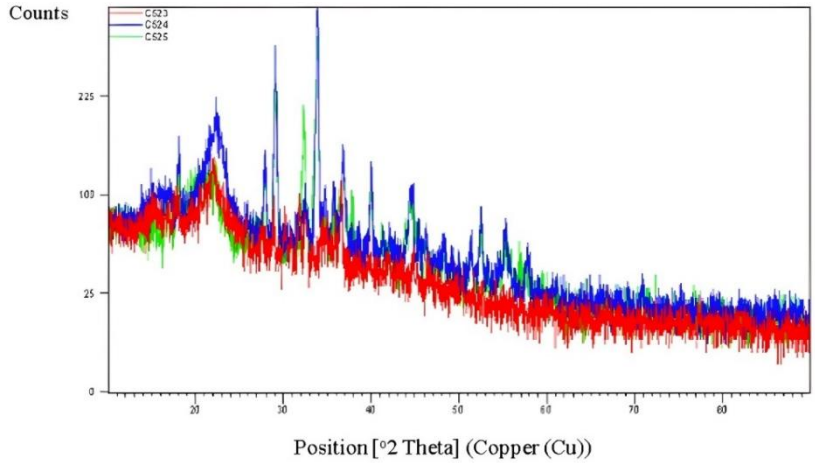


Figure 5. XRD pattern of filler

3.3. Water Absorption

Figure 6 illustrates the effect of filler and glycerol concentrations on the water absorption of bioplastic.

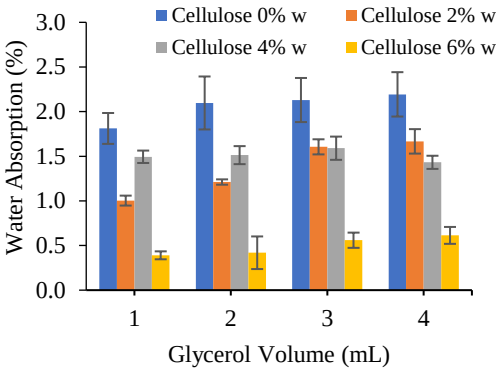


Figure 6. Effect of glycerol volume and filler concentration on the water absorption of bioplastics

Each sample was analyzed in triplicate, with error bars representing the variability in the results. Increasing the filler concentration in the bioplastic enhanced its hydrophobic properties, as indicated by a reduction in water absorption. This trend is most evident in the sample with the highest filler concentration (6%), which showed the lowest water absorption value. The bioplastic's water absorption capacity is influenced by the hemicellulose and lignin content. The reduction of these components—achieved through delignification and bleaching of the filler—improves hydrophobicity. This result is consistent with previous findings, which reported that decreasing hemicellulose and lignin content in raw materials reduces water absorption in bioplastics (Nasution et al., 2020).

The water absorption capacity of bioplastic is influenced by the amount of glycerol used. In addition to the filler concentration, the plasticizer content (in this case, glycerol) also impacts the water absorption of bioplastic. The results indicate that using the highest glycerol concentration of 4 mL leads to the highest water absorption values. Adding glycerol reduces internal hydrogen bonding, which increases the distance between molecules, making the bioplastic more prone to absorbing water (Cifriadi et al., 2017). Thus, the greater the glycerol content, the more the bioplastic's water absorption capacity increases (Acquavia et al., 2021). According to the Indonesian National Standard (SNI) 7188.7:2016, the maximum allowable water absorption for bioplastics is 99%, as their hydrophilic properties can weaken physical strength. Based on the research results, water absorption for all bioplastic variations was below 99%, meeting the established hydrophobicity standard.

The addition of cellulose filler in bioplastics is generally expected to enhance the material's hydrophobic properties. However, test results show that bioplastics with 4% filler concentration exhibit higher or comparable water absorption compared to those with 2% filler. This inconsistency indicates that increasing the filler content does not directly guarantee improved water resistance. Several factors that may influence these results are explained below.

First, the distribution and dispersion of the filler within the polymer matrix play a crucial role. At higher concentrations, filler particles tend to agglomerate due to stronger interactions between particles than with the matrix. This agglomeration leads to the formation of microvoids within the bioplastic

structure, which can enlarge the diffusion pathways for water.

Second, the inherently hydrophilic nature of cellulose also contributes to the increased water absorption. Cellulose contains numerous hydroxyl (-OH) groups that are polar and capable of attracting water molecules through hydrogen bonding. At a 4% concentration, the number of available hydroxyl groups increases, thereby enhancing the potential for water interaction.

3.4. Density of Bioplastic

Figure 7 shows the effect of filler and glycerol concentrations on the density of the bioplastic. Measuring the density of bioplastic is crucial, as it is closely related to its ability to protect products from free atmospheric substances, such as water, oxygen, and carbon dioxide (Darni et al., 2014). The research findings indicate that filler concentration influences the density of bioplastic. An increase in cellulose concentration by 2% w resulted in an increase in bioplastic density, but at a concentration of 4% w, there was a decrease in density-except in the highest glycerol variation (4 mL), where the density increased significantly. The lowest density was observed in bioplastic with a filler-to-glycerol ratio of 4% w : 1 mL, while the highest density was observed with a ratio of 4% w : 4 mL glycerol. This variation is attributed to the different densities of each component: starch density ranges between 0.72–0.81 g/mL (Stelescu et al., 2024), cellulose density is 0.833 g/mL (Lismeri et al., 2016), and glycerol has a much higher density at 1.264 g/mL (Takamura et al., 2012).

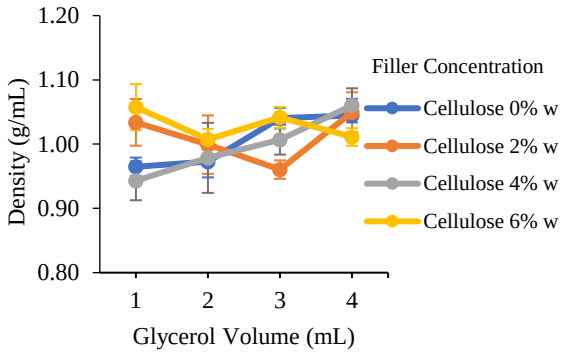


Figure 7. Effect of glycerol volume and filler concentration on the density of bioplastics

Gujar et al. (2014) also stated that in the gelatinization process, glycerol and cellulose-based fillers are absorbed into the starch granules. This makes the starch structure denser, resulting in an increase in density as glycerol and cellulose are added to the bioplastic (Nasution et al., 2020). The density values of the bioplastic samples were then compared to the density standard of LDPE plastic, which is 0.910-0.925 g/mL (Darni et al., 2014). The research results showed that the density of the bioplastic ranged from 0.94 -1.23 g/mL, which is higher than LDPE density and therefore does not meet this standard. The higher the density value of a material, the more compact its molecular structure (Darni et al., 2014).

3.5. Tensile Strength Analysis

Tensile strength testing is conducted to determine the mechanical properties of bioplastics and their resistance to deformation. The produced bioplastics are tested for tensile strength according to ASTM D882 standards, with a crosshead speed of 12.5 mm/min.

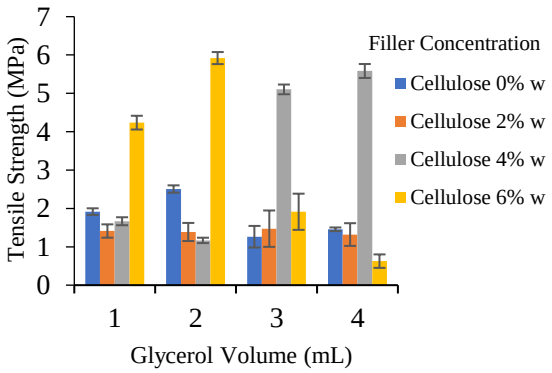


Figure 8. Effect of glycerol volume and filler concentration on the tensile strength of bioplastics

Figure 8 shows that the concentration of filler and glycerol affects the tensile strength of the resulting bioplastics. The filler increases the tensile strength, as seen in the 6% w : 2 mL variation, which produces the highest tensile strength of 5.92 MPa. The addition of cellulose as a filler can improve tensile strength at certain concentrations because hydrogen bonds form between the hydroxyl (O-H) groups of starch and the hydroxyl (O-H) and carboxyl (COOH) groups of cellulose. This aligns with the research of Gao et al (2021), which states that the hydrogen bonds between starch and cellulose groups enhance the strength of the bioplastic (Acquavia et al., 2021). Furthermore, the addition of glycerol at certain concentrations can also increase the tensile strength, as seen in the 6% w : 1 mL variation, which results in a tensile strength of 3.90 MPa, and

increases to 5.92 MPa with the addition of 2 mL glycerol at the same filler concentration. However, the effect of adding glycerol on increasing the tensile strength of the bioplastic only applies up to a certain concentration. This is evident from the Fig. 8, which shows that further increases in glycerol concentration decrease the tensile strength. This is consistent with the study by (Acquavia et al., 2021), which states that increasing the glycerol concentration leads to an increase in starch macromolecule mobility, thereby reducing the tensile strength of the bioplastic.

The tensile strength of the bioplastics produced in this study was then compared to the standard tensile strength for bioplastics. According to the Japan International Standard (1975), the minimum tensile strength for bioplastics is 0.39 Mpa (Sartika et al., 2022). The tensile strength of the bioplastics produced in this study ranged from 0.63 to 5.92 MPa, thus meeting the established standard. Bioplastics with a tensile strength of 1-10 MPa are categorized as medium quality (Nandiyanto et al., 2020).

3.6. Elongation at Break Analysis

The elongation at break test was conducted simultaneously with the tensile strength test, following the ASTM D882 standard and using a crosshead speed of 12.5 mm/min. The test was performed with three repetitions for each variation.

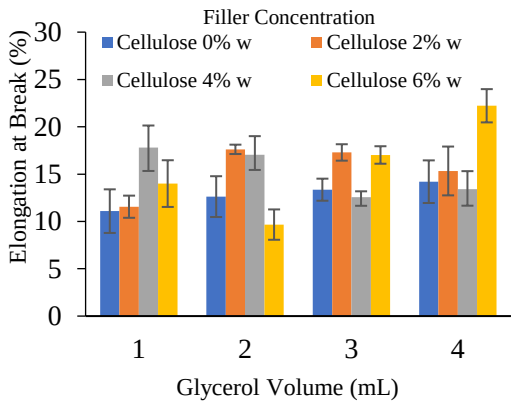


Figure 9. Effect of glycerol volume and filler concentration on the elongation of bioplastics

Figure 9 shows that the concentration of filler and glycerol significantly affects the elongation at break of the produced bioplastics. Glycerol significantly increases the elongation at break value as the glycerol concentration increases. This is evident in the sample variations 0% w: 1 mL to 0% w: 4 mL, which show successive increases in elongation at break values of 11.09%, 12.62%, 13.36%, and 14.20%. Glycerol acts as a plasticizer that weakens hydrogen bonds between starch and cellulose, making the bioplastic more flexible. With enough glycerol, the plastic becomes easier to stretch. A study by Acquavia et al (2021) also showed that more glycerol increases elongation. Higher elongation values indicate that the bioplastic samples are more prone to deformation. This deformation behavior is caused by the loose distribution of molecules within the bioplastic sample. Nandiyanto et al (2020) stated that this indicates a reduction in intermolecular interactions between starch and cellulose due to longer hydrogen bonds (Nandiyanto et al., 2020). The elongation at break results were compared to the Japan International Standard (1975), where values below 10% are considered poor and above 50% are good (Sartika et al., 2022). In this study, the bioplastics showed elongation between 8% and 22.22%, which indicates poor to medium quality (Nandiyanto et al., 2020).

3.7. Functional Group of Materials

FTIR characterization was performed on starch, cellulose treated with 17.5% NaOH, and bioplastics containing cellulose filler. The spectra obtained from the starch of the Kepok banana corm, the cellulose from the banana stem, and the bioplastic sample revealed several peaks, indicating the presence of various functional groups in each material.

Figure 10(a) presents the FTIR analysis results of starch extracted from the corm of the Kepok banana. A relatively broad peak observed in the 3000–3500 cm^{-1} range indicates the presence of O–H stretching vibrations, typically associated with hydroxyl groups, and suggests compounds with higher molecular weights compared to those producing sharper peaks. In the 2200–2500 cm^{-1} region, a peak corresponding to the C≡C (alkyne) group is identified. Additionally, two sharp peaks in the 1000–1300 cm^{-1} region indicate C–O stretching, while peaks in the 500–700 cm^{-1} range are associated with phenyl (C–H) bending vibrations (Darni et al., 2014).

Figure 10 (b) shows the FTIR analysis results of kepok banana stem cellulose. In the range of 3500-4000 cm^{-1}, an N-H group is detected, while in the range of 2100-2400 cm^{-1}, several peaks indicate the presence of alkyne groups (C≡C and C≡N). In the range

of 1500-1750 cm^{-1}, an alkene group (C=C) is shown, and in the range of 650-1000 cm^{-1}, C-H and C=C-H groups are present (Darni et al., 2014).

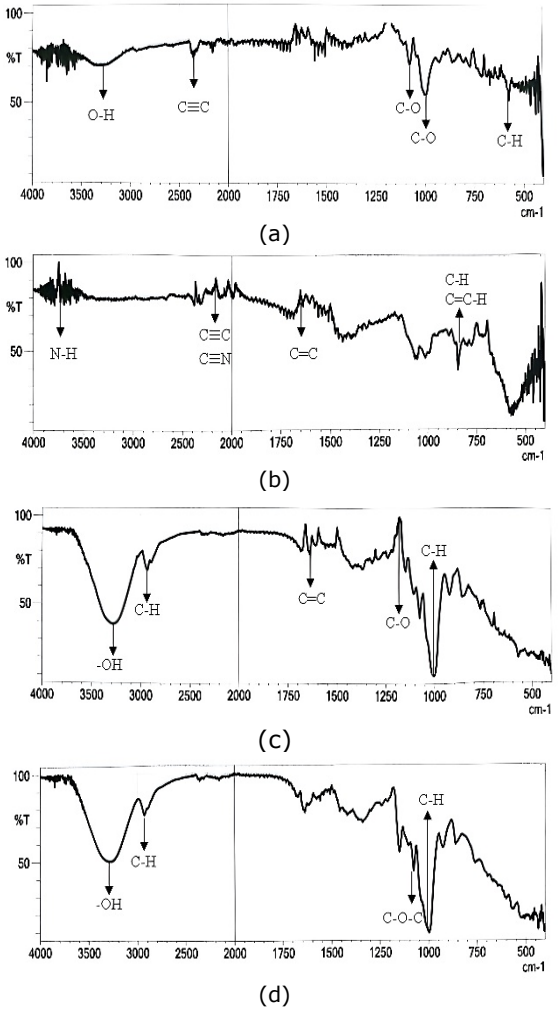


Figure 10. IR spectra of (a) banana corm starch (b) cellulose (c) bioplastic without filler (d) bioplastic with cellulose filler

Figures 10 (c) and 10 (d) shows in the range of 3000-3500 cm^{-1}, an alcohol (-OH) group is detected, and in the range of 2800-3000 cm^{-1}, a peak indicates the presence of an alkane (C-H) group, which functions as a matrix. In the range of 1000-1200 cm^{-1}, an ester group (C-O-C) is found, while at 1000 cm^{-1}, a peak shows the presence of a C-H group. From these FTIR results, it can be concluded that modification has occurred due to the addition of cellulose (Darni et al., 2014). The resulting bioplastic contains a combination of functional groups from its components, without the formation of new functional groups, as blending occurs only physically, making the bioplastic exhibit properties similar to its constituent components (Abe et al., 2021). A summary of the functional groups in the sample can be seen in Table 2.

Table 2. Interpretation of IR spectra of cellulose, starch, and bioplastic with filler

Type of Bond	Compound Type	Frequency Range (cm^{-1})
O-H	Alcohol	3200-3600
C=C	Alkene	1600-1700
C≡C and C≡N	Alkyne	2100-2300
C-O	Ester	1050-1200
C-H	Alkane	675-1000
N-H	Amine	3600-3700
C-O-C	Ether	1050-1150

3.8. Surface Morfology

Surface morfology characterization was performed on bioplastic without filler and bioplastic with filler based on the highest tensile strength values obtained, without filler : 2 mL of glycerol and 6% : 2 mL of glycerol.

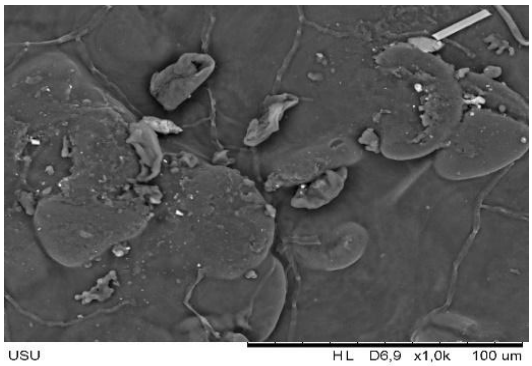
3.8.1. Bioplastic-Without Filler

Figure 11 (a) shows a clear white bioplastic. This is the best variation with the highest tensile strength, achieved with a 0% w : 2 mL glycerol variation. This bioplastic is easy to release from the mold, can be handled, and is stronger (not brittle). This indicates that glycerol, as a plasticizer, plays an important role in enhancing the flexibility and reducing the brittleness of the bioplastic. Glycerol works by increasing the distance between polymer chains, making the material more elastic (Shanmathy et al., 2021). In the 0% w : 2 mL glycerol variation, glycerol appears to have successfully balanced the bioplastic's strength—enough to reduce brittleness without making the bioplastic too soft. A bioplastic that is too soft lacks sufficient tensile strength, while one that is too hard tends to be brittle (Berghuis, 2023).

Figure 11(b) shows the surface morphology of filler-free bioplastic at 1000× magnification. The surface appears relatively smooth overall, but the presence of clumps and fine cracks indicates voids (gaps or empty spaces) within the bioplastic. These defects are likely caused by rapid temperature fluctuations during the heating or cooling stages, leading to thermal stress. Such voids and cracks suggest the need for better temperature control during the bioplastic manufacturing process to minimize thermal stress. This is important, as thermal stress can negatively impact the mechanical strength and physical properties of the bioplastic. In addition, the surface appears

somewhat rough, with undissolved starch particles still visible (Fauziyah et al., 2021).

(a)



(b)

Figure 11. (a) Filler-free bioplastic with 2 mL glycerol (b) SEM analysis results of bioplastic-without filler at 1000x magnification

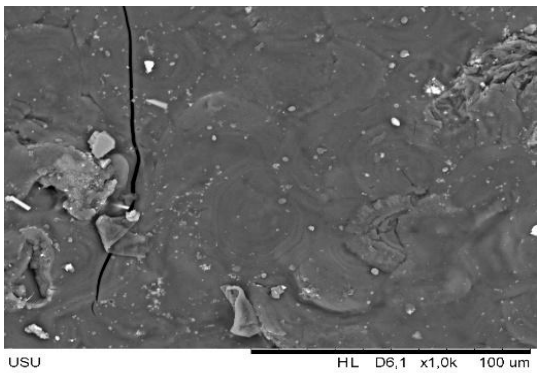
3.8.2. Bioplastic with Filler

Figure 12 (a) shows a yellowish-white bioplastic. This is the best variation with the highest tensile strength, achieved with a 6% w : 2 mL glycerol variation. This bioplastic is easy to release from the mold, can be handled, and is stronger. This demonstrates that the filler, cellulose from the kepok banana pseudostem, helps reinforce the bioplastic structure. This filler serves to enhance the strength and structural stability of the bioplastic. The cellulose fibers provide additional support to the polymer matrix, helping to prevent deformation and improve resistance to mechanical stress. The presence of cellulose also helps reduce shrinkage and increase the tensile strength of the bioplastic. The combination of glycerol and cellulose in the bioplastic creates a material that is not only strong but also flexible. Glycerol provides the elasticity needed to prevent brittleness, while cellulose adds strength and structural stability (Berghuis, 2023).

The surface morphology of the bioplastic shows a rough texture with filler particles spread across the matrix (Figure 12b). Although the fillers are mostly well-distributed, some areas show clumps or agglomeration. Small voids and microcracks are also visible, suggesting that the filler has not fully blended with the matrix. These defects may result from poor dispersion or weak bonding between the filler and matrix (Fauziyah et al., 2021).

Despite these issues, adding filler has been shown to improve the mechanical strength of the bioplastic. When glycerol levels are kept constant, a higher filler content increases tensile strength. This is due to the filler's reinforcing effect, where the matrix sticks well to the filler particles, helping the material resist stretching forces (Acquavia et al., 2021).

(a)



(b)

Figure 12. (a) Bioplastic with filler, 6% w : 2 ml glycerol, (b) SEM image of bioplastic with filler at 1000x magnification

4. Conclusion

The addition of cellulose isolated from banana pseudostem—and glycerol as a plasticizer influences the properties and characteristics of the resulting bioplastics. The optimal bioplastic formulation was obtained with 6% filler and 2 mL glycerol,

achieving a density of 1.14 g/mL, which is higher than the standard density of LDPE plastic. The water absorption rate of 0.24% meets bioplastic standards, while the elongation value of 8% remains below the standard for bioplastic flexibility. However, the tensile strength of 5.92 MPa meets the required standard. XRD analysis of the cellulose filler revealed a crystallinity of 97.78%. FTIR results confirmed the presence of functional groups from both starch and cellulose in the bioplastic. SEM images showed that the filler was mostly well-distributed throughout the matrix. Although some surface defects, such as voids and agglomerates, were observed, the addition of filler still improved the mechanical strength of the bioplastic, indicating its reinforcing effect despite some uneven dispersion. Further research is recommended to optimize the filler formulation to achieve better bioplastic performance. Additionally, exploring alternative cellulose isolation methods is suggested to compare and potentially enhance the quality of the resulting cellulose.

Author Contribution Statement

H.N.: Conceptualization, supervision, editing final draft. B.H.M.: Investigation, data analysis, writing—original draft. N.N.: project administration, validation, writing—original draft

Data Availability Statement

The data presented in this work are included in the article.

Declaration of Competing Interest

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