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THE EFFECT OF GLYCEROL CONCENTRATION ON STARCH-BASED BIOPLASTICS DERIVED FROM BANANA PEELS (*Musa acuminata*)

(Kesan Kepekatan Gliserol ke atas Bioplastik Berasaskan Kanji yang Diperolehi daripada Kulit Pisang (*Musa acuminata*))

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Abstract

The widespread use of plastics in everyday life will cause serious harm to the ecosystem if not managed properly. To solve this problem, more sustainable alternatives like bioplastics, made from plant-based materials such as starch, have been developed. In this study, banana peel is seen as a good resource for bioplastics productions as it contains a high starch content compared to other fruit peels. Furthermore, there is no further research on bioplastics starch derived from *Musa acuminata*. In addition, plastics made from starch have a low mechanical property such as low tensile strength and are easily infected by fungal and bacteria. Therefore, the ability of starch derived from *Musa acuminata* and the effect of plasticizers on the mechanical properties of the bioplastics were investigated. The potential of these bioplastics is demonstrated through rigorous physical testing, which includes biodegradability, solubility, tensile strength, and FTIR analysis. Based on the results obtained, the solubility rate increased from 3.2 ± 0.29% to 14.5 ± 0.28% as glycerol volume increased, and a similar trend was observed in the biodegradability test, where the weight loss of the bioplastic increased from week 1 until week 2, showing that as the concentration of glycerol increases, the solubility and biodegradability will also increase. Regarding tensile strength, elevating the glycerol content enhances the strength and durability of the bioplastic, but excessive use can lead to brittleness. Therefore, the most suitable glycerol concentration is found to be at 1 wt. (%) which represents 1 wt. (%) of banana peel starch.

Keywords: bioplastics, starch, solubility, biodegradability, tensile strength

Abstrak

Penggunaan plastik secara meluas dalam kehidupan seharian akan menyebabkan kemudaratan serius kepada ekosistem jika tidak diuruskan dengan baik. Untuk menyelesaikan masalah ini, alternatif yang lebih mampan seperti bioplastik, diperbuat daripada bahan berasaskan tumbuhan seperti kanji, telah dibangunkan. Dalam kajian ini, kulit pisang dilihat sebagai sumber yang baik untuk penghasilan bioplastik kerana ia mengandungi kandungan kanji yang tinggi berbanding kulit buah-buahan lain. Tambahan pula, tiada kajian lanjut mengenai kanji bioplastik yang diperoleh daripada *Musa acuminata*. Selain itu, plastik yang diperbuat daripada kanji mempunyai sifat mekanikal yang rendah seperti kekuatan tegangan yang rendah dan mudah dijangkiti kulat dan bakteria.

Oleh itu, keupayaan kanji yang diperoleh daripada Musa acuminata dan kesan pemplastis terhadap sifat mekanikal bioplastik telah disiasat. Potensi bioplastik ini ditunjukkan melalui ujian fizikal yang ketat, yang merangkumi kebolehbiodegradan, keterlarutan, kekuatan tegangan, dan analisis FTIR. Berdasarkan keputusan yang diperoleh, kadar keterlarutan meningkat daripada 3.2 ± 0.29% kepada 14.5 ± 0.28% apabila volum gliserol meningkat, dan trend yang sama diperhatikan dalam ujian biodegradasi, di mana penurunan berat bioplastik meningkat dari minggu 1 hingga minggu 2 , menunjukkan bahawa apabila kepekatan gliserol meningkat, keterlarutan dan kebolehbiodegradan juga akan meningkat. Berkenaan dengan kekuatan tegangan, meningkatkan kandungan gliserol meningkatkan kekuatan dan ketahanan bioplastik, tetapi penggunaan yang berlebihan boleh menyebabkan kerapuhan. Oleh itu, kepekatan gliserol yang paling sesuai didapati pada 1 wt. (%) yang mewakili 1 wt. (%) pati kulit pisang.

Kata kunci: bioplastik, kanji, keterlarutan, biodegradasi, kekuatan tegangan

Introduction

Plastic was discovered to be an excellent material for domestic use due to its various additional properties, such as its strong texture and widespread availability. However, the excessive use of plastics can be harmful to our environment, leading to pollution. Thus, the development of environmentally friendly plastics, known as bioplastics, offers a potential solution to this issue. Bioplastics are a type of plastic that can be easily degraded by microorganisms and are made from plant-derived compounds such as starch, cellulose, and fiber [1]. Biodegradable plastics have roughly the same mechanical qualities as regular plastic, but they can be decomposed by microbes, distinguishing them from standard plastics. Starch is the major material utilized in the production of bioplastics and may be obtained from domestic plants such as cassava, maize and tapioca [2]. This plant-based starch is a natural polymer known for its affordability and eco-friendliness. However, starch-based bioplastics have certain limitations, such as poor mechanical properties, low water barrier, and high susceptibility to fungi and bacteria due to their natural hydrophilic properties [2].

Banana plants are abundant, particularly in Asia, making them inexpensive and widely consumed worldwide [3]. The banana, *Musa acuminata* is the most common type used in the food industry, often for making banana chips or fried bananas [4]. After the flesh is consumed, most stall vendors will throw away the banana peels in abundance at dumping areas, creating lots of food waste pollution. Additionally, some research has found that banana peels contain high levels of starch, approximately 18.5%, making them a suitable source for manufacturing bioplastics [5]. However, there are few efforts in producing bioplastics from banana peels. Most of the research used banana peel paste consisting of polysaccharides, nutrients, and minerals, resulting in a poor texture of the bioplastic produced, as shown in figure 1 [5]. There is no further research on the use of pure starch derived from *Musa acuminata* to produce bioplastics and the effects of varying glycerol content on mechanical properties of banana peel bioplastics. Thus, the ability of pure starch extracted from banana peel *Musa acuminata* to form bioplastics was investigated. The effect of glycerol concentration on the mechanical properties of bioplastics was also studied by conducting a variety of tests such as solubility, biodegradability, tensile and FTIR analysis. Furthermore, sodium metabisulfite was used as an antioxidant to increase the shelf life and inhibit bacterial growth on the bioplastic produced [6]. These findings will be pivotal in ensuring that the bioplastic exhibits desirable mechanical properties, such as tensile strength and flexibility, thus facilitating its potential applications in various industries.

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1 [5]. There is no further research on the uses of pure starch derived from *Musa acuminata* to produce bioplastic and the effects of varying glycerol content on mechanical properties of banana peel bioplastic. Thus, the ability of pure starch extracted from banana peel *Musa acu*minata to form bioplastic was investigated. The effect of glycerol concentration on the mechanical properties of bioplastic was also studied by conducting a variety of tests such as solubility, biodegradability, tensile and FTIR analysis. Furthermore, sodium metabisulfite was used as an antioxidant to increase the shelf life and inhibit bacterial growth on the bioplastic produced [6]. These findings will be pivotal in ensuring that the bioplastic exhibits desirable mechanical properties, such as tensile strength and flexibility, thus facilitating its potential applications in various industries.

Materials and Methods

Materials

Banana peels *Musa acuminata* were collected for free from local food stalls near USIM. Analytical grade sodium hydroxide, hydrochloric acid (HCl; 36 % v/v) and glycerol (99.5 % v/v) were purchased from Accot Lab Supplies (Balakong, Selangor).

Extraction process of starch from banana peels

An amount 300 g of banana peel *Musa acuminata* were washed with tap water to remove unwanted impurities. Then, the banana peels were cut into small pieces using a stainless-steel knife. The sample was soaked in 0.5% sodium metabisulphite solution for 1 hour in a 1 L beaker. Later, the banana peels were boiled for 30 minutes on a hot plate. The peels were carefully separated from the water and placed on a dry gauze pad to remove excess water. The banana peels were blended with 500 mL distilled water in a mixing blender. After blending, the result in starch slurry (banana peel paste) was transferred to a beaker for settling where the process took approximately 24 hours. The starch sediment was isolated from the slurry, washed with distilled water, and subjected to a second settling stage. Following this, the starch sediment was dried in an oven at 60 ºC to eliminate excess water until it reached a constant weight. Lastly, the dried banana peel starch was collected and placed in a closed bottle, ready to be used in the next phase. In this project, untreated banana peels were used as the control sample.

Preparation of biodegradable plastic film

A stock solution was prepared by heating 1 wt.(%) banana peel starch and 0.5 wt.(%) acetic acid with distilled water in a 200 mL beaker. The mixture was stirred until the starch well dissolved. Then, 0.25 wt.(%) glycerol and 1 wt.(%) of calcium carbonate were introduced into the mixture and stirred again until homogenized solution obtained. 0.5 wt.(%) sodium hydroxide was added into the mixture and stirred for 5 minutes to neutralize the pH. The mixture was poured into a petri dish and dried in an oven at 50 ºC for 24 hours. Consequently, the film was carefully scraped from the petri dish. This process was performed in triplicate with varying glycerol concentrations as shown in Table 1.

Table 1. Formulation of banana peel starch bioplastic

Sample	Banana Peel Starch wt.(%)	Volume of (200 mL) Calcium Carbonate wt.(%)	Glycerol wt.(%)	Distilled Water wt.(%)
S1	1	1	0.25	97.25
S2	1	1	0.5	97
S3	1	1	0.75	96.75
S4	1	1	1	96.5
S5	1	1	1.25	96.25

Physical tests on bioplastics: Water solubility

This test was conducted according to the method by Ghasemlou et al. [7]. The film samples were cut into a square segment with a dimension of 10 cm x 5 cm. The initial dry weight (W_o) of each sample was recorded and the samples were immersed in a beaker containing 100 mL distilled water and was left for about 2 weeks. After this period, the remaining parts of the film were separated using filtration. The sample was dried in a hot air oven at 110°C until a constant weight was achieved and the final weight of the film was recorded. The percentage of total soluble matter, denoted as % solubility, was calculated using Equation 1.

$$WS\ (\%) = [(W_o - W_f)/W_o] \times 100 \qquad (1)$$

where WS is solubility in water; W_o is the initial weight of bioplastics; and W_f is the final weight of bioplastics.

Biodegradability

The degradation test was carried out according to a standard test method, ASTM D5988-18 standard. Firstly, the sample was cut into a rectangular shape with a dimension of 10 cm x 5 cm. A quantity of 100 g soil, containing nitrogenous bacteria with slight moisture content, was gathered from an area near the plant roots. The soil was stored in a container. The sample was buried in the soil for 2 weeks at room temperature. The weight of the specimen was measured before and after the testing period. Regular intervals of water spraying were maintained during the testing period. Soil samples were collected approximately every 1 week and cleaned with distilled water. Subsequently, the specimens were dried, and their weights were recorded. The degradation of the test samples was analyzed before and after soil burial, following the methodology outlined in Equation 2.

$$\text{Weight Loss}\ (\%) = [(W_o - W_f)/W_o] \times 100 \qquad (2)$$

where W_o and W_f are the weights of samples before and after the test.

Tensile test

The tensile properties were evaluated according to ASTM D882-02 standard. In this testing, a texture analyzer (TA. XTExpressC) with a loading cell of 5 kg was used. Initially, the film samples were cut into a rectangular piece with dimensions of 10 cm x 1 cm and the crosshead speed was set at 50 mm/min. The evaluation of the tensile properties was carried out using the average value of the measurements. This test will provide data for tensile strength, breaking strain, and toughness of the sample.

Fourier transform infrared spectroscopy analysis

FTIR analysis was conducted following the ASTM 5477-18 Standard Practice for Identification of Polymer Layers or Inclusions. A small piece was cut from the bioplastic film and placed onto the germanium plate. The spectra were taken in 256 scans between 4000 and 400 cm^{-1} using Spectrum 100 Perkin Elmer FTIR.

Results and Discussion

Banana peel bioplastic appearance

Figure 1 (a) and (b) provides a visual comparison between bioplastics treated with antioxidants and a control film (without antioxidants). Notably, the banana peel bioplastic treated with sodium metabisulphite (SMBS), showed an improved texture and flexibility. Over an extended period of several weeks, the treated bioplastic sustains its structural integrity without any signs of molding or fungal growth on its surface, increasing its shelf-life compared to the control film. Meanwhile, Figure 2 shows the effects of adding antioxidant on banana paste solutions. Figure 2 (a) shows the starch solution without treatment where it turned browned and had a bad odor, compared to figure 2 (b) the treated solutions remain their natural color even after a few days. The color stays constant, and no trace of the formerly intense odor demonstrating the efficacy of the chemical treatment. SMBS is often used in the food industry to prevent enzymatic and non-enzymatic browning. Sulphite solution can be used when soaking banana peels. In enzymatic browning, sulphite will reduce disulfide bonds in enzymes to prevent enzyme catalyzation of the oxidation of phenol compounds which could cause browning [10]. This observation emphasizes the crucial role of incorporating antioxidants, like SMBS, consistently throughout the production process to enhance the stability and extend the shelf life of bioplastics. Furthermore, the bioplastic produced from banana peel starch is more attractive compared to using banana peel paste, Figure 3 (a) and (b) shows the comparison between banana peel film made from paste and starch, respectively.

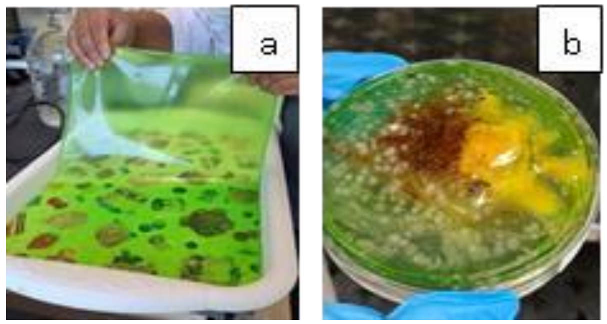


Figure 1. Appearance of bioplastic after few weeks (a) treated with antioxidants, and (b) control film

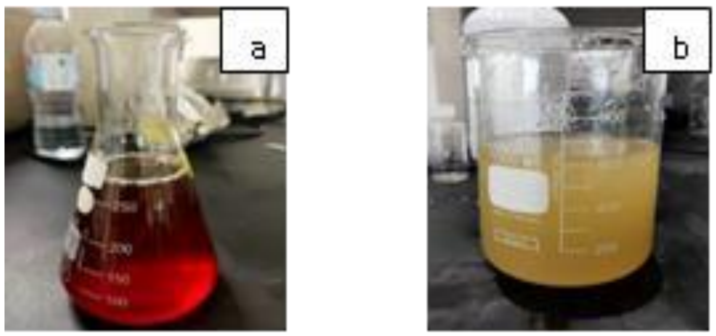
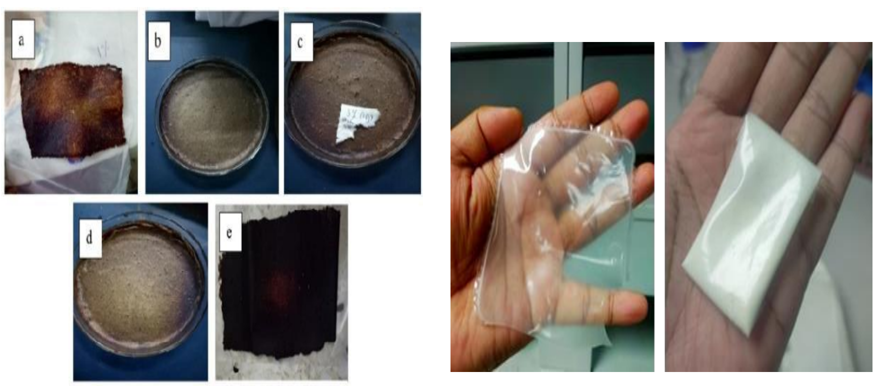


Figure 2. Banana peel paste solution: (a) untreated, and (b) treated with antioxidants



(a) (b)

Figure 3. Physical texture of bioplastic made from banana peel: (a) paste, and (b) starch (new finding)

Water solubility

Figure 4 shows how glycerol concentration affects the water solubility of plasticized starch-based bioplastics in a period of 2 weeks. The characteristic of bioplastics against solubility is one of the essential indicators to show the level of loss of bioplastics in contact with water. S5 with 1.25% glycerol demonstrated the highest water solubility rate 30 ± 0.014 % compared to other samples. The solubility of the bioplastic is caused by the hydrophilic nature of starch bioplastic, making it more susceptible to water interactions [1]. In addition, the properties of glycerol such being a hydrophilic lowmolecular-weight carbohydrate also contribute to the increasing rate of bioplastic solubility [11]. With three carbons attached to its backbone and one hydroxyl group attached to each carbon, glycerol molecules have a high affinity towards water, corresponding to their weight portion. The concentration of hydroxyl groups in the bio composite matrix increases as the size of the hydroxyl groups increases, leading to an increased water absorption by the film. This shows that bioplastics containing more glycerol concentration dissolve better in water. Thus, as the concentration of glycerol increases, the solubility rate of the bioplastic also increases, making the bioplastic easy to dissolve in water [11].

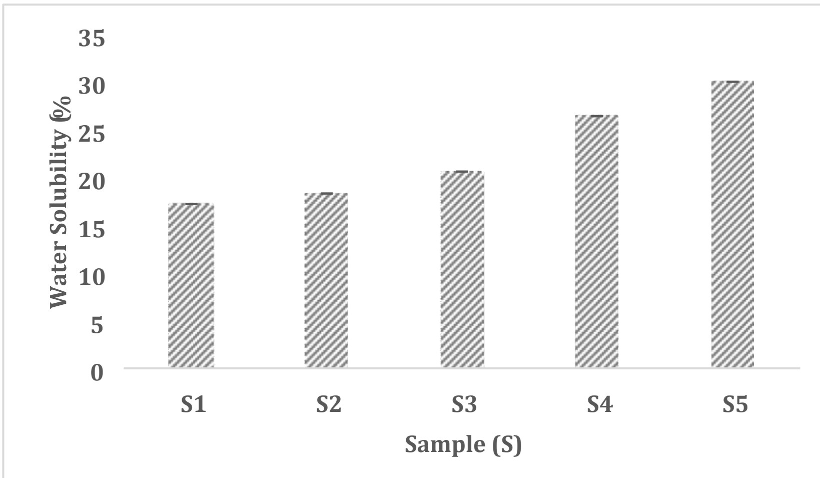


Figure 4. Water Solubility of banana peel-bioplastic with different glycerol concentrations

Biodegradability

Figure 5 depicts the degradation process of banana peel bioplastic with different glycerol concentrations. As shown, S5, characterized by the highest glycerol concentration, exhibited the highest weight loss compared to other samples. The study focused on assessing how glycerol concentration influences the breakdown of biodegradable plastic over a four-week period.

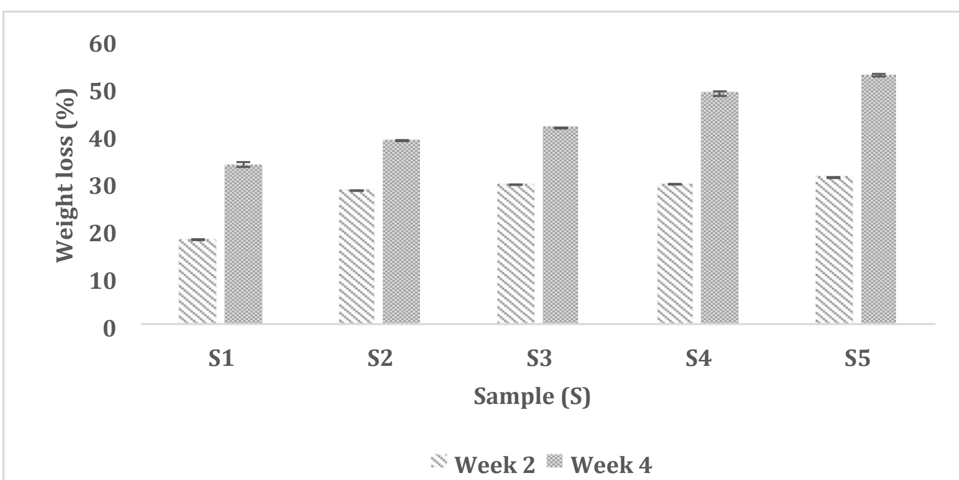


Figure 5. Weight loss of banana peel bioplastic in 4 weeks

The findings indicate a consistent increase in weight loss of bioplastics over the course of the week. Through visual examination, in the first two weeks, it was noted that the texture of the bioplastics started to show visible damage, causing them to shrink in size and eventually tear apart. The biodegradable plastic with 1.25% glycerol (S5) showed the fastest degradation among other samples, reaching 30.9 ± 0.1%. Meanwhile, S1, S2, S3 and S4 were found to have a rate of 17.8 ± 0.1%, 28.15 ± 0.07%, 29.4 ± 0.05% and 29.5 ± 0.07% respectively. This highlights the pivotal role of glycerol in enhancing the biodegradability of bioplastics [12]. In the fourth week, S5 was found to have the highest weight loss rate showing the fastest degradation rate followed by other samples. Glycerol, serving as a readily available carbon source for microorganisms, supports their growth and activity [4]. The addition of more glycerol to bioplastics provides extra nutrients, accelerates microbial breakdown and, consequently, reduces the environmental impact of bioplastics. Moreover, banana peels themselves are extremely rich in basic nutrients such as carbohydrates, proteins, and several others that could support microbial growth and promote the degradation process [13]. Thus, as the glycerol concentration increases, the biodegradability rate will also increase. This shows that bioplastics containing more glycerol concentration degrade better in nature.

Tensile properties

Table 2 summarizes the effects of glycerol content on the tensile properties of banana peel bioplastic. The tensile strength of a bioplastic refers to its ability to withstand stretching or pulling forces without breaking. It is a crucial mechanical property that indicates the material's resistance to deformation under tension.

Table 2. Tensile properties of bioplastic with different volume of glycerol

Samples	Tensile Strength (MPa)	Breaking Strain (%)	Toughness (MJ/m^3)
S1	0.118	108.296	0.005
S2	0.142	113.258	0.011
S3	0.169	121.272	0.005
S4	0.181	138.978	0.008
S5	0.159	121.386	0.008

Bioplastic samples, S1, S2, S3, and S4 have tensile strength of 0.118 MPa, 0.152 MPa, 0.169 MPa, 0.181 MPa respectively. As can be seen S4, featuring 1% glycerol, shows the highest tensile strength at 0.181 MPa, whereas S1 exhibits the lowest tensile strength at 0.118 MPa, attributed to its lower glycerol content. S4 also has one of the highest breaking strains 138.978 % and 0.008 MJ/m^3 of toughness, indicating its strength, compared to other samples. In addition, the breaking strain of each sample increases as the glycerol content increases. For toughness, it shows how much energy a material can absorb until the point of fracture. S2 has the highest toughness which is 0.011 MJ/m^3 compared to other samples. Glycerol acts as a plasticizer which made the film more flexible as the intermolecular bonds between the polymer chains were reduced and the mechanical properties were improved [11]. Therefore, increasing glycerol content will increase the flexibility of the bioplastic. However, S5 shows a decreased value of tensile strength which is 0.159 MPa due to an excessive concentration of glycerol where it can disrupt the polymer structure, causing the bioplastic to become brittle. In conclusion, the most optimal flexibility and good tensile strength were observed in bioplastics with 1% glycerol content (S4).

Fourier transform infrared spectroscopy analysis

To characterize the biodegradable plastic based on banana peel, FTIR analysis was carried out using Infrared (FTIR) spectrophotometer. This analysis aims to determine the functional groups present in the bioplastic film. The FTIR spectrum of banana peel starch bioplastic is shown in Figure 6, in which the highest band spectrum representing O-H bond is at 3292.33 cm^{-1}. The absorption band of 2939.56 cm^{-1} shows the aliphatic C-H stretch vibration; the typical absorption of bioplastic is seen in the wave number of 1640.46 cm^{-1} which is due to the C=O bond vibration. The absorption band at 1029.49 cm^{-1} shows the vibration of C-O bond. The FTIR spectrum of the bioplastic produced in this study displayed the presence of these four major absorption peaks consisting of O-H stretch, C-H stretch, C=O stretch and CO stretch, which are the same as those studied by Sultan et al. [14]. The major absorption peaks for bioplastics are summarized in Table 3.

Table 3. The main FTIR absorption peaks for banana peel starch-based bioplastic

Functional Group	Wavenumber (cm^{-1})
O-H	3292.33
C-H	2939.56
C=O	1640.46
C-O	1029.49

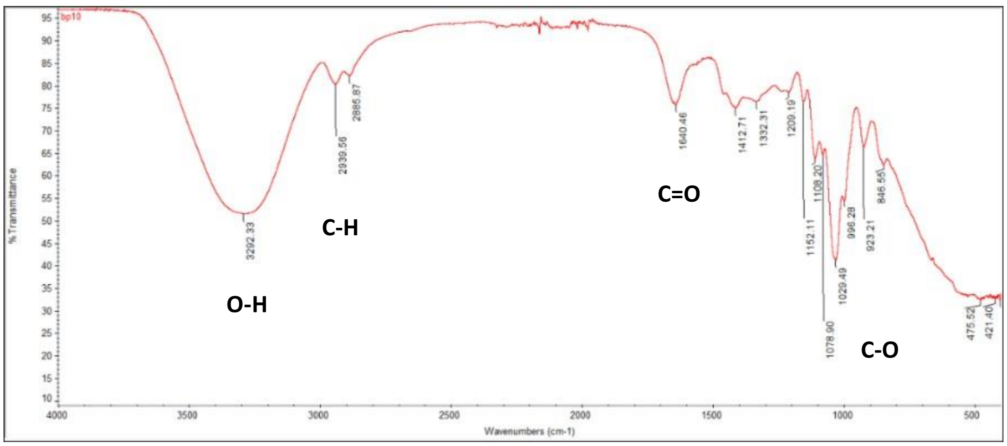


Figure 6. FTIR spectra of banana peel starch-based bioplastics

Conclusion

The utilization of banana peel *Musa acuminata* starch as the source of biopolymer to produce a biodegradable plastic has been successfully studied. In this study, it was discovered that bioplastics made from banana peels can degrade naturally and are soluble in water. As the concentration of glycerol increases, the biodegradation and solubility rates also increase, respectively. In the tensile test, it was found that bioplastic with 1 wt.(%) glycerol has the highest tensile strength compared to other samples, while an excessive use of glycerol can cause the bioplastic to become brittle. Since this study is preliminary, it is advisable to conduct further tests in the future to enhance the performance of the film such as water vapor permeability, the color of the film, and scanning electron microscope (SEM) analysis. Introducing co-biopolymers such as chitosan is suggested to improve the strength of the films and while producing an active film. Thus, new formulations could be explored in the future to meet the standard requirements for bioplastic applications.

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References

1. Abe, M. M., Martins, J. R., Sanvezzo, P. B., Macedo, J. V., Branciforti, M. C., Halley, P., ... and Brienzo, M. (2021). Advantages and disadvantages of bioplastics production from starch and lignocellulosic components. *Polymers,* 13(15): 2484.

2. Marichelvam, M. K., Jawaid, M., and Asim, M. (2019). Corn and rice starch-based bioplastics as alternative packaging materials. *Fibers*, 7(4): 32-32.
3. Mostafa, H. S. (2021). Banana plant as a source of valuable antimicrobial compounds and its current applications in the food sector. *Journal of Food Science*, 86(9): 3778-3797.
4. Hikal, W. M., Said-Al Ahl, H. A., Bratovcic, A., Tkachenko, K. G., Sharifi-Rad, J., Kačániová, M., ... and Atanassova, M. (2022). Banana peels: A waste treasure for human being. *Evidence-Based Complementary and Alternative Medicine*, 2022(1): 7616452.
5. Astuiti, P., and Erprihana, A. A. (2014) Antimicrobial edible film from banana peels as food packaging. *American Journal Oil Chemical Technology*, 2(2): 65-70.
6. Sadeghizadeh-Yazdi, J., Habibi, M., Kamali, A. A., and Banaei, M. (2019). Application of edible and biodegradable starch-based films in food packaging: A systematic review and meta-analysis. *Current Research in Nutrition and Food Science Journal*, *7*(3): 624-637.
7. Ghasemlou, M., Aliheidari, N., Fahmi, R., Shojaee-Aliabadi, S., Keshavarz, B., Cran, M. J., and Khaksar, R. (2013). Physical, mechanical and barrier properties of corn starch films incorporated with plant essential oils. *Carbohydrate Polymer*, 98: 1117-1126.
8. Silva, R. R. A., Marques, C. S., Arruda, T. R., Teixeira, S. C., and de Oliveira, T. V. (2023). Biodegradation of polymers: stages, measurement, standards and prospects. *Macromol*, 3(2): 371-399.
9. Salarbashi, D., Tajik, S., Ghasemlou, M., Shojaee-Aliabadi, S., Noghabi, M. S., and Khaksar, R. (2013). Characterization of Soluble Soybean Polysaccharide Film Incorporated Essential Oil Intended for Food Packaging. *Carbohydrate Polymer*, 98: 1127-1136.
10. Laeliocattleya, R. A., and Wijaya, J. (2019). The effect of sodium bisulfite immersion to the potential of candi banana peel ethanol extract as radical scavenger and UV protection. *IOP Conference Series: Earth and Environmental Science* (Vol. 230, No. 1, p. 012024). IOP Publishing.
11. Tarique, J., Sapuan, S. M., and Khalina, A. (2021). Effect of glycerol plasticizer loading on the physical, mechanical, thermal, and barrier properties of arrowroot (Maranta arundinacea) starch biopolymers. *Scientific Reports*, 11(1): 13900.
12. Rahmawati, H., Mutmainna, I., Ilyas, S., Fahri, A. N., Wahyuni, A. S. H., Afrianti, E., ... and Tahir, D. (2020, May). Effect of carbon for enhancing degradation and mechanical properties of bioplastics composite cassava starch/glycerin/carbon. In *AIP Conference Proceedings* (Vol. 2219, No. 1). AIP Publishing.
13. Kopp, J., Christoph Slouka, Ulonska, S., Kager, J., Fricke, J., Spadiut, O., and Herwig, C. (2017). Impact of glycerol as carbon source onto specific sugar and inducer uptake rates and inclusion body productivity in *E. coli* BL21(DE3). *Bioengineering*, *5*(1): 1–1.
14. Sultan, N. F. K., and Johari, W. L. W. (2017). The development of banana peel/corn starch bioplastic film: a preliminary study. *Bioremediation Science and Technology Research*, 5(1): 12-17.