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Profiling and Characterizing of Banana (*Musa paradisiaca*) Flower Bracts-based Bioplastic with Sorbitol as A Plasticizer

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Abstract: *Banana flower bracts (BFB) are a promising source of starch as a bioplastic material. However, starch-based bioplastics products are primarily stiff and rigid in shape. Polyvinyl alcohol (PVA) may improve the elasticity and increase the force resistance of starch-based bioplastics. Therefore, this study aims to analyze the characteristics and determine the optimal combination of BFB starch and PVA concentration for bioplastic production. The BFB was chopped and boiled until soft, soaked in sodium bisulfite solution for 30 minutes, and dried to produce fine powder. The powder was macerated in clean water for two days to produce starch, which was then combined with 0.5 g of chitosan and various concentrations of PVA. Physical characteristic tests, including Force, tensile strength, elongation, and biodegradation, were measured to determine the best composition. This study found that the combination of 0.5 g of BFB starch, 0.5 g of chitosan, and 10 mL of PVA improved the capability of bioplastic to hold more than 13 N and tensile strengths up to 25 MPa. Furthermore, increasing BFB concentration is in line with enhanced durability but reduces flexibility. Conversely, PVA significantly increased plasticity and elasticity while maintaining high biodegradability (61.2% per day).*

Keywords: *Banana Flower Bract, Bioplastic, Polyvinyl Alcohol*

INTRODUCTION

Indonesia is the fifth most significant contributor of plastic waste globally, producing around 7.8 million tons yearly. It is estimated that in 2021, as much as 4.9 million tons of unmanaged plastic waste and 346.5 kton/plastic were discharged into the sea, of which two-thirds came from Java and Sumatra (World Bank, 2021). The plastic garbage is then fragmented to form microplastics due to mechanical destruction caused by ocean heat and waves. Recent research also shows the presence of plastic contamination in the digestive tract of marine animals such as shellfish, turtles, and seabirds (Kühn et al., 2018; Li et al., 2019; P. Wu et al., 2019). Currently, landfill activities and plastic waste recycling have not completely reduced plastic pollution in the environment (Velis & Cook, 2021). Furthermore, the community prefers to burn plastic waste, which releases dangerous chemicals, such as dioxin, benzo(a)pyrene (BAP) (Kumar et al., 2015; Simoneit et al., 2005), and polyaromatic hydrocarbon (PAH) (Hoffer et al., 2020; D. Wu et al., 2021) that contribute to the rise of lung cancer. Therefore, there needs to be more effective efforts to solve the plastic waste problem, one of which is through bioplastics.

In general, bioplastics are mainly made from organic materials such as starch, cellulose, lignin, proteins, and lipids, which can decompose naturally and have the potential to be used as a substitute for petroleum-based plastics (Arikan & Ozsoy, 2015; Shah et al., 2021). Bioplastic using a mixture of chitosan, cassava starch, and polyvinyl alcohol has a tensile strength of 31.93 MPa, elongation of 93.3%, and can be degraded up to 50.45% within 30 days (Ayyubi et al., 2022). Furthermore, other research shows that adding 5% sugar palm fiber (SPF) and polypropylene increases the tensile strength to 78.00 MPa, with material degradation reaching 94.12% in 28 days (Jangong et al., 2021). This confirms that materials high in organic fibers have physical characteristics and performance that have the potential to be used in making bioplastics (Anugrahwidya et al., 2021).

Several studies have shown the potential for developing bioplastics using organic polymers such as starch and cellulose fiber from vegetable sources (Asrofi et al., 2021; Sagnelli et al., 2016). Apart from that, one of the organic materials that has the potential to be used as bioplastic is banana flower bracts (BFB). BFB is a source of natural fiber containing 56.48% cellulose with a density of 1.39 g/cc and an average length of 27.6 cm (Amutha et al., 2022). In addition, BFB fiber has a breaking strength of up to 60.1 gf, a tensile strength of up to 178.17 MPa, an average elongation at break of 20.9%, and a Young's Modulus of 2.99 GPa. Thermo-gravimetric analysis shows that BFB fibers remain stable up to 200°C and decompose at 400°C (Amutha et al., 2022). The characteristics of the fiber content in BFB have the potential to be developed as a primary material for making bioplastics.

Nevertheless, the degradation of starch-based bioplastics is generally faster than that of bioplastics derived from other sources due to the higher hygroscopicity of starch (Pooja et al., 2023a). However, the degradation rate in soil is low, and new bioplastics with high degradation rates in soil that are safe for environmental microorganisms should be developed. Therefore, this research aims to analyze the characteristics of bioplastic from banana blossoms (Musa paradisiaca) as a solution for dealing with plastic waste.

METHOD

This experimental study compared the composition of BFB-based bioplastic with a polyvinyl alcohol mixture to obtain the best durability. The BFB from the *Musa paradisiaca* Norowito variety was obtained from local plantations in Jerukwangi Village, Bangsri subdistrict, Jepara district, Indonesia. A total of 5 kg of banana flowers were left at room temperature for 24 hours, and all parts of the BFB were chopped and boiled for 2 minutes. The boiled product was then drained and washed twice using running water. The BFB was then soaked in sodium bisulfite solution for 30 minutes to prevent browning (Sondak et al., 2018). The chopped BFB that has gone through the soaking process is then drained and dried using an oven at 120 °C for 1 hour and continued at 60 °C for two days (Haryani, 2017). Dry BFB was blended and sieved until it passed 80 mesh and macerated in clean water for two days, then filtered to separate the filtrate and dregs. The dregs were then squeezed until dry, and the condensed water was mixed with the filtrate and left in a container for 24 hours to separate the water and starch sediment. The water resulting from settling was discarded, while the starch obtained at the bottom of the container was collected to make bioplastic.

Chitosan and Polynivil Alcohol (PVA) preparation

A total of 100 ml of 2% acetic acid was stirred using a magnetic stirrer at room temperature at medium speed, then 5 g of chitin from shrimp shell (Cat. Number: C7170, Sigma-Aldrich, Missouri, USA) was added slowly. The speed of the magnetic stirrer was then increased until the solution became clear. The solution was stored in a black container at room temperature for further use. The addition of chitosan aims to the manufacture of polyvinyl alcohol (PVA) (H.S.Code: 39053000) was carried out by following the manufacturer's standard procedures. 5 g of PVA was slowly added to 100 ml of distilled water and stirred using a magnetic hotplate stirrer for 30 minutes at room temperature. Then, the hotplate stirrer temperature was adjusted to 90-95°C and left constant for 1-2 hours.

Making bioplastic from BFB starch

Each 0.1, 0.25, and 0.5 g of stark BFB was added with 100 ml of acetic acid and stirred with a hotplate stirrer at 60 °C for 45 minutes until the solution became homogeneous, that is, all the stark BFB is evenly distributed in the acetic acid solution. A dose of 0.5 g of chitosan was added to each solution, then stirred until homogeneous using a hotplate stirrer at 60 °C for 30 minutes. The solution was homogeneous, indicated by the absence of chitosan debris, then divided into four parts, and 3, 5, 7, and 10 ml of 5% PVA were added, respectively, then heated again until the temperature reached 80°C for 10 minutes. Each solution was poured into a rectangular mold with 15 x 15 cm dimensions. The mold was dried in the sunlight for two days. Adding the chitosan solution strengthens the structure, while the PVA solution is a bioplastic plasticizer.

Bioplastic characterization

Bioplastic characterization is explained through bioplastics' physical capabilities against tests, including shape deformation, stress in Newtons, tensile strength, elongation at break, functional group characteristics, and biodegradability. Biolastic characteristics testing refers to the American Society for Testing and Materials (ASTM) D638-02a Standard Test Method for Tensile Properties of Plastics. The bioplastic that has been produced was cut into a rectangle measuring 20 × 5 mm and used for testing.

Bioplastic functional group analysis

Testing of bioplastic characteristics was continued using the Alpha II Fourier Transform Infra Red (FTIR) spectrophotometer (Bruker; Leipzig, Germany), in the range 4000–600 cm^{-1}, with a resolution of > 0.7 cm^{-1}, short-term stability reached 0.9%, then frequency repeatability is @1918 cm^{-1}: 0.001 cm^{-1}, and frequency accuracy reaches @1918 cm^{-1}: 0.06 cm^{-1}. The bioplastic sample is crushed and placed on one KBr plate, then covered with a second plate. The plate was then placed in a sample holder and analyzed according to standard procedures. Data obtained through compact FTIR spectrophotometry was then used for functional group analysis, referring to standard identification tables according to https://www.ru.nl/publish/pages/608075/ir-tables.pdf.

Biodegradability test

The biodegradability test was carried out using the soil burial test technique; namely, a bioplastic sample measuring 4 x 1 cm^2 was placed in a pot filled with soil and left exposed to open air. Sample observations were conducted on the first day until the sample experienced complete degradation. Biodegradation can be determined by observing the percentage of plastic mass lost. The losing mass percentage of plastic can be determined using the following formula:

$$\text{lossing mass }(\%)=\frac{W_i\text{-}W_f}{W_i}$$

W_i is the mass of plastic before degradation, while W_f is the mass of plastic after degradation, the mass was recorded every day until it cannot be measured or disappear from the soil surface.

Data analysis

The appearance and functional groups of the bioplastic samples were described qualitatively. At the same time, the Force, tensile strength, and elongation at break data were analyzed by one-way ANOVA with a confidence level of 95% and significance $p \leq 0.050$ using GraphPad PRISM 10 for Mac software.

RESULT AND DISCUSSION

The bioplastic produced from BFB Norowito material has a characteristic brown-black color, which tends to be thick with an elastic and sturdy texture. However, the mixture of BFB starch with the plasticity materials chitosan and PVA increases the viscosity of the solution, making it difficult to distribute the solution evenly in the mold container. The resulting bioplastic has a smooth surface texture because it is made from starch with a granule size of ≤ 100 µm and is relatively uniform. Furthermore, the BFB starch raw material produces a dark color, which causes the bioplastic to tend to be black or blackish brown. Cutting and processing BFB releases polyphenol oxidase and peroxidase, which oxidize polyphenols into quinones, which are highly reactive and can bind with other compounds to form brown pigments (Kaewjumpol et al., 2021). Other research shows that using sodium metabisulfite and oxalic acid can prevent the browning of BFB (Kaewjumpol et al., 2021; Moon et al., 2020). This has the potential to be developed to produce transparent bioplastic. Physical character testing also shows increased durability and flexibility of bioplastic, which is relevant to increasing the composition of BFB and PVA starch (Figure 1).

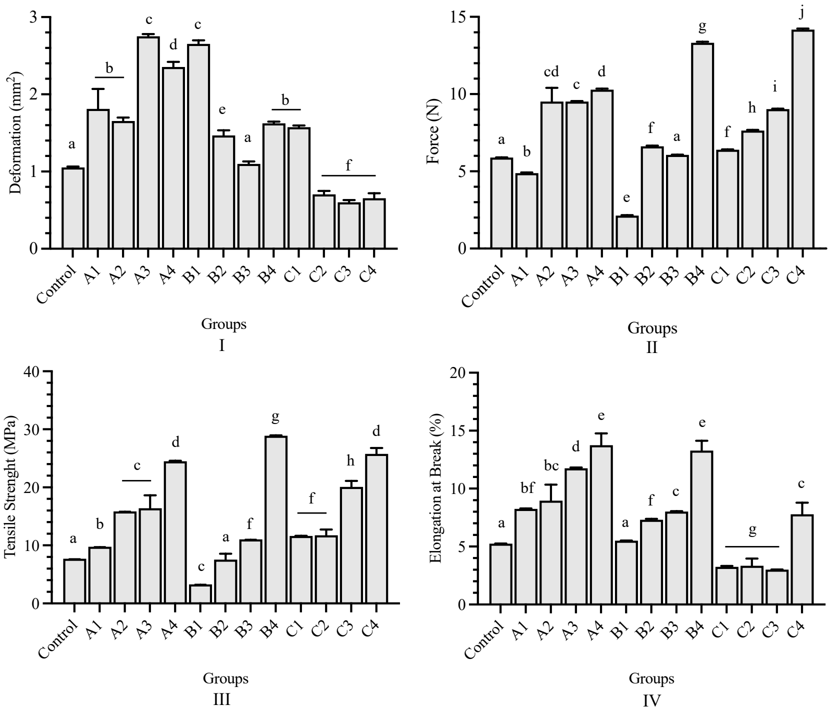

Figure 1. Physical characteristics (deformation test, force test, tensile strength and elongation at break test) of BFB-based bioplastic performed in all samples.

Based on the analysis results, the BFB starch composition of 0.5 g significantly increases the durability of bioplastic, as shown by the reduction in damage due to pressure on samples C2-C4 (Figure 1-I). Apart from that, this research also shows that adding 10 mL of PVA significantly improves durability compared to other compositions (Figure 1). The highest concentration of PVA, namely 10 mL, at various BFB starch concentrations also has an impact on the ability of bioplastic to withstand pressure up to more than 13 N (Figure 1-II), tensile strength up to more than 22 MPa (Figure 1-III). Furthermore, we found that the best bioplastic product was obtained from a composition of 5 grams of BFB starch mixed with 5 mL of PVA.

The results of the physical characteristic analysis show that the formation of fiber and matrix bonds occurs homogeneously, there is no shift between the fiber and matrix, and the deformation rate of the fiber and matrix is the same. These physical characteristics are further supported by the results of FTIR analysis, which shows the interactions between the materials that form bioplastic products. The analysis showed covalent and ester bonds formed when starch, chitosan, and PVA were mixed.

The results of FTIR analysis of BFB bioplastic show that there are at least 9-11 wave absorption peaks with low (weak) infrared wave absorption or high transmittance (> 84%). These absorption peaks indicate the presence of specific functional groups, which indicate the presence of complex compounds resulting from mixing starch, chitosan, and PVA. This was confirmed by the peak of the O-H stretching absorption wave at 3295.67 cm^{-1} at a PVA concentration of 3 ml and 3279.14 cm^{-1} at a concentration of 5 ml (Table 1). This peak can be assigned to O-H stretching in hydrogen bonds or hydroxyls in the starch or chitosan. A broad peak here strongly suggests the presence of alcohols, carboxylic acids, or water. Hydrogen bonding is the major contributor to this broadening. Broad absorption bands appear as wide, rounded peaks, often spanning a significant range of wavenumbers (as opposed to narrow, sharp peaks). Broad absorption indicates a less precisely defined vibrational energy transition within a molecule and suggests various factors influencing that bond.

Table 1. The main FTIR absorption peaks for BFB starch-based bioplastic.

Wavenumber (cm^{-1})		**Appearance**	**Possible Functional Groups**	**Material sources**
3 ml PVA	**5 ml PVA**			
3295.67	3279.14	Weak, broad	O-H stretching	Starch, chitosan, PVA
2919.25	2918.09	Weak, sharp	C-H stretching	Starch and chitosan
1614.68	1625.65	Weak, finger	Amide I/II bands, C=C stretching, C=O stretching	Chitosan
1550.25	1540.84	Weak, finger	N-H bending	Chitosan
1374.50	1375.52	Weak, finger	C-H bending	Starch and chitosan
1316.84	1317.68	Weak, finger	C-H bending (predicted)	CH3 and CH2 from starch
1244.98	1244.41	Weak, finger	C-O stretching (amine predicted)	Starch, chitosan, PVA
1023.26	1022.56	Weak, narrow	C-O stretching (ester)	Starch, chitosan, PVA
-	668.97	Weak, sharp,	C=C bending	Starch
-	572.54	Weak, sharp	Skeletal vibration	Starch
511.58	508.68	Weak, sharp	Skeletal vibration	starch

The presence of C-H stretching functional groups is proven by the narrow, sharp peaks wavenumber range of 2919.26 – 2918.09 cm^{1}. This peak position indicates C-H stretching on sp3 hybridized carbons (alkanes) and could reflect: 1) regular chain lengths in specific components like the starch, particularly those with higher amylose content (linear chains) (Yahia et al., 2023); 2) a specific chain length or restricted variety of branching patterns within the contributing polymer structures; 3) sharpness may signify some C-H groups experiencing limited hydrogen bonding interactions within the bioplastic blend (Rao et al., 2022; Skvorčinskienė et al., 2023). However, related C-H bonds' sharper peaks also possibly formed from the PVA hydroxyl groups that are not extensively involved in hydrogen bonding within the bioplastic composite (Shrestha et al., 2023). A narrow peak could mean a lesser influence of hydrogen bonding on the C-H functionality. Some degree of localized ordering or crystallinity within bioplastic could lead to specific groups having defined environments, reflected in sharper peaks(Japir et al., 2021).

The moderately sharp peaks indicate that hydrogen bonding is less influential in these targeted functional groups. Furthermore, this predicted result suggests that the functional groups (amine, hydroxy, and potential amide) may be less exposed or reside in harder-to-reach areas of the bioplastic structure (Nandiyanto et al., 2022). Further analysis may help pinpoint whether other factors like polymer conformation or crystallinity are also at play.

FTIR analysis revealed a fingerprint region from 1625.65 to 1244.41 cm^{-1} wavenumbers with moderately sharp and distinct peaks, indicating less influence of strong hydrogen bonding on certain functional groups in the bioplastic product (Amin et al., 2019). The high transmittance, up to 93-95%, of the BFB starch-based bioplastic product suggests lower concentrations of specific functional groups or specific binding molecules in the bioplastic matrix. The peaks consistently arise from 1625.65 and 1614.68 cm^{-1} wavenumbers, primarily representing N-H bending (primary amines) from chitosan. However, it still has a lower chance with potential minor overlap from weaker C=C stretching (alkenes) (Nandiyanto et al., 2019), which is less typical in purely biopolymer-based systems. Then, the peaks 1550.25 and 1540.84 cm^{-1} indicate N-H bending (secondary amines/amides) also from the result of chitosan deformation (Wahab et al., 2023), supporting the possibility of amide bond formation during interactions between chitosan and starch.

The peaks at 1375.52 cm^{-1} and 1316.84 cm^{-1} likely correspond to C-H bending vibrations in both methyl ($-CH_3$) and methylene ($-CH_2-$) groups from various components of the bioplastic, such as starch, chitosan, and PVA. The final peak in the finger-shaped region, at 1244 cm^{-1}, could originate from C-O stretching in esters (Nandiyanto et al., 2019). However, as this is less probable for a pure bioplastic, it more likely indicates C-O-C stretching vibrations typical of polysaccharides present in starch and chitosan (Dewi et al., 2023). Additionally, this peak might involve some contribution from PVA's ether linkages.

Several distinctive peaks and patterns were observed in the FTIR analysis of the bioplastic samples. A consistent peak around 1022 cm^{-1} across all samples (1022.56 and 1023.26 cm^{-1}) suggests C-O stretching vibrations common to carbohydrates and other organic molecules present (Amin et al., 2019). Intriguingly, the bioplastic with 3 mL PVA exhibited a gap in absorbance between 1000-500 cm^{-1} wavenumber, which was absent in the bioplastic with 5 mL PVA. This difference warrants further investigation to understand its possible origins.

Careful attention to peak shapes and consideration of potential protein contributions are essential for accurate interpretation. Two long, narrow, and sharp peaks at 572.54 and 668.97 cm^{-1} likely represent fingerprint vibrations uniquely characteristic of the BFB starch bioplastic blend. Finally, peaks at 508.68 and 511.58 cm^{-1} could indicate skeletal vibrations arising from the polysaccharide components of the bioplastic. This study demonstrates that increasing the composition of BFB and PVA can yield bioplastic blends with enhanced physical characteristics, such as increased tensile strength and decreased elongation. This is attributed to the addition of PVA, a polymer of ester compounds, which imparts elasticity to the bioplastic. Furthermore, the FT-IR analysis results also indicate that blending BFB starch, chitosan, and PVA does not form new functional groups. Furthermore, the FT-IR analysis results also indicate that blending BFB starch, chitosan, and PVA does not form new functional groups.

Biodegradation analysis of bioplastic

This study examined various bioplastic samples from different combinations of composition material, all demonstrating complete biodegradation within a 20-day observation period. Interestingly, while all samples can be classified as relatively thin based on ASTM D638-02a tightness measurements (ranging from 0.09 mm to 0.18 mm), they displayed substantial variations in physical characterization tests, especially destruction analysis (1.02 mm² to 6.20 mm²), and average daily degradation rates from 11.18% up to 61.21% (Table 2). These observations highlight the potential for diverse degradation behaviors driven by bioplastic composition and structure differences.

While one might intuitively expect tighter bioplastics to degrade more slowly, these results show that biopolymer-based materials' degradation is not simply determined by physical tightness alone. The sample B1, with the tightest structure, which is 0.18 mm, has a smaller destructed area up to 1.47 mm² and only needs ± 9 days to degrade. Conversely, looser structures like C4 did show correlations with faster degradation rates. However, there is no universally consistent linear relationship, emphasizing that several factors influence biodegradation dynamics. This condition may relate to the characteristics of polysaccharides that contribute to the bioplastic's paramount consistency. BFB starch often contains three main structural polysaccharides (that mainly compose the cell wall), including cellulose 29.80 ± 0.22), hemicellulose 14.26 ± 1.10), and lignin 9.20 ± 0.00 (Thokchom et al., 2023).

Tabel 2. Physical characteristics of bioplastics and the length of the degradation process

Sample	Physical characteristic		Biodegradation Process	
	Thickness (mm)	Destructed area (mm²)	Degradation (days)	Average degradation rate per day (%)
C	0.13 ± 0.01	2.75 ± 0.03	20.01 ± 1.08	19.29 ± 0.32
A1	0.15 ± 0.01	2.35 ± 0.08	17.42 ± 1.42	21.06 ± 3.23
A2	0.09 ± 0.08	1.81 ± 0.30	11 80 ± 2.22	28.64 ± 5.77
A3	0.12 ± 0.03	1.57 ± 0.03	13.70 ± 1.78	20.91 ± 5.46
A4	0.10 ± 0.05	2.65 ± 0.05	13.80 ± 1.38	17.67 ± 7.75
B1	0.18 ± 0.03	1.47 ± 0.08	9.36 ± 1.79	41.78 ± 8.82
B2	0.12 ± 0.05	1.65 ± 0.05	12.00 ± 2.07	25.55 ± 3.51
B3	0.13 ± 0.03	1.10 ± 0.03	11.70 ± 2.32	23.41 ± 6.59
B4	0.10 ± 0.08	1.62 ± 0.03	9.10 ± 2.23	34.49 ± 6.92
C1	0.13 ± 0.03	1.02 ± 0.01	14.33 ± 1.89	11.18 ± 3.58
C2	0.13 ± 0.05	0.70 ± 0.05	7.92 ± 1.60	49.33 ± 10.36
C3	0.11 ± 0.08	0.60 ± 0.03	6.20 ± 1.20	54.42 ± 11.46
C4	0.09 ± 0.03	0.65 ± 0.08	5.00 ± 1.56	61.21 ± 13.09

Lignin has many hydroxyl groups that support high compatibility for molecule interactions, making it easier to mix with most polymers, such as starch, although limited (Mariana et al., 2021a; Ridho et al., 2022). Mixing starch with hydrophobic polymers usually increases the water resistance, mechanical strength, and thermal stability of starch. Lignin is a good candidate for mixing with starch because of its high solubility (Ago et al., 2016) and potential component for biocompatibility (Aqlil et al., 2017; Gunathilake et al., 2017; C. Ma et al., 2021). Adding lignin can increase the compatibility between cellulose and the matrix, decreasing impact properties. In contrast, the Modulus of Young and tensile strength can be significantly increased (Mariana et al., 2021b). Cellulose and lignin play different roles in cellulose-lignin bioplastics. In general, cellulose strengthens the mechanical strength of the composite. At the same time, lignin retains water molecules, increasing the thermal stability of the polymer matrix and guaranteeing a good dispersion of cellulose in the biopolymer (Y. Ma et al., 2015; Yang et al., 2019).

Based on the previous explanation, the wide range of destroyed areas during physical characterization may be influenced by the polysaccharide's composition, which warrants closer attention. For example, the C2, C3, and C4 bioplastic samples notably have smaller destroyed areas than the control, A, or B groups. Furthermore, the bioplastic from the C group also has better physical durability than other samples from the A and B groups. This potentially indicates the inherent structural strength of the bioplastic itself, meanwhile indicating a specific formulation that is also easier to use during the biodegradation process. However, such fragmenting behaviour has practical implications since it could influence the end-use performance and the potential environmental impact of certain bioplastics (Cruz et al., 2022).

This study reveals that the selected bioplastic samples possess various degradation characteristics. For example, some, like C1, balance moderate degradation with relatively low material loss, while others, like B4, focus on extremely rapid degradation. This spectrum of degradation profiles can be an asset when selecting bioplastics for specific purposes. Whether rapid disintegration or longer-term integrity is prioritized will inform the selection of specific formulations for subsequent investigations. Furthermore, recent studies suggest that amylose significantly influences the characteristics of composite bioplastics (Santana et al., 2018). When incorporated into plastic films, high amylose concentrations form more rigid, denser, stronger films but can make the bioplastic more brittle or less elastic (Muñoz et al., 2013). Therefore, the comparison of the composition of amylose and amylopectin in BFB needs to be analyzed further to determine the appropriate proportion of starch used in the making.

Despite its structure, starches, in general, are inherently susceptible to breakdown by soil microbes. The slower degradation observed might also be tied to specific types of microorganisms present in the soil that are not effectively targeting such starches in the observation's limited duration. In previous studies, plenty of common microorganisms found in soil have been shown to degrade bioplastics made from starch, including *Bacillus* sp. *Aspergillus* sp. *Saccharothri, Kibdelosporangium, Pseudonocardia, Lentzea, Amycolatopsi, Actinomadura keratinilytica* (in the presence of PLA film samples) (Kamarudin et al., 2021; Nchedo Ariole & George-West, 2020). This microorganism provides lysis enzymes such as proteinases, cutinases, and esterases that play a crucial role in the degradation process.

Furthermore, specific properties of the bioplastic also contribute to the degradation period. Research indicates that starch-based bioplastics can degrade at different rates in soil. For example, a study showed that starch-based shoppers degraded by 69% (weight basis) within 236 days (Ahsan et al., 2023). Another study reported that cassava starch-based bioplastic weight was reduced by 56% after 30 days, with a 74% weight decrease by day 120 (Wicaksono et al., 2022). Additionally, it was observed that starch-based bioplastic biodegrades much faster compared to bioplastics developed from other material sources (Pooja et al., 2023a). However, it is important to note that various factors can influence the degradation process rate, and the complete biodegradation ($\geq$ 90%) of starch-based bioplastics prevents accumulation in soil (Ahsan et al., 2023; Emadian et al., 2017; Pooja et al., 2023b). Meanwhile, this study only uses a conditioned composting area and may less represent natural conditions that may contribute to the rate of bioplastic biodegradation. Hence, further study should be conducted to identify the microorganism composition that may contribute to the degradation process of bioplastic. Then, the bioplastic degradation analysis can be conducted in an unconditioned open space to represent natural conditions.

In several studies, adding PVAs plays an important role in bioplastic manufacturing by enhancing the flexibility and elasticity of bioplastics by acting as a plasticizer and disrupting some rigid bonding interactions between other polymers (Atika Adnan et al., 2023). With limited PVA in the formulation, the interactions between BFB starch chains dominate, creating a more complex matrix, potentially more brittle but less vulnerable to rapid breakdown by microorganisms or environmental factors (Syamani et al., 2020). While PVA can degrade in soil, the specific timeframes and mechanisms differ from the natural, enzyme-driven processes governing starch or chitosan degradation. PVA has a semicrystalline structure, which results in lower water adsorption capacity, high tensile strength, flexibility, and elongation at break. For example, a study reported that PVA with a concentration of about 100% based on starch weight can reach 10.0 MPa tensile strength and 77% elongation at break (Syamani et al., 2020). PVA breakdown often starts with water interaction and involves specific microorganisms capable of secreting PVA-targeting enzymes. Increasing the relative proportion of PVA dramatically shifts the properties of the bioplastic. With more PVA available, the bioplastic gains considerable flexibility. It can better manage deformation, explaining the higher resilience against forces. Simultaneously, the degradation of this much higher ratio of PVA, even when combined with BFB starch, may recruit a wider variety of soil microorganisms than the BFB starch-focused (5:1) sample. These microbes act not only on PVA but can potentially accelerate the overall breakdown of the entire bioplastic more effectively.

CONCLUSION

The use of BFB starch has the potential to be developed as a material for making bioplastics. The physical characteristics show that bioplastic made from BFB can withstand pressures of more than ±13 forces and tensile strength of up to ±25 MPa. The addition of BFB concentration can significantly increase the durability of bioplastic, but makes the bioplastic more rigid and prone to breaking easily. The addition of PVA has been proven to significantly increase the plasticity and elasticity of bioplastic and reduce physical damage. However, it still has the fastest biodegradable ability, with a degradation rate of ~61.2% per day. This research has limitations because it does not analyze the starch component in BFB, so it cannot describe the exact polysaccharide content in plastic making. Further analysis must be conducted to profile the type, composition, and concentration of polysaccharides in BFB to produce more suitable bioplastics.

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