PEAT

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The Production of Bioplastic from Banana Peel via Power Ultrasonic Extraction

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Abstract

Banana is one of the popular fruits among consumers due to their rich nutritional value. The banana peel that is the secondary product is often discarded as a waste despite its potential value. However, the use of banana peel waste is being considered as useful due to having the potential to produce sustainable things. Therefore, this study aimed to extract and evaluate pectin and starch from banana peel using the power ultrasonic (PUS) extraction method. The presence of starch and pectin was confirmed using the iodine test and preliminary alcohol precipitation test. The presence of starch is indicated by a dark blue-black color while pectin formation appears as a cloudy or precipitated solution. The results showed that the highest yields obtained were 18.235% for starch and 20.187% for pectin, using 100% amplitude with lapse sonication. The extracted starch and pectin were then used to develop the bioplastic by using solution casting method. The morphology properties such as Scanning electron microscopy (SEM) and Fourier Transform Infrared Spectroscopy (FTIR) were examined for the production of bioplastic to know the characterization of the bioplastic. The results indicated that the bioplastic exhibited a relatively smooth surface morphology with visible starch granules and FTIR analysis showed characteristic functional groups. Mechanical testing using a universal testing machine (UTM) showed highest a tensile strength of 1.623 MPa, a Young's modulus of 240.97 MPa and an elongation at break of 60%. In conclusion, the bioplastic showed good morphological and mechanical properties, suggesting that it is suitable for sustainable packaging. This research highlights the potential of innovative solutions in promoting sustainable practices in environmentally friendly material development.

1. Introduction

Bananas are recognized globally as a widely consumed fruit in the world. Also, it is the cheapest and the most nourishing fruit. Naturally, bananas are popular for their texture, aroma and are easy to peel and eat. However, rather than focusing only on the banana itself, the peel can also give valuable benefits. This means that the peel is not only waste, but a resource that can be reused to produce beneficial products such as bioplastic. The bananas are chosen as a component to manufacture the bioplastic rather than other fruit because their peels

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contain rich starch that works well as the main ingredient. Apart from that, banana peels also contain pectin which can improve the bioplastic strength, enhance the flexibility and work as natural binders in bioplastic formation.

Global banana production reaches approximately 119.83 million tons, representing about 16% of total fruit production and ranking bananas as the second most widely consumed tropical fruit worldwide. But a lot of waste is produced along with a lot of consumption. Approximately 3.5 million tons of banana peel waste are generated annually from banana consumption, with the peel contributing about 30–40% of the total fruit weight. The waste from banana peels contains carbon-rich organic compounds that can take up to two years to biodegrade and break down, causing pollutants and excessive emissions of greenhouse gases (GHG). As a result, environmental pollution is increasing due to the widespread use of non-biodegradable, petroleum-based bioplastic which cause serious harm to ecosystems, human health and global sustainability.

Thus, the sustainable alternatives have increased in response to current environmental waste challenges. This highlights the need for sustainable waste management strategies and investigates the potential of agricultural residues such as banana peels, as renewable resources for bioplastic production. Numerous studies have been developed focusing on exploring the process of extraction from banana peel. Many researchers extracted the banana peel using a variety of methods including conventional methods like boiling or extracting hot water, as well as extraction technologies like ultrasonic assisted extraction. However, further investigation is needed to determine the suitable ultrasonic extraction parameters, such as sonication time, amplitude, and sonication mode, to achieve effective extraction for bioplastic production. Therefore, exploring these parameters is important to identify the optimal extraction conditions and improve the properties of the resulting bioplastic.

This study is necessary due to the fact that plastic pollution has become a major environmental problem, causing significant harm to humans, animals and natural ecosystems. This problem can be addressed by employing banana waste as a renewable and sustainable alternative for bioplastic production. By conducting this study, it can contribute to a new and sustainable method for producing biodegradable plastic from banana waste, offering an eco-friendly alternative. Without this research, banana peel waste will continue neglected, contributing to inefficient waste management practices [1].

Hence, this research aims to extract and evaluate pectin and starch from banana peel using the PUS extraction method with different sonication parameters. The extracts are analyzed for pectin and starch using the iodine test and preliminary alcohol precipitation test followed by the development of bioplastic using the solution casting method. For further research, the characterization of bioplastic involved the morphological and mechanical properties for various parameters including the surface, particle size, functional group, tensile strength, young's modulus and elongation at break. Additionally, the biodegradability of the bioplastic is evaluated through soil burial tests to assess its environmental decomposition over time. Through this testing and analysis, this study seeks to explore the feasibility of utilizing banana peel as a renewable resource for producing sustainable and eco-friendly bioplastic.

2. Methodology

This section describes all the material, equipment and experimental methods used in this study. It includes details on the sources and preparation of materials and the procedure carried out from the initial preparation to final analysis.

2.1 Sample Preparation

The banana peels were collected then washed with distilled water to remove any dirt, debris or other contaminants. The banana peels were cut on a cutting board into small pieces approximately 1-2 centimeters in length by using a knife. The banana peels were prepared and each of the banana peels weighed 300 g by analytical balance. Then, the banana peels were washed again to soak in sodium metabisulphite in the beaker for 30 and 45 minutes. After that, each of the banana peels were removed from the beaker and put in aluminum foil. The banana peel was dried in an oven at 55^{0}C for 20 hours. After 20 hours, the banana peels were grinded by grinding into a fine powder and placing it in a beaker. The powdered banana peel of each sample was kept in the chiller at 4 ^{0}C. The sample preparation was showed in Figure 1 above.



(a) **(b)** **(c)** **(d)**

Figure 1: *Sample preparation (a) Banana peel were soak in sodium metabisulphite (b) Banana peel were put in the aluminium foil (c) Banana peel before drying (d) Banana peel after grinding*

2.2 Iodine Test

1 gram of the dried banana peel powder were weighed and placed into a clean test tube. 5 mL of distilled water were added and the mixture was shaken vigorously. After vigorously, the mixture was filtered. 3 drops of iodine potassium iodide (I_2KI) solution were added to the test tube. The solutions were observed for a color change.

2.3 Preliminary Alcohol Precipitation Test

1 gram of the dried banana peel powder was added to a test tube containing 10 mL of distilled water. The mixture was gently heated at approximately 60°C for 15 minutes then were allowed to cool. The extract was filtered and the clear filtrate was transferred into a clean test tube. Subsequently, 15 mL of 95% ethanol was slowly added. The test tubes were gently swirled and allowed to stand for 5 to 15 minutes. The formation of a white or cloudy precipitate was observed.

2.4 UV-Vis Spectrophotometer

The UV-Vis spectrophotometer was turned on and allowed to warm up until all the conditions passed. The blank solution was prepared. The blank was placed in a cuvette followed by liquid samples in another cuvette. The exterior of each of the cuvette was wiped with Kimwipe and placed into a spectrophotometer sample holder. The absorption spectrum was run at 620 nm.

2.5 Power Ultrasonic Extraction (PUS)

Pectin was extracted from dried banana peel powder using ultrasonic probe. 500 mL of distilled water and 1 mL of citric acid were mixed and the pH was adjusted to 2.5. 50 g of dried banana peel powder was added and the mixture was sonicated. All the extractions were conducted in triplicate as shown in Table 1. The suspension was centrifuged at 5500 rpm for 15 minutes. The supernatant was precipitated with 95% ethanol before dried at 50°C until constant weight. The pectin yield was determined using equation (1).

$$\textbf{Pectin yield } (\%) = \frac{\textit{Weight of extracted dried pectin } (g)}{\textit{Weight of sample } (g)} \textbf{ x } 100\% \quad (1)$$

Table 1: Parameter of 8 samples of 50 g banana peel powder for extraction pectin.

No.	Distilled water (mL)	Citric acid solution (mL)	Sonication time (min)	Amplitude (%)	Type of sonication
1	250	1	5	60	Continuous
2	250	1	5	60	Lapse
3	250	1	5	100	Continuous
4	250	1	5	100	Lapse
5	250	1	15	60	Continuous
6	250	1	15	60	Lapse
7	250	1	15	100	Continuous
8	250	1	15	100	Lapse

For starch extraction, 50 g of dried banana peel powder was dispersed in 500 mL distilled water and sonicated. The slurry was filtered and the filtrate was centrifuged 1000 rpm for 10 minutes until pellet formation occurred.

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The supernatant was removed and the pellet was dried at 40°C until constant weight. The starch yield was determined using equation (2). All the extractions were conducted in triplicate as shown in Table 2.

$$Starch\ yield\ (\%) = \frac{Weight\ of\ extracted\ dried\ starch\ (g)}{Weight\ of\ sample\ (g)}\ x\ 100\% \quad (2)$$

Table 2: Parameter of 8 samples of 50 g banana peel powder for extraction starch.

No.	Distilled water (mL)	Sonication time (min)	Amplitude (%)	Type of sonication
1	250	5	60	Continuous
2	250	5	60	Lapse
3	250	5	100	Continuous
4	250	5	100	Lapse
5	250	15	60	Continuous
6	250	15	60	Lapse
7	250	15	100	Continuous
8	250	15	100	Lapse

2.6 Solution Casting Method

Starch and pectin were separately dissolved in distilled water and heated using a hot plate magnetic stirrer until gelatinization occurred. The two solutions were then combined. Glycerol and acetic acid were added to the mixture and the solution was continuously stirred until a homogeneous mixture was obtained. The homogeneous mixture was poured into a tray and the bioplastic was dried in an oven for 24 hours. Table 3 shown the formulation of bioplastic.

Table 3: Formulation of bioplastic.

Formulation	Starch (%)	Pectin (%)	Distilled water (mL)	Glycerol (mL)	Acetic acid (mL)
F1	5.117	2.254	100	5	10
F2	7.623	2.98	100	10	5
F3	5.345	2.395	100	5	10
F4	7.745	3.065	100	10	5
F5	10.623	7.561	100	5	10
F6	15.105	9.366	100	10	5
F7	11.703	15.85	100	5	10
F8	18.235	20.187	100	10	5

2.7 Characterization of bioplastic

The bioplastic was examined using Scanning electron microscope (SEM), Fourier transform Infrared Spectroscopy (FTIR), mechanical test and biodegradability test to study the material in more details and to understand its characteristics.

2.7.1 Scanning Electron Microscope (SEM)

The bioplastic approximately 1 cm x 1 cm was cut by using a sharp blade. The cut bioplastic samples were mounted onto a standard SEM stub using double-sided carbon tape. Once the samples are prepared, the samples are ready for imaging in the SEM. The SEM stub was carefully transferred with the coated bioplastic sample into the vacuum chamber of the SEM. Start with low magnification 500x then increase the magnification 1000x and 2000x to observe the surface morphology. Images at magnifications of 300x, 600x and 1500x were captured.

2.7.2 Fourier Transform Infrared Spectroscopy (FTIR)

2 cm x 2 cm of bioplastic was cut and placed onto the FTIR spectrometer. The spectral range was set typically 4000 cm^{-1} to 400 cm^{-1}. The samples of bioplastic were carefully placed in the sample holder of the FTIR spectrometer. The prominent peaks were identified in the spectrum and the wavenumbers were observed for each of the samples.

2.7.3 Mechanical Test

The bioplastic specimens were prepared by cutting the bioplastic sheet into test specimens according to the ASTM D882 standard for thin plastic sheeting. The specimens were then tested using a Universal Testing Machine (UTM) with appropriate grips to hold the specimens in place. The machine applied a control tensile force. The bioplastic specimen was secure in the clamps on UTM. The sample was pulled by machine at a constant speed while recording the applied force and elongation until sample breaks.

2.7.4 Biodegradability Test

The bioplastic from banana peel was prepared with commercial grade bioplastic. Each bioplastic sample was cut into a consistent size of [5 × 3 × 0.5] cm and weighed accurately before the soil burial test. Initial weight of each bioplastic and commercials was accurately measured and recorded. The two bioplastic samples and commercial grade bioplastic were buried in separate areas in soil. It was buried at a consistent depth at least 2 - 3 cm. The samples were observed for 10 days. Then, the weight loss of bioplastic was determined by using equation (3).

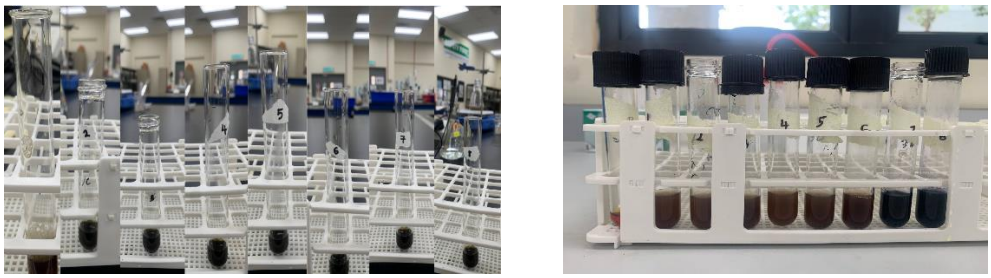
$$\textbf{Weight loss}\ (\%) = \frac{W_0 - W_t}{W_0}\ \textbf{x}\ 100\% \tag{3}$$

3. Results and Discussion

This part presents the result of the research, followed by the further discussion of the findings. The discussion is highlight as it focuses on the implications of the results by observing key trends and difference of how parameters of extraction and processing are affecting the results. The results are evaluated in relation to the research objectives.

3.1 Iodine Test

All the samples were tested with iodine-potassium iodide solution. The colour changes were observed and compared in each of the samples before and after extraction.



(a) **(b)**

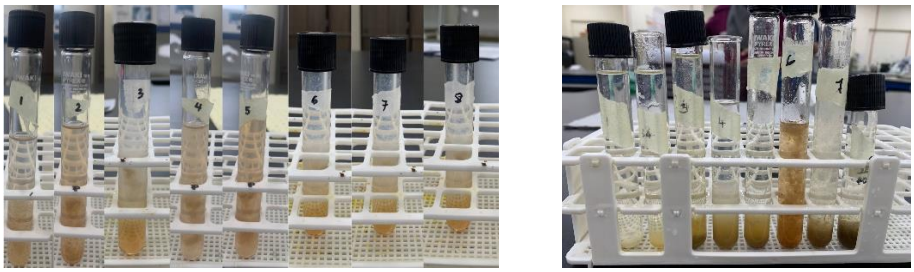
Figure 2: Iodine test (a) before and (b) extraction

All the samples for both before and after extraction showed a colour change when iodine potassium iodide solution was added as shown in Figure 2. Theoretically, this colour change occurs due to the amylose, a component in starch, forms a blue-black color when iodine is added. When iodine is added, it is trapped inside the helical cavity, forming a charge transfer complex that absorbs light differently. The blue-black color confirms that the starch is present in the sample. However, the brown color showed that the starch present in that samples were less [2].

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3.2 Alcohol Preliminary Precipitation Test

The presence of pectin can be identified by alcohol preliminary precipitation test by using 95% ethanol. Figure 3 highlights the difference between the presence of pectin before and after adding the solvent.



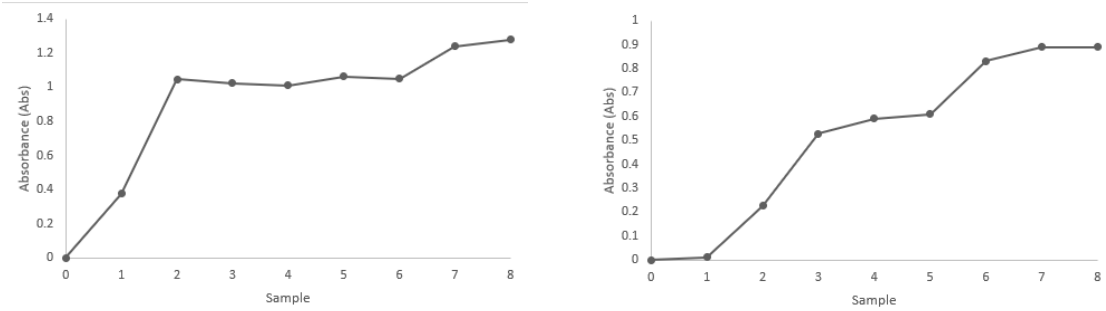
(a) **(b)**

Figure 3: Alcohol preliminary precipitation test (a) before and (b) after extraction

From Figure 3, it can be observed that all the samples exhibited visible precipitation appearing as a cloudy substance after adding 95% ethanol. This indicates that the pectin and other soluble compounds in the banana peel powder were completely dissolved in the solution [4].

3.3 UV-Vis analysis of banana peel powder

The iodine test was analyzed by a UV-Vis spectrophotometer. Figure 4 shows the sample vs absorbance graph for eight samples to identify the presence of starch in banana peel powder before and after extraction.



(a) **(b)**

Figure 4: *Graph of sample vs absorbance (a) before and (b) after extraction*

From Figure 4, the graph shows the absorbance of eight samples. The graph shows the amount of light absorbed over the visible portion of the spectrum for each sample typically observed at 620 nm.

Among all the samples tested, as shown in Figure 4(a), Sample 1, with a sonication time of 5 minutes, 60% amplitude, and continuous sonication, showed the lowest absorbance value. The lower absorbance in sample 1 contains less starch or has weaker interaction with the iodine reagent. When there is less starch, the color formed is not strong so it measures less light. In comparison, Sample 8, which used a sonication time of 15 minutes, 100% amplitude, and lapse sonication, showed the highest absorbance value. This indicates that sample 8 contained a higher amount of starch which absorbed more light, confirming that these samples had more starch.

While in Figure 4 (b), the graph showed the sample influenced the absorbance values during extraction. Sample 1 has the lowest absorbance value while sample 8 has the highest absorbance value. This is because sample 1 only takes 5 minutes to extract the starch. In consequence, a small amount of starch was extracted, leading to weaker reaction with iodine solution. When compared with Sample 8, these samples take a long time period to extract which is 15 minutes. The longer extraction time allows better interaction between the solvent and the banana peel particles. With more starch extracted, iodine becomes stronger to form a blue-black color and higher absorbance value. The results indicate that increasing the extraction time leads to higher absorbance values [5].

3.4 Effects of power ultrasonic extraction on starch and pectin

The various extraction parameters such as sonication time (5 and 15 minutes), amplitude (60 and 100%) and type of ultrasonication (continuous and lapse) were evaluated for their effect on the extraction of starch and pectin. These parameters were to determine the optimal ultrasonication condition for maximizing starch and pectin.

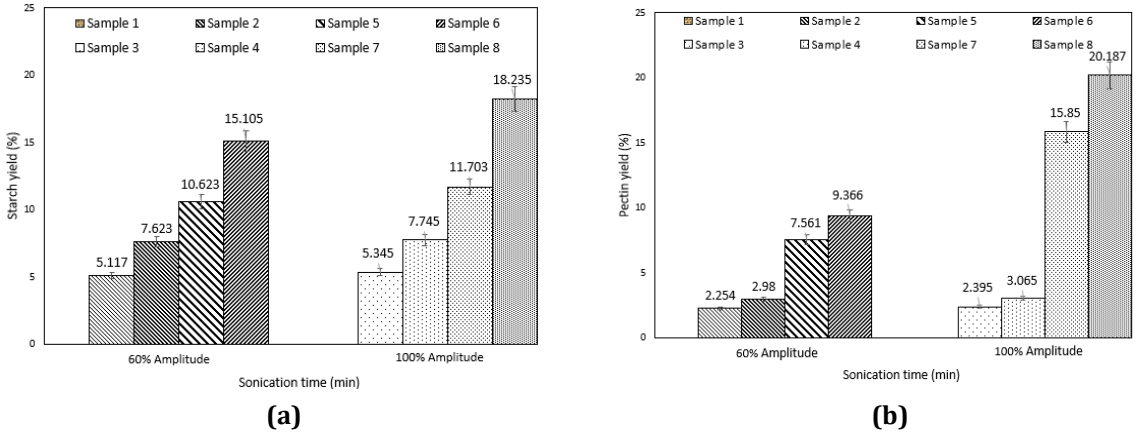


Figure 5: *Effects of power ultrasonic extraction on (a) starch and (b) pectin*

As shown in Figure 5 (a), Sample 1 obtained a starch yield of 5.117%, whereas Sample 6 achieved a higher starch yield of 15.105% at 60% amplitude. The significantly higher starch yield observed in Sample 6 can be attributed to the use of pulsed sonication, which enhances cavitation efficiency and promotes more effective starch release compared to continuous sonication. At 100% amplitude, Sample 8 achieved the highest starch yield of 18.235%, while Sample 3 obtained a starch yield of 5.345%. Sample 8 was also subjected to pulsed sonication. The higher starch yield observed in Sample 8 can be attributed to the combined effects of pulsed sonication and longer sonication time, which enhance cavitation intensity and facilitate greater starch release. On the whole, the results indicate that longer sonication times and pulse mode extraction are the most effective strategies for maximizing starch yield.

In Figure 5 (b), it can be observed that only Samples 7 and 8 falls within the desirable range of pectin yield which is 10-25%. The sonication conditions applied to Samples 7 and 8 were more effective in enhancing pectin extraction compared to the other samples. The high amplitude applied in both samples provided sufficient energy to break down the banana peel cell walls, allowing more pectin to diffuse into the solvent. However, the difference in extraction mode between continuous and pulse sonication influences the stability and quality of the extracted pectin. Pulse sonication at high amplitude and extended duration appears to be a more suitable condition for optimizing pectin extraction, as it balances strong cavitation effects with reduced thermal damage [6].

3.5 Bioplastic formation

Variations in the appearance and texture of the bioplastic indicate that the ratio of starch to pectin significantly influenced the final properties of the bioplastic. Differences in transparency, surface smoothness, thickness uniformity and flexibility were observed among the samples, knowing that each of the formulations responded differently during gelatinization and bioplastic formation. Figure 6 showed the result of bioplastic formation.

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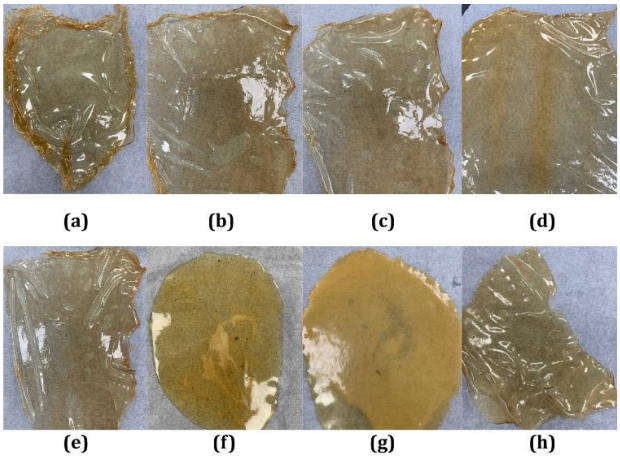


Figure 6: *Final result of bioplastic formulation (a) Sample 1, (b) Sample 2, (c) Sample 3, (d) Sample 4, (e) Sample 5, (f) Sample 6, (g) Sample 7 and (h) Sample 8*

3.6 SEM analysis of bioplastic

SEM is a technique for observing the microstructure and surface morphology of bioplastics. Its capability is to examine the physical properties such as porosity, surface roughness and particle size.

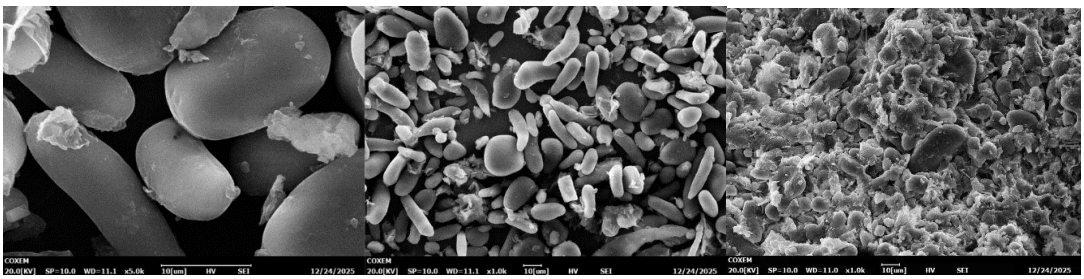
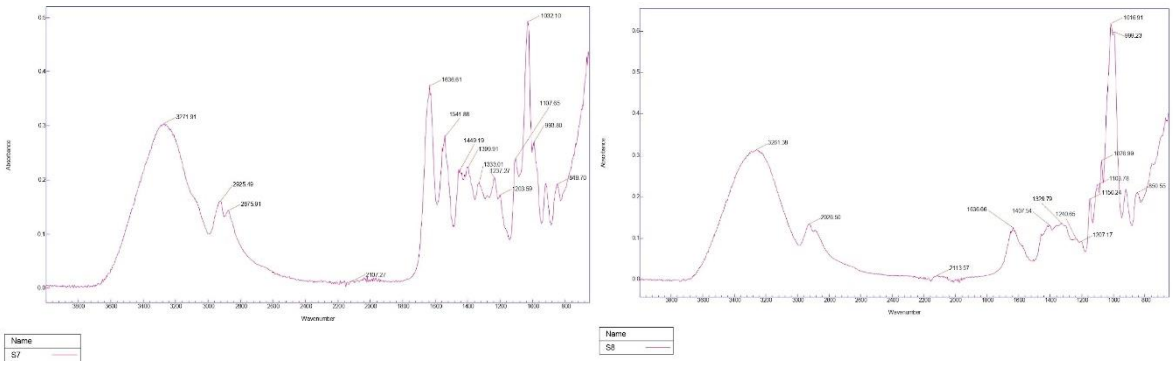


Figure 7: *SEM images at magnification (a) 2000x, (b) 1000x and (c) 500x*

Figure 7 shows the surface morphology at magnifications of 2000x, 1000x and 500x. At 2000x magnification, the particles appear smooth, rounded and well defined. The particle size is relatively large and uniform and the structure is densely packed with minimal surface defects. This smooth surface suggests low porosity, which may reduce interaction with environmental factors such as moisture, oxygen and microorganisms. At 1000x magnification, the particles become smaller and show irregular and non-uniform shapes. Instead of smooth and rounded surfaces, the particles appear elongated, flaky and uneven with rough edges. Some small particles are attached to larger ones, forming a loosely packed structure with noticeable variation in particle size. At 500x magnification, the surface shows clear signs of damage and degradation. The structure appears highly irregular, rough and porous with visible cracks and gaps between particles. Many empty spaces are observed, indicating a less compact and more porous surface structure.

3.7 FTIR analysis of bioplastic

To ensure the optimal starch and pectin contained in bioplastic, the FTIR analysis was performed.



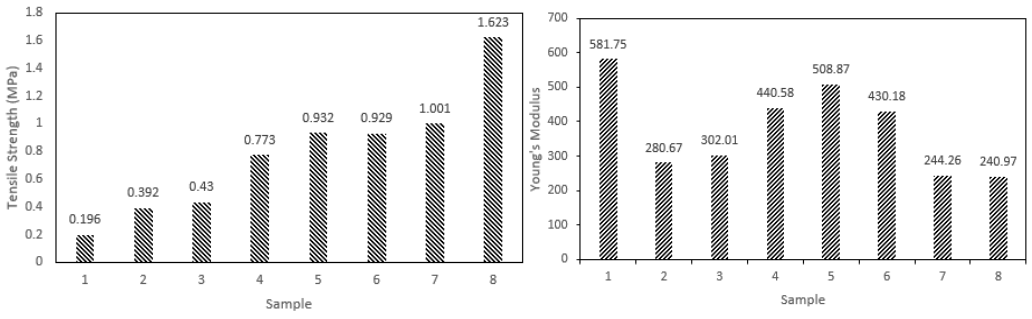
(a) **(b)**

Figure 8: *FTIR spectrum (a) Sample 7 and (b) Sample 8*

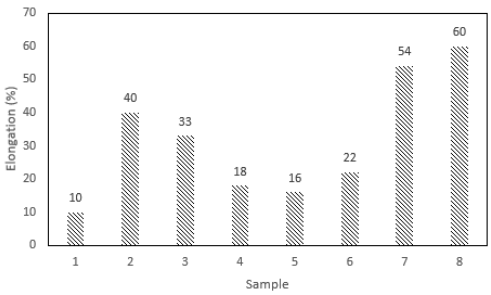
Both Sample 7 and 8 showed a broad absorption band around 3270-3260 cm^{-1}, corresponding O-H stretching vibrations which are characteristic of hydroxyl groups present in polysaccharides such as starch and pectin. However, the O-H band in Sample 8 is more intense and broader when compared with Sample 7. Hydrogen bonding in this sample were stronger, possibly due to higher polysaccharide content or molecular interaction within bioplastic matrix. The C-H stretching vibrations around 2925-2926 cm^{-1} appear in both samples indicating aliphatic group, suggested similar backbone structures. The peak of 1636 cm^{-1} corresponding of C=O stretching or absorbed water (O-H bending). The peak in Sample 7 were sharper and more prominent while in Sample 8 weaker and wide. There are differences in moisture content or polymer chain mobility in Sample 7 that retains more bound water or has more rigid structure compared to Sample 8. Significant differences are observed in the fingerprint region typically from about 1500-800 cm^{-1}. Sample 7 express more numerous and well-defined peaks which match to C-O-C, C-O and glycosidic bond vibrations typical of polysaccharide structures. In contrast, Sample 8 shows fewer but stronger peaks specify more organized and compact polysaccharide. The stronger peaks in Sample 8 increased intermolecular bonding and better dispersion of extracted components within the bioplastic. It can be concluded that Sample 7 appears to have more and heterogeneous molecular structure whereas Sample 8 shows stronger and more defined polysaccharide-related bands [7].

3.8 Mechanical test of bioplastic

The bioplastic samples were tested using a universal testing machine (UTM) to evaluate their mechanical properties.



(a) **(b)**



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(c)

Figure 9: *Mechanical test (a) Tensile Strength, (b) Young's Modulus and (c) Elongation*

Figure 9 (a) showed the graph of sample vs tensile strength. A higher tensile strength indicates that the bioplastic has a stronger and more stable structure. Sample 8 obtained the highest 1.623 MPa of tensile strength, different with sample 1 that only obtained 0.196 MPa. Sample 8 showed the highest tensile strength because it likely had better interaction between starch, pectin and plasticizer. When the ratio of starch and pectin is more balanced and the plasticizer is well distributed, the polymer chains can interact more effectively through hydrogen bonding. These strong interactions help the bioplastic resist applied force during the tensile test [8].

Figure 9 (b) presented the graph Young's Modulus. Bioplastic with higher Young's Modulus values are stiffer and more rigid while samples with lower values are more flexible. Sample 7 (244.26 MPa) and Sample 8 (240.97 MPa) had the lowest Young's modulus values, which indicate that these bioplastics were relatively flexible. The flexibility of the bioplastics could be attributed to their higher plasticizer concentrations or the low intermolecular forces in the polymer matrix, which allow greater chain mobility. Sample 1, which gave a result of 581.75 MPa, demonstrating that these bioplastics have the highest stiffness. This can be attributed to the fact that a high Young's modulus is usually linked to high crystallinity index or low plasticizer content.

From Figure 9 (c), Sample 1 showed the lowest elongation at break while Sample 8 showed the highest elongation at break. Due to the 10% of elongation at break for Sample 1, the bioplastic had a limited flexibility and reduced capacity to undergo plastic deformation before breaking. Sample 8 with 60% elongation at break showed the greatest elongation at break values, indicating atypical stretchability and flexibility.

3.9 Biodegradability test of bioplastic

For the biodegradability test, the bioplastics of Samples 7 and 8 were compared to determine the which degrade in soil over time. The samples were buried, monitored for changes in weight loss.



(a) **(b)**

Figure 10: *(a) Sample buried in soil and (b) After 10 days*

Microorganisms such as bacteria and fungi present in the soil can absorb and metabolize the bioplastic as a source of energy and all that remains are CO2, water, salts and biomass. The rate of biodegradation is strongly influenced by environmental factors like temperature, soil moisture, pH and sunlight exposure where it can accelerate or slow down the biodegradation process, as they influence microbial activity and the chemical breakdown. Sample 7 and 8 were buried in soil as shown in Figure 10 (a).

Table 4: Initial weight and final weight of bioplastic

Sample	Initial weight (g)	Final weight (%)
7	12.857	91.7
8	17.712	95.05

Table 4 showed the initial weight and final weight of bioplastic. The weight before being buried in the soil for Sample 7 and 8 were 12.857 g and 17.712 g respectively. After 10 days, the weight loss of each of Samples 8 were 91.7% and 95.05%. The slightly higher degradation rate of Sample 8 may be attributed to higher elongation at break and lower stiffness, which could have facilitated better penetration of water and microbial enzymes. These bioplastics' capacity breakdown effectively in natural soil lowers the long-term environmental degradation and supports circular economy principles [9].

4. Conclusion

In conclusion, the study successfully extracted the starch and pectin to produce the bioplastic from banana by using power ultrasonic extraction. The optimal bioplastic formulation achieved a tensile strength of 1.623 MPa and an elongation at break of 60%, indicating that the bioplastic had good strength and flexibility. By addressing the issue that bananas cannot turn into wealth, this research contributes to sustainable development practices in the biodegradable aspect. This research highlights that banana peel-based bioplastics have the potential to be environmentally friendly. Unlike traditional plastics which can take hundreds of years to break down and often harm the environment, these bioplastics can naturally decompose. This means they can reduce plastic waste and pollution. By using waste materials like banana peels, this also promotes recycling and reduces the use of non-renewable resources. By converting food waste into useful biodegradable, this research present circular economy and more sustainable waste management practices. The analysis and testing that have been conducted showed that bioplastic exhibited suitable mechanical, morphological, and functional properties. Hence, these findings show that bioplastics have an important role in supporting a global shift toward sustainable and green materials. These bioplastics could eventually be produced as a substitute for traditional plastics with additional refinement and optimization.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of paper.

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