



EcoThin: Innovation of Plant-Based Biopolymer Food Packaging as a Strategy for Preventing Microplastic Pollution

Syarafina Khoirunnisa[✉], Usamah, Ainun Azka Rohmatillah, Rizkiy Amaliyah Barakwan
Universitas Airlangga

Keywords

Biodegradable;
Packaging; Plastic
Waste; Sustainable
Consumption;
SEMs.

Abstract

Indonesia faced a microplastic emergency in 2024, with average human intake reaching 15 g per month, the highest globally. Dominant polymers such as Polypropylene, High-density Polyethylene, and Polystyrene from single-use packaging were prevalent in the culinary sector and SEMs, underscoring the urgency for biodegradable alternatives. This study developed EcoThin, a food packaging film made from cassava starch, banana pseudostem fibers, and banana peel pectin as natural binder with glycerol as plasticizer and acetic acid as solvent. Films were produced using solvent casting and evaluated for sensory attributes, morphology, water uptake, and moisture content. The fiber-pectin ratio of 50:50 showed optimal performance, producing homogeneous, flexible films with improved water retention. EcoThin demonstrates potential as a biodegradable substitute for plastic packaging, supports the prevention principle in solid waste management, offers applicability to UMKM in the culinary sector, and contributes to SDG 12 on responsible consumption and production.

INTRODUCTION

The phenomenon of microplastic pollution has emerged as a serious global environmental issue, with human exposure estimated to reach tens of thousands of particles per person annually (Zhao & You, 2024). In Indonesia, studies indicate that the population ingests an average of 15 grams of microplastics per month, the highest level globally equivalent to approximately one ATM card. One of the dominant sources of these particles originates from the degradation of single-use polymers, such as Polypropylene (PP), High-Density Polyethylene (HDPE), and Polystyrene (PS), which are widely utilized in food packaging (Wibowo et al., 2021). Globally, the food industry accounted for 47% of total plastic production for packaging in 2022, driven by the increasing demand for low-cost and practical packaging solutions in the culinary sector, including small and medium enterprises (SMEs) in Indonesia (Williams & Rangel-Buitrago, 2022). These findings highlight that plastic food packaging constitutes a major contributor

the urgent need to develop sustainable alternatives.

Indonesia holds significant potential for the development of alternative materials through the utilization of abundant local biomass. National cassava production, which reached more than 14.98 million tons in 2022, has positioned it as an inexpensive and renewable source of starch (Kementerian Pertanian RI, 2023). In addition, bananas represent a major tropical commodity, with national production exceeding 92.6 million quintals in 2024. This substantial production volume contributes to post-harvest practices in which approximately 80% of the banana plant biomass is discarded without further processing, generating waste in the form of pseudostems rich in cellulose fiber and peels with high pectin content (Mardiana et al., 2022). To date, such biomass residues remain underutilized and are often discarded, indicating considerable untapped potential. The integration of

✉ Syarafina.khoirunnisa-2023@fkm.unair.ac.id, Surabaya, East Java

cassava starch with banana waste, such as cellulose fibers derived from pseudostems and pectin extracted from banana peels into biopolymers presents not only a sustainable solution for agricultural waste valorization but also an effective approach for substituting conventional plastic packaging (Ishara et al., 2024).

Based on this potential, EcoThin was developed as a plant-based biopolymer that integrates cassava starch with banana pseudostem and peel waste through a functionalization strategy to produce food packaging that substitutes single-use plastics while extending shelf life without requiring multilayer synthetic polymers. Its advantages include reducing sources of microplastics through the substitution of petroleum-based polymers with plant-derived materials, as well as minimizing microplastic residues through a material design that is readily biodegradable.

The urgency of this innovation is underscored by estimates of human exposure to tens of thousands of microplastic particles annually, highlighting the need to mitigate pollution at its source, particularly from packaging as a logical preventive strategy (Zhao & You, 2024). The novelty of EcoThin lies in its end-of-life-oriented formulation, achieved through the integration of plant-based bio-polymers with targeted functionalization that enhances physicochemical and mechanical properties without compromising biodegradability, aligning with recent advances in biopolymer-based food packaging films (Dirpan et al., 2023).

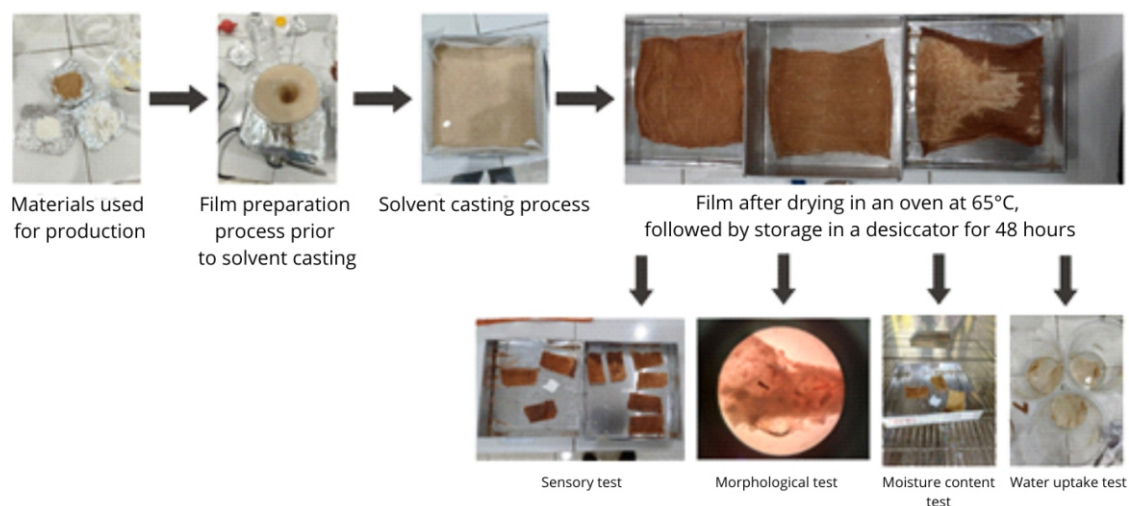
The utilization of abundant and low-cost local materials positions this plant-based biopolymer as a promising candidate for sustainable food packaging production, with strong potential for integration into the supply chains of culinary SMEs, which represent one of the largest users of single-use packaging. This potential demonstrates that EcoThin can provide an environmentally friendly material solution characterized by high availability and relatively low production

costs. Its contribution is not only effective in mitigating microplastic pollution but also aligns with the prevention principle within the solid waste management hierarchy. Furthermore, the implementation of EcoThin supports the achievement of Sustainable Development Goal (SDG) 12, namely Responsible Consumption and Production.

RESEARCH METHODS

This study employed a laboratory-scale experimental design conducted at Universitas Airlangga using the solvent casting method to produce biopolymer films based on cassava starch, banana pseudostem fiber, and banana peel pectin. The base composition used in each formulation consisted of 18 g of cassava starch, 5.47 g of glycerol, 600 mL of distilled water, and 1.8 g of acetic acid, a formulation previously demonstrated to be effective in related studies. Fiber and pectin were incorporated as additives at a total proportion of 40% of the dry weight of the base materials, following prior findings indicating that this ratio yields films with good stability. Cassava starch (*Manihot utilissima*) with 100% starch content, banana peel pectin (*Musa paradisiaca* L.) with 100% pectin, glycerol (99%), and acetic acid (100%) were obtained from the laboratory supplier UD. Sumber Ilmiah Persada, Surabaya. Meanwhile, banana pseudostem fiber was sourced from *Musa paradisiaca* L. plants located in the vicinity of Universitas Airlangga. In this formulation, fiber and pectin functioned as reinforcing additives, glycerol acted as a plasticizer, and acetic acid served as the solvent. The formulations were arranged as follows: Sample A (control) without fiber and pectin; Sample B (50:50) consisting of 3.6 g fiber and 3.6 g pectin; Sample C (25:75) consisting of 1.8 g fiber and 5.4 g pectin; and Sample D (75:25) consisting of 5.4 g fiber and 1.8 g pectin.

The banana pseudostem was subsequently processed through an extraction procedure involving cleaning, oven-drying at 60°C for 48 hours, and



Sumber: Processed Primary Data, (2025)

Figure 1
Plant-Based Biopolymer Production Process

grinding to obtain dried fibers, which were then sieved using a 0.2 mm mesh. The mixture of starch, fiber, and pectin was dissolved in distilled water and heated on a hot plate with continuous stirring for 20 minutes until gelatinization occurred, resulting in a homogeneous viscous solution. The solution was then cast into a mold measuring 22 × 22 cm with a thickness of 0.5 cm, followed by drying in an oven at 65°C until a thin film was formed. The dried film was subsequently stabilized in a desiccator for 48 hours to achieve equilibrium and structural stability (Abera et al., 2024).

The types of data collected included qualitative data, such as color, texture, aroma, and mechanical strength obtained through sensory evaluation, as well as morphological observations using a binocular light microscope (Olympus Cx21). Quantitative data were obtained through laboratory testing. Characterization of the biopolymer films was conducted through morphological analysis, water uptake testing, and moisture content determination. The water uptake test was performed by immersing the samples in 100 mL of distilled water in a 500 mL beaker at room temperature. The sample mass was recorded at the onset of degradation by removing the sample and eliminating

surface water. The percentage of water uptake was calculated using the following equation:

$$W_A(\%) = (W_s - W_o) / W_s \times 100 \quad (1)$$

where W_s represents the weight of the sample after immersion (wet weight), and W_o represents the weight of the sample before immersion (dry weight).

The moisture content was determined using the oven-drying method, in which the initial weight of the plant-based biopolymer film was recorded, followed by drying at 105 °C for 24 hours until a constant weight was achieved. The percentage of moisture content was calculated using the following equation:

$$\text{Moisture Content}(\%) = (w - d) / w \times 100 \quad (2)$$

where w represents the initial weight of the sample (gram) and d represents the constant dry weight (gram).

Data analysis techniques included qualitative descriptive analysis for sensory and morphological results, and quantitative descriptive analysis for laboratory test results. Statistical analysis of quantitative data, including moisture content and water uptake, was performed using Jamovi. Data were presented as mean values from three replicates ($n = 3$) to ensure statistical reliability. Differences among treatments were analyzed using Analysis of Variance (ANOVA), followed

Table 1
Composition of Materials in Plant-Based Biopolymer Production

Ratio	Banana pseudostem fiber (gram)	Banana peel pectin (gram)	Cassava starch (gram)
0:0	0	0	18
50:50	3,6	3,6	18
25:75	1,8	5,4	18
75:25	5,4	1,8	18

Source: Processed Primary Data, 2025

by Tukey's post hoc test to compare mean values. Differences were considered statistically significant at a confidence level of $p < 0.05$.

RESULTS AND DISCUSSION

Sensory Evaluation of Plant-Based

Biopolymer Films The results of the sensory evaluation of cassava starch-based bioplastic films with the addition of banana pseudostem fiber and banana peel pectin are presented in Table 2. Variations in the weight ratio of additives banana pseudostem fiber and banana peel pectin (0:0; 50:50; 25:75; 75:25) demonstrated a clear influence on the color, texture, odor, and mechanical strength of the bioplastic films.

The control biopolymer sample (0:0) exhibited a white color with a smooth texture, was odorless, and highly brittle. The 50:50 formulation showed a brown color with a slightly coarse and dry texture, a mildly sweet and slightly acidic odor, and strong as well as flexible mechanical properties. The 25:75 formulation produced a light brown color with a smoother dry texture, a mildly sweet and slightly acidic odor, and good strength, although it was less flexible. Meanwhile, the 75:25 formulation exhibited a dark brown color with a coarse dry texture, a mildly sweet and slightly acidic odor, and strong properties with limited flexibility.

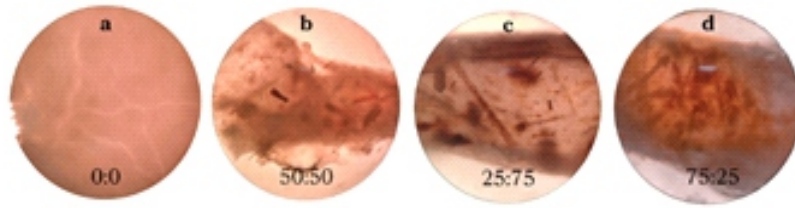
The color changes followed a pattern associated with increasing biomass fraction, where brown intensity increased with higher fiber content, while pectin dominance resulted in a lighter hue. This pattern is consistent with the findings of Azmin et al. (2020) who reported the influence of cellulose and plant fiber

proportions on the color gradation of biopolymers. Surface texture exhibited a differential role, with pectin tending to produce smoother films, whereas fiber contributed to more pronounced roughness. This observation aligns with the results of Othman et al. (2020) on starch-based biopolymer films reinforced with banana fiber. The slightly sweet and mildly acidic odor observed in additive-containing formulations is attributed to natural volatile compounds present in pectin and fiber, consistent with several studies utilizing banana biomass as a primary material (Ishara et al., 2024; Putra et al., 2022).

The qualitative mechanical properties indicated an overall improvement in strength across all formulations compared to the control. The 50:50 composition provided the most balanced combination of strength and flexibility. In contrast, the 25:75 formulation exhibited a stiffer structure with a smoother surface, while the 75:25 formulation showed a rougher texture with high strength but limited flexibility. These findings are consistent with the study by Othman et al. (2020) which demonstrated the role of fiber in enhancing tensile strength, albeit with some impact on film homogeneity, as well as with Ishara et al. (2024) who confirmed the contribution of banana biomass in improving the mechanical properties of starch-based biopolymers.

Morphological Analysis

Figure 2 presents the morphology of plant-based biopolymer films at varying ratios of banana pseudostem fiber and banana peel pectin. The microscopic visual differences observed at the given magnification indicate the influence of composition on the homogeneity and compactness of the



Source: Processed Primary Data, (2025)

Figure 2
Morphology of the Four Formulations of Plant-Based Biopolymer Films

films.

The control film (0:0) in Figure 2a exhibited a smooth and homogeneous surface, reflecting a compact structure, consistent with pure starch-based films reported by Othman et al. (2020). The 50:50 formulation (Figure 2b) showed a dense yet rough surface with uneven fiber distribution, which aligns with the findings of Ishara et al. (2024), who reported increased surface roughness due to fiber incorporation. The 25:75 formulation (Figure 2c) displayed a relatively smoother surface with a more uniform distribution, indicating the role of pectin in enhancing matrix homogeneity. Meanwhile, the 75:25 formulation (Figure 2d) exhibited fiber agglomeration and non-uniform distribution, consistent with the study by Sivakumar et al. (2022) which associated higher fiber concentrations with increased heterogeneity





in biopolymer films.

Water Uptake Analysis

The water uptake test was conducted to evaluate the water absorption capacity of the biopolymers based on variations in the composition of banana pseudostem fiber and banana pectin.

The comparative results of water uptake values are presented in Table 3. The water uptake test revealed that the control sample exhibited a negative value of -273.49%, indicating structural instability and material fragility. This occurred because the control sample consisted solely of starch without the addition of fiber or pectin, resulting in relatively weak intermolecular bonding and an inability to withstand water penetration (Sivakumar et al., 2022). This finding is consistent with Halimatul et al. (2019), who reported that pure starch-based films are highly hydrophilic, readily absorb water, and

Table 2
Sensory Evaluation of Plant-Based Biopolymer Films

Ratio	Color	Texture	Odor Characteristics	Mechanical Strength	Physical Documentation
0:0	White	Smooth	Odorless	Highly brittle	
50:50	Brown	Dry and slightly coarse	Sweet and mildly acidic	Strong and flexible	
25:75	Light brown	Dry and slightly smooth	Sweet and mildly acidic	Strong	
75:25	Dark brown	Dry and coarse	Sweet and mildly acidic	Strong and slightly flexible	

Source: Processed Primary Data, 2025

Table 3
Water Uptake Analysis of Each Formulation

Ratio	Dry Weight (gram)	Wet Weight (gram)	Water Uptake (%)
0:0	0.57	0.16	-273.49
50:50	7.011	14.568	52.74
25:75	8.164	28.089	70.66
75:25	6.718	15.662	57.07

Source: Processed Primary Data, 2025

degrade rapidly, leading to low dimensional stability.

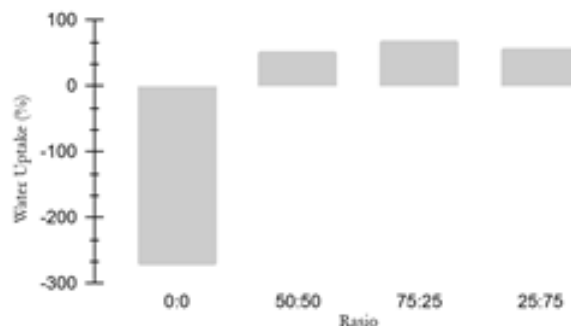
In samples with the addition of fiber and pectin, water uptake values increased, ranging from 52.74% to 70.66%. The 50:50 composition exhibited the lowest water uptake (52.74%), the 25:75 composition showed the highest (70.66%), and the 75:25 composition reached 57.07%. The ANOVA results indicated significant differences among groups ($p < 0.001$). Tukey's post hoc test revealed that the control differed significantly from all formulations ($p < 0.001$), whereas no significant differences were observed among the three formulations (50:50, 25:75, and 75:25) ($p > 0.05$). Thus, the addition of fiber and pectin generally increased water uptake compared to the control. This finding is consistent with previous studies on plant-based biopolymers, which indicate that fiber contributes to strengthening the structure and reducing film porosity, while pectin influences moisture-related properties and dimensional stability (Awad et al., 2024; Bai et al., 2023; Hazrati et al., 2021). The variation in their ratios in this study did not produce significant differences, suggesting that the presence of fiber and

pectin itself plays a more dominant role in enhancing water uptake than the specific compositional ratio.

Moisture Content Analysis

The moisture content test was conducted to determine the amount of residual water present in the biopolymer films after the drying process. The film samples were dried in an oven at 105 °C for 24 hours and removed once they began to show signs of degradation. Low moisture content in biopolymers is crucial, as it influences storage stability, mechanical properties, and resistance to microbial growth (Bozyigit et al., 2021; Ishara et al., 2024). The average moisture content values for each variation are presented in Table 4.

Based on the measurement results, the highest average moisture content was observed in the sample with a fiber:pectin ratio of 50:50 at 15.51%, while the lowest was found in the 75:25 ratio at 5.56%. The control sample (without fiber and pectin) exhibited a moisture content of 6.77%, and the 25:75 sample showed 7.42%. These variations indicate that the composition of fiber and pectin influences the film's ability to bind and retain water. The higher moisture content in the 50:50 sample is attributed to the more balanced of fiber



Source: Processed Primary Data, (2025)

Figure 3
Water Uptake Analysis of Each Formulation

Table 4
Moisture Content Analysis of Each Formulation

Ratio	First Weight (gram)	Last Weight (gram)	Moisture Content (%)
0:0	0.858	0.800	6.77
50:50	5.075	4.606	15.51
25:75	4.846	4.458	7.42
75:25	5.363	5.079	5.56

Source: Processed Primary Data, 2025

and pectin, consistent with Bernhardt et al. (2017) who reported that variations in fiber concentration in pectin-based films can affect moisture levels and water retention. In contrast, at a fiber-dominant ratio (75:25), the moisture content decreased, as the increased fiber content tends to produce a denser film structure, thereby limiting water diffusion (Azmin et al., 2020; Pan et al., 2019).

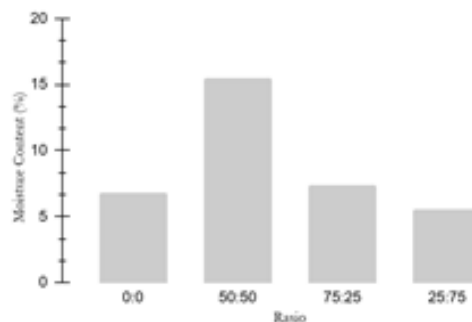
The statistical analysis further supports these findings, as ANOVA revealed significant differences among groups ($p = 0.006$). Tukey's post hoc test indicated that the 50:50 sample differed significantly from the control ($p = 0.015$), the 1:3 ratio ($p = 0.023$), and the 3:1 ratio ($p = 0.007$), while the other groups did not show significant differences. This confirms that the increase in moisture content predominantly occurs in the balanced formulation (50:50), whereas other variations tend to yield values comparable to the control. This pattern is consistent with the findings of Bernhardt et al. (2017) which highlight the role of balance between starch and fiber in biopolymer formation, and also aligns with studies indicating that fiber dominance can reduce moisture content

due to the formation of a denser film structure (Sivakumar et al., 2022). Thus, these results demonstrate that a balanced fiber: pectin ratio produces the most distinct properties and has important implications for the stability of biopolymer films as biodegradable food packaging.

Potential Application for SMEs

The results of this study indicate that plant-based biopolymer films derived from cassava starch, banana pseudostem fiber, and banana peel pectin have strong potential to be developed as environmentally friendly food packaging materials. Although the research is still limited to laboratory-scale film production, the evaluated characteristics, such as moisture content, water uptake, morphology, and sensory properties provide an initial indication of the material's feasibility as an alternative to single-use plastics. This is particularly relevant to the needs of culinary small and medium enterprises (SMEs), which generally still rely on packaging materials made from polypropylene (PP), high-density polyethylene (HDPE), and polystyrene (PS).

The plant-based biopolymer films



Source: Processed Primary Data, (2025)

Figure 3
Moisture Content Analysis of Each Formulation

developed in this study, derived from cassava starch, banana pseudostem fiber, and banana peel pectin, demonstrate strong potential to be further developed into biodegradable food packaging that is more applicable for SMEs. The utilization of abundant local raw materials can reduce production costs while simultaneously increasing the added value of agricultural waste such as banana stems and peels. Future development should focus on the application of processing techniques such as molding and hot-press forming to produce packaging resembling food containers, quantitative evaluation of mechanical properties including tensile strength and tear resistance, and pilot-scale trials to assess the feasibility of mass production. Thus, this innovation not only contributes to reducing microplastic generation but also supports the sustainability of small enterprises by providing environmentally friendly packaging alternatives that are ready for adoption by SMEs. Furthermore, future distribution through digital platforms may accelerate the wider adoption of this product.

CONCLUSION

This study successfully developed biocomposite films based on cassava starch, banana pseudostem fiber, and banana peel pectin using the solvent casting method with variations in fiber and pectin ratios. The results demonstrated that the addition of fiber and pectin significantly influenced the sensory characteristics, morphology, water uptake, and moisture content of the films. The balanced formulation of banana pseudostem fiber and pectin (50:50) provided the best combination of flexibility and homogeneity. In general, the resulting films exhibited low moisture content and relatively compact morphology, indicating their potential as biodegradable food packaging. For further development, future studies should include quantitative mechanical testing, such as tensile strength, as well as

the formation of biopolymers into three-dimensional food container shapes to enhance their applicability for culinary SMEs.

REFERENCES

- Abera, W. G., Kasirajan, R., & Majamo, S. L. (2024). Synthesis and characterization of bioplastic film from banana (*Musa Cavendish* species) peel starch blending with banana pseudo-stem cellulosic fiber. *Biomass Conversion and Biorefinery*, 14(17), 20419–20440. <https://doi.org/10.1007/s13399-023-04207-8>
- Awad, S. A., Jawaid, M., Ismail, A. S., Khalaf, E. M., & Abu-Jdayil, B. (2024). Dimension stability, tensile and thermomechanical properties of bamboo/oil palm fibre reinforced bio-epoxy hybrid biocomposites. *Journal of Materials Research and Technology*, 30(May), 7440–7446. <https://doi.org/10.1016/j.jmrt.2024.05.130>
- Azmin, S. N. H. M., Hayat, N. A. B. M., & Nor, M. S. M. (2020). Development and characterization of food packaging bioplastic film from cocoa pod husk cellulose incorporated with sugarcane bagasse fibre. *Journal of Bioresources and Bioproducts*, 5(4), 248–255. <https://doi.org/10.1016/j.jobab.2020.10.003>
- Bai, W., Vidal, N. P., Roman, L., PortilloPerez, G., & Martinez, M. M. (2023). Preparation and characterization of self-standing biofilms from compatible pectin/starch blends: Effect of pectin structure. *International Journal of Biological Macromolecules*, 251 (August), 126383. <https://doi.org/10.1016/j.ijbiomac.2023.126383>
- Bernhardt, D. C., Pérez, C. D., Fissore, E. N., De'Nobili, M. D., & Rojas, A. M. (2017). Pectin-based composite film: Effect of corn husk fiber concentration on their properties. *Carbohydrate Polymers*, 164, 13–22. <https://doi.org/10.1016/j.carbpol.2017.01.031>

- Bozyigit, I., Javadi, A., & Altun, S. (2021). Strength properties of xanthan gum and guar gum treated kaolin at different water contents. *Journal of Rock Mechanics and Geotechnical Engineering*, 13(5), 1160–1172. <https://doi.org/10.1016/j.jrmge.2021.06.007>
- BPS. (2024). *Produksi Tanaman Buah-buahan dan Sayuran Tahunan Menurut Provinsi dan Jenis Tanaman, 2024*. Badan Pusat Statistik. <https://www.bps.go.id/id/statistic-table/3/U0dKc1owczVSalJ5VFdOMWVETnlVRVJ6YIRJMFp6MDkjMw=/produksi-tanaman-buah-buahan-dan-sayuran-tahunan-menurut-provinsi-dan-jenis-tanaman--2024.html?year=2024>
- Dirpan, A., Ainani, A. F., & Djalal, M. (2023). A Review on Biopolymer-Based Biodegradable Film for Food Packaging: Trends over the Last Decade and Future Research. *Polymers*, 15(13). <https://doi.org/10.3390/polym15132781>
- Halimatul, M. J., Sapuan, S. M., Jawaid, M., Ishak, M. R., & Ilyas, R. A. (2019). Water absorption and water solubility properties of sago starch biopolymer composite films filled with sugar palm particles. *Polimery/Polymers*, 64(9), 596–604. <https://doi.org/10.14314/polimery.2019.9.4>
- Hazrati, K. Z., Sapuan, S. M., Zuhri, M. Y. M., & Jumaidin, R. (2021). Preparation and characterization of starch-based biocomposite films reinforced by *Dioscorea hispida* fibers. *Journal of Materials Research and Technology*, 15, 1342–1355. <https://doi.org/10.1016/j.jmrt.2021.09.003>
- Ishara, G. K. K., Koliyabandara, P. A., & Samarakoon, G. (2024). Eco-friendly bio-composite sheets: a study on the utilization of banana peels, cassava starch, and banana stem fibers. *Frontiers in Sustainability*, 5(September). <https://doi.org/10.3389/frsus.2024.1410986>
- Kementerian Pertanian. (2023). Analisis Kinerja Perdagangan Ubi Kayu. *Pusat Data Dan Sistem Informasi Pertanian Sekretariat Jendral, Kementerian Pertanian*, 1–65.
- Mardiana, R., Yuniati, Y., & Dita, S. F. (2022). Pemanfaatan Limbah Organik Kulit Pisang Awak (*Musa balbisiana*) Sebagai Bahan Sediaan Sabun Padat untuk Menangkal Radikal Bebas. *Lantania Journal*, 10(1), 34. <https://doi.org/10.22373/lj.v10i1.13413>
- Othman, S. H., Najhah Tarmity, N. A., Shapi'i, R. A., Mohd Zahiruddin, S. M., Amin Tawakkal, I. S. M., & Basha, R. K. (2020). Starch/banana pseudostem biocomposite films for potential food packaging applications. *BioResources*, 15(2), 3984–3998. <https://doi.org/10.15376/biores.15.2.3984-3998>
- Pan, Y., Xian, G., & Li, H. (2019). Numerical modeling of moisture diffusion in an unidirectional fiber-reinforced polymer composite. *Polymer Composites*, 40(1), 401–413. <https://doi.org/10.1002/pc.24664>
- Putra, N. R., Aziz, A. H. A., Faizal, A. N. M., & Che Yunus, M. A. (2022). Methods and Potential in Valorization of Banana Peels Waste by Various Extraction Processes: In Review. *Sustainability (Switzerland)*, 14(17), 1–18. <https://doi.org/10.3390/su141710571>
- Setyorini, D., Arisandi, P., Aprilianti, R., & Khomsah, K. (2024). *Indonesia Darurat Mikroplastik: Kajian Penetapan Baku Mutu Mikroplastik pada Air, Biota Air, Sedimen, Udara & Tubuh Manusia*. Ecological Observation and Wetlands Conservation. <https://ecoton.or.id/wp-content/uploads/2024/10/Dokumen-Kajian-Penentuan-Baku-Mutu-Mikroplastik.pdf>

- Sivakumar, A. A., Canales, C., Roco-Videla, Á., & Chávez, M. (2022). Development of Thermoplastic Cassava Starch Composites with Banana Leaf Fibre. *Sustainability (Switzerland)*, 14(19). <https://doi.org/10.3390/su141912732>
- Wibowo, A. T., Nugrahapraja, H., Wahyuono, R. A., Islami, I., Haekal, M. H., Fardiansyah, Y., Sugiyo, P. W. W., Putro, Y. K., Fauzia, F. N., Santoso, H., Götz, F., Tangahu, B. V., & Luqman, A. (2021). Microplastic contamination in the human gastrointestinal tract and daily consumables associated with an Indonesian farming community. *Sustainability (Switzerland)*, 13(22). <https://doi.org/10.3390/su132212840>
- Williams, A. T., & Rangel-Buitrago, N. (2022). The past, present, and future of plastic pollution. *Marine Pollution Bulletin*, 176(February), 113429. <https://doi.org/10.1016/j.marpolbul.2022.113429>
- Zhao, X., & You, F. (2024). Microplastic Human Dietary Uptake from 1990 to 2018 Grew across 109 Major Developing and Industrialized Countries but Can Be Halved by Plastic Debris Removal. *Environmental Science and Technology*, 58(20), 8709–8723. <https://doi.org/10.1021/acs.est.4c00010>