JBIO : jurnal biosains
(the journal of biosciences)
Vol. 12 No. 1. March 2026

ISSN 2443-1230 (print)
ISSN 2460-6804(online)
DOI: https://doi.org/10.24114/nrt8fk52

JBIO: jurnal biosains (the journal of biosciences)
http://jurnal.unimed.ac.id/2012/index.php/biosains
email : jbiosains@unimed.ac.id
Universitas Negeri Medan

Physical Characterization of Bioplastics Made from Sweet Orange (*Citrus sinensis*) Peel Waste Pectin and Pandan Leaf (*Pandanus amaryllifolius*) Cellulose

Gabriella Marry Ayu[1*] , Nikmatul Khoiriah Harahap[1] , Syarifah Riska Mela Putri[1]
[1] Public Health Department, STIKes Widya Husada, Medan, Indonesia
*Corresponding author: gabriellamarryayu@gmail.com

Received : Agust 2025
Revised :February 2026
Accepted :March 2026

First Publish Online :
March, 30, 2026

Keywords : Bioplastic; pectin; cellulose; waste management; biodegradable

ABSTRACT

One effort to reduce environmental pollution is developing bioplastics from organic waste, such as pectin from sweet orange peel (Citrus sinensis) and cellulose from fragrant pandan leaves (Pandanus amaryllifolius). Pectin, a polysaccharide from orange peel, and cellulose from pandan leaves can produce biodegradable plastics easily decomposed by soil microorganisms. This study addresses the growing issue of plastic waste accumulation by creating eco-friendly packaging alternatives. Utilizing orange peel and pandan leaves aligns with the circular economy concept by turning food waste into valuable materials. The research aims to reduce plastic pollution and process organic waste into bioplastics based on pectin and cellulose. An experimental laboratory design using a Completely Randomized Design (CRD) was applied with pectin concentrations of 1 g, 2 g, and 3 g, each repeated three times. The formulation also included 1 g of pandan cellulose, carrageenan (0.8 g) as a stabilizer, and glycerol (2%) as a plasticizer. Data were analyzed using one-way ANOVA in SPSS 24. Results showed that increasing pectin concentration enhanced bioplastic thickness, reduced water absorption, and accelerated degradation over four weeks, indicating improved biodegradable performance.

.

.

Introduction

In recent decades, the increasing volume of plastic waste has triggered the search for more environmentally friendly alternative materials. One such material is bioplastic, a plastic made from natural, biodegradable biopolymers (Utami et al., 2023; Iisyrin, 2020). One potential raw material for bioplastic production is pectin. Pectin is a water-soluble polysaccharide found in plant cell walls and functions as a gelling agent, thickener, and stabilizer. Sweet orange peel waste is an abundant source of pectin, a source often underutilized in agriculture. Utilizing orange peel waste for pectin extraction not only helps reduce agricultural waste but also reduces dependence on synthetic plastic raw materials (Hanani, 2014; Hareva et al., 2023). Furthermore, pectin contains phytochemical compounds that have the potential to provide bioactive properties, such as antioxidants and antimicrobials, which can increase the added value of bioplastic products (Hanani, 2014).

On the other hand, pandan leaves are a highly potential source of plant-based cellulose. Cellulose, as a natural polymer, has good mechanical strength and is the main raw material for bioplastic production. Cellulose isolated from pandan leaves has demonstrated adequate transparency and mechanical properties, as well as its abundant availability and relatively low production cost (Dewi et al., 2021). Therefore, the combination of pectin from sweet orange peel waste and cellulose from pandan leaves is expected to produce bioplastic with optimal mechanical properties and high biodegradability.

Several previous studies have examined the use of pectin from various citrus waste sources. Previous research (Latupeirissa et al., 2019) showed that extracting pectin from sweet orange peel can produce pectin of suitable quality for edible film and coating applications. Meanwhile, another study (Muryeti, 2024) evaluated the effect of adding orange peel pectin with additives such as chitosan and peppermint oil on the characteristics of bioplastics. However, this study did not integrate the use of pandan leaf cellulose as a reinforcing component, so there is still room for developing hybrid bioplastics that combine these two natural materials.

Conceptually, pectin acts as a matrix capable of forming a gel network, while cellulose functions as a filler and reinforcement, increasing the mechanical strength of the final product. The combination of these two materials is expected to provide a synergy that produces bioplastics with better thickness, tensile strength, and elasticity. Furthermore, the presence of phytochemical compounds in pectin can also provide additional benefits, such as antioxidant and antimicrobial properties, so that the resulting bioplastic is not only environmentally friendly but also has added value for food packaging applications (Tambunan et al., 2022; Arimpi & Pandia, 2019).

Utilizing sweet orange peel waste as a source of pectin and pandan leaves as a source of cellulose not only provides an innovative solution for agricultural waste management but also supports the concept of a circular economy. By processing abundant waste into high-value products, it is hoped that the negative impact of synthetic plastic waste can be reduced and opportunities for industrial-scale applications, particularly in the production of biodegradable packaging. This aligns with global efforts to reduce plastic pollution and encourage the use of renewable materials (Jabbar, 2017).

In addition to environmental benefits, pectin and cellulose-based bioplastics also have the potential to improve the safety and quality of packaging products. Biodegradable plastics are able to decompose by microorganisms in a relatively short time, thereby reducing waste accumulation and potential pollution risks. This research is expected to make a significant contribution to the development of environmentally friendly materials that are not only technically sound but also economically and applicably feasible, thus supporting the implementation of green technology in Indonesia (Iisyrin, 2020; Jabbar, 2017).

Thus, research on the phytochemical characterization of sweet orange waste pectin as a raw material for pandan leaf cellulose-based bioplastics is highly relevant. The research results are expected to provide innovative alternatives for developing high-quality biodegradable packaging and support sustainable agricultural waste management. This research is also expected to serve as a basis for the development of bioplastic products that can be widely applied in the packaging industry and various other sectors (Hareva et al., 2023; Tambunan et al., 2022).

ISSN 2443-1230 (print)
ISSN 2460-6804(online)
DOI: https://doi.org/10.24114/nrt8fk52

Materials and Methods

Types and Design of Research

This research is a laboratory experimental study with a quantitative approach using a completely randomized design (CRD). Treatment variations were determined based on the concentration of pectin extracted from sweet orange peel waste, namely 1 g, 2 g, and 3 g. Each treatment was repeated three times to obtain representative and valid data. In addition, this study also involved the addition of additional ingredients such as carrageenan (0.8 g) as a stabilizer, glycerol (2% of the total dry mass) as a plasticizer.

Materials and tools

The main materials used in this study were sweet orange peel waste as a source of pectin and fragrant pandan leaves as a source of cellulose. Sweet orange peel was obtained from street vendors, while fragrant pandan leaves were chosen because of their high cellulose content and abundant availability. Other additional materials include carrageenan, glycerol, 96% ethanol, citric acid, and distilled water. The tools used included a digital scale for weighing the ingredients, an oven for drying, a hot plate and blender for processing, and laboratory equipment such as a Buchner funnel with filter paper.

Research Procedures

Pectin Extraction from Sweet Orange Peel

The process begins with the preparation of the ingredients, where the sweet orange peel is washed thoroughly to remove dirt, then cut into small pieces and dried in an oven at 50–60°C for 24 hours to reduce the water content. The dried peel is then ground using a blender until it becomes a homogeneous powder. Next, 50 g of orange peel powder is extracted by dissolving it in 500 mL of citric acid solution that has been adjusted to pH 2, by heating at 80°C for one hour with constant stirring. The extracted solution is then filtered using filter paper to separate the solid pulp, and the liquid filtrate obtained is mixed with 96% ethanol at a volume ratio of 1:2 to precipitate the pectin. The pectin precipitate formed is collected and dried at 40°C until it reaches a dry powder form.

Cellulose Isolation from Pandan Leaves

Fresh pandan leaves are first washed and dried, then crushed using a blender to produce a pulp. The pandan leaf pulp is processed through a delignification stage by soaking it in a 4% NaOH solution at 80°C for two hours. The delignification process aims to remove lignin and hemicellulose to obtain pure cellulose. After soaking, the material is filtered and washed until the solution reaches a neutral pH, then dried at 50–60°C. Next, the cellulose powder is sieved to obtain a homogeneous particle size so it can be used as a reinforcing material in bioplastic formulations.

Bioplastic Manufacturing

The basic formulation for making bioplastic involves mixing pectin from sweet orange peel with varying concentrations (1 g, 2 g, and 3 g) and 1 g of pandan leaf cellulose, plus additional ingredients in the form of carrageenan as much as 0.8 g and glycerol as a plasticizer (2% of the total dry mass). This mixture of materials is dissolved in 100 mL of distilled water and heated at a temperature of 70–80°C with constant stirring until homogeneous. The resulting solution is then poured into acrylic or glass molds, and the drying process is carried out at room temperature for 2–3 days to produce a uniform and dry bioplastic film.

Bioplastic Characteristics Test

After the forming process, the resulting bioplastic is thoroughly tested. Physical properties include:

ISSN 2443-1230 (print)
ISSN 2460-6804(online)
DOI: https://doi.org/10.24114/nrt8fk52

- Thickness measurement using a screw micrometer,
- Biodegradation tests were conducted by burying bioplastic samples in moist soil and measuring weight loss periodically over four weeks.
- Water Absorption Test is conducted to evaluate the ability of bioplastic to withstand water penetration.

Data analysis

Data obtained from bioplastic characteristic testing was processed using statistical software. A one-way analysis of variance (ANOVA) test was used to determine the effect of pectin concentration on bioplastic properties. If significant differences were found, further tests such as Duncan's or Tukey's HSD were performed at a 5% significance level.

Results and Discussion

Table 1. Effect of Using Sweet Orange Peel Waste Pectin Based on Pandan Leaf Cellulose on Bioplastic Thickness

Treatment	Thickness (mm)
P1 (1 g pectin + 1 g cellulose)	0.21 ± 0.01
P2 (2 g pectin + 1 g cellulose)	0.25 ± 0.01
P3 (3 g pectin + 1 g cellulose)	0.29 ± 0.02

The results showed that the thickness of the bioplastic increased with the addition of pectin concentration in the formulation. In treatment P1 (1 g pectin + 1 g cellulose), the thickness obtained was 0.21 ± 0.01 mm, then increased to 0.25 ± 0.01 mm in P2 (2 g pectin + 1 g cellulose), and reached 0.29 ± 0.02 mm in P3 (3 g pectin + 1 g cellulose). This indicates a consistent trend of increasing thickness with increasing pectin. Pectin is thought to act as a matrix former that can increase film density, resulting in bioplastics with higher thickness. However, in treatment P3, the thickness variation was greater (± 0.02 mm) compared to P1 and P2, which indicates that the use of high amounts of pectin can cause the bioplastic structure to become less homogeneous. Thus, it can be concluded that the more pectin added, the thicker the bioplastic produced, but it is necessary to pay attention to the homogeneity of the structure so that the thickness remains uniform.

Recent studies support the finding that increasing pectin levels in formulations tends to increase film/bioplastic thickness and that cellulose reinforcement can improve film mechanical properties and consistency. A recent review of pectin films confirmed that higher pectin concentrations result in thicker and less translucent films, with some experimental studies showing an increase in thickness when pectin is increased from ~3% to 5% (w/v) (Adiansyah et al., 2025) . Other experimental studies have shown that when polymer concentrations (including pectin) are increased from 2.5% to 5% (w/w), film thickness increases significantly ($p < 0.05$) before reaching a plateau at higher concentrations (Van Rooyen et al., 2023) . In pectin–cellulose composite systems, a 2024 comparative study reported that the addition of pectin in a cellulose derivative-based matrix modifies the thickness while improving certain mechanical properties, while a 2024 nanocellulose review and a 2025 pectin–cellulose fiber composite study highlight the role of hydrogen network and crystallinity in strengthening the film while influencing its thickness characteristics (Ursachi et al., 2024; Xu et al., 2024; Idahagbon et al., 2025) . In addition, variations in composition (e.g., plasticizer or essential oil) can also change the thickness—usually increasing it—although the effect can be small/not always statistically significant, confirming that the formulation composition greatly influences the final thickness (Akachat et al., 2025) . Overall, this 2023–2025 literature is consistent with your data: the increase in pectin from P1→P3 is in line with the increasing trend in thickness, while the potential increase in variation (SD) at high concentrations can be attributed to the homogeneity of the polymer network and processing conditions (Adiansyah et al., 2025; Van Rooyen et al., 2023; Ursachi et al., 2024; Xu et al., 2024; Idahagbon et al., 2025)

Table 2. Effect of Using Sweet Orange Peel Waste Pectin Based on Pandan Leaf Cellulose on the Water Absorption Capacity of Bioplastics

Treatment	**Water Absorption Capacity (%)**
P1 (1 g pectin + 1 g cellulose)	29.4 ± 1.6
P2 (2 g pectin + 1 g cellulose)	24.8 ± 1.4
P3 (3 g pectin + 1 g cellulose)	21.6 ± 1.3

The results showed that the water absorption capacity of bioplastics tended to decrease with increasing pectin concentration in the formulation. In treatment P1 (1 g pectin + 1 g cellulose), water absorption was recorded at 29.4 ± 1.6%, then decreased to 24.8 ± 1.4% in P2 (2 g pectin + 1 g cellulose), and reached the lowest value in P3 (3 g pectin + 1 g cellulose) at 21.6 ± 1.3%. This decrease in absorption capacity indicates that increasing pectin results in a denser and more homogeneous bioplastic structure, thereby reducing the material's ability to absorb water. In addition, pectin plays a role in forming a denser polymer matrix through hydrogen bonds with cellulose, thereby decreasing film porosity. The consistency of the results is also seen from the relatively small standard deviation value, indicating the stability of the formulation in each treatment. Thus, it can be concluded that the higher the pectin concentration, the lower the water absorption capacity of bioplastics, which is a positive characteristic in environmentally friendly packaging applications because it increases resistance to moisture.

Previous research has shown that pectin- and cellulose-based bioplastic formulations affect water absorption properties. Al Fath *et al.* (2024) reported that the addition of nanocrystalline cellulose (NCC) to a pectin-starch matrix can reduce water absorption and increase film stability, thus demonstrating the important role of cellulose in improving the physical properties of bioplastics. Meanwhile, Putri *et al.* (2024) found that increasing the cellulose content from water hyacinth and kepok banana peels can actually increase water absorption, confirming that polymer composition significantly influences the hydrophobicity of bioplastics. Another study using pectin films with microfibrillated cellulose (MFC) also showed a decrease in water solubility, which is directly related to the film's reduced water absorption capacity (Carullo, 2024). Furthermore, a recent review by Dirpan *et al.* (2024) confirmed that pure pectin is highly hydrophilic and therefore tends to absorb high amounts of water, but this property can be minimized through combination with reinforcing materials or other modifications such as cellulose. The results of this study are consistent with the data obtained, where increasing the amount of pectin in the P1–P3 formulations was able to significantly reduce the water absorption capacity of bioplastics.

ISSN 2443-1230 (print)
ISSN 2460-6804(online)
DOI: https://doi.org/10.24114/nrt8fk52

Table 3. Effect of Using Sweet Orange Peel Waste Pectin Based on Pandan Leaf Cellulose on Bioplastic Degradation Time

Treatment	4 Week Degradation (%)
P1 (1 g pectin + 1 g cellulose)	65.1 ± 3.2
P2 (2 g pectin + 1 g cellulose)	70.3 ± 2.8
P3 (3 g pectin + 1 g cellulose)	74.5 ± 2.6

The results showed that the rate of bioplastic degradation over 4 weeks increased with increasing pectin concentration in the formulation. In treatment P1 (1 g pectin + 1 g cellulose), the degradation rate was recorded at 65.1 ± 3.2%, then increased to 70.3 ± 2.8% in P2 (2 g pectin + 1 g cellulose), and reached the highest value in P3 (3 g pectin + 1 g cellulose) at 74.5 ± 2.6%. This increase indicates that the addition of pectin contributed to the bioplastic's easy degradation properties. This is thought to be because pectin is a polysaccharide that is easily broken down by microorganisms through hydrolysis and enzymatic processes, so the higher the pectin content in the film, the faster and greater the percentage of degradation. The relatively small standard deviation value in each treatment also indicates stable consistency of the results. Thus, it can be concluded that formulations with higher pectin content have better biodegradability potential, which is an important characteristic to support the development of environmentally friendly bioplastics.

Previous studies have shown that increasing pectin content in bioplastic formulations has a positive impact on increasing degradation rates in soil or similar environments. Idahagbon *et al.* (2025) reported that pectin–nanocellulose (CNF) composite films underwent significant degradation over several weeks in soil, confirming that the pectin-based structure is readily biodegradable and that cellulose helps form an efficient degradation mechanism. Furthermore, a review by Pooja (2023) concluded that the biodegradation rate of bioplastics is highly dependent on the polymer type, the presence of microbial enzymes, and environmental conditions—including humidity, temperature, and microbial activity—adds to the scientific rationale for pectin as a readily biodegradable polysaccharide. Brunšek *et al.* (2023) also found that lignin and pectin content significantly accelerated the degradation of cellulose and polylactide (PLA) fibers in soil, while crystallinity had little effect. Furthermore, Dirpan *et al.* (2024) emphasized that pure pectin is a highly biodegradable polymer and that with the addition of fillers or modifications, such as cellulose, degradation can be optimized—in line with your data that increasing pectin (from P1 to P3) increases the percentage of degradation with low variation. These findings are consistent with your data: the increase in degradation from 65.1 ± 3.2% (P1) to 74.5 ± 2.6% (P3) indicates that higher pectin content accelerates consistent and stable biodegradation over a 4-week period.

Conclusions

Based on the research results, it can be concluded that the addition of sweet orange peel waste pectin based on pandan leaf cellulose significantly affected the properties of the resulting bioplastic. The higher the pectin concentration, the bioplastic showed increased thickness, decreased water absorption, and a higher degradation rate. This indicates that pectin plays an important role in forming a denser and more easily degraded polymer matrix, resulting in bioplastic with better mechanical characteristics and biodegradability. These findings confirm the potential of utilizing orange peel waste pectin as an environmentally friendly raw material in the development of sustainable bioplastics.

Acknowledgment

On this occasion, the author expresses infinite gratitude to Allah SWT. The acknowledgments include appreciation for those who have contributed to the research, particularly the Ministry of Higher Education and Science and Technology (Ministry of Higher Education and Science and Technology) and the Directorate of Research, Technology, and Community Service (DRTPM), which provided funding for the implementation of the activities. The author also extends sincere thanks to LLDikti 1 and STIKes Widya Husada Medan for their assistance in the form of financial support, facilities, permits, consultancy, and help with data collection.

Reference

Adiansyah, S., Muflih, M. H., Izzah, N., Fadillah, U., Ainani, A. F., & Dirpan, A. (2025). Pectin-based edible films and coatings: From extraction to application on food packaging towards circular economy—A review. *Carbohydrate Polymers Technologies and Applications, 9,* 100680. https://doi.org/10.1016/j.carpta.2025.100680

Akachat, B., et al. (2025). Evaluation of glycerol concentration in the production of lemon oil incorporated pectin-based films using principal component analysis. *Foods, 14*(9), 1576. https://doi.org/10.3390/foods14091576

Akachat, B., Himed, L., Salah, M., D'Elia, M., Rastrelli, L., & Barkat, M. (2025). Development of pectin-based films with encapsulated lemon essential oil for active food packaging: Improved antioxidant activity and biodegradation. *Foods, 14*(3), 353. https://doi.org/10.3390/foods14030353

Al Fath, F. M. T., Nasution, H., Harahap, H., Ayu, G. E., Hasibuan, G. C., & Alexander, V. (2024). Pectin-starch biocomposite reinforced with rattan-derived cellulose nanocrystals: A study of mechanical and water absorption properties. *Tropical Journal of Natural Product Research, 8*(11), 9138–9144. https://doi.org/10.26538/tjnpr/v8i11.24

Arimpi, A., & Pandia, S. (2019). Pembuatan pektin dari limbah kulit jeruk (*Citrus sinensis*) dengan metode ekstraksi gelombang ultrasonik menggunakan pelarut asam sulfat (H2SO4). *Jurnal Teknik Kimia USU, 8*(1), 18–24.

Brunšek, R., Kopitar, D., Schwarz, I., & Marasović, P. (2023). Biodegradation properties of cellulose fibers and PLA biopolymer. *Polymers, 15,* 3532. https://doi.org/10.3390/polym15173532

Carullo, D. (2024). Pectin-based films for applications in the horticultural sector: A preliminary characterization. *Chemical Engineering Transactions, 110,* 283–288. https://doi.org/10.3303/CET2411048

Dewi, R., Rahmi, R., & Nasrun, N. (2021). Pembuatan bioplastik berbasis selulosa daun pandan. *Jurnal Agroindustri Berkelanjutan*. Retrieved April 7, 2025, from https://jurnal.fp.unila.ac.id/index.php/JAB/article/view/10073

ISSN 2443-1230 (print)
ISSN 2460-6804(online)
DOI: https://doi.org/10.24114/nrt8fk52

Dirpan, A., Deliana, Y., Ainani, A. F., Irwan, & Bahmid, N. A. (2024). Exploring the potential of pectin as a source of biopolymers for active and intelligent packaging: A review. *Polymers, 16*(19), 2783. https://doi.org/10.3390/polym16192783

Hanani, E. (2014). *Analisis fitokimia*. Jakarta: Buku Kedokteran EGC.

Hareva, B. I., Sumarni, S., & Purwanti, A. (2023). Pembuatan plastik ramah lingkungan dari pisang klutuk dan serat pandan duri. *Jurnal Inovasi Proses, 8*(1), 24–30.

Idahagbon, N. B., Nicholas, R. J., & Wei, A. (2025). Pectin–cellulose nanofiber composites: Biodegradable materials for modified atmosphere packaging. *Food Hydrocolloids, 162,* 110976. https://doi.org/10.1016/j.foodhyd.2024.110976

Isyrin, M. (2020). Analisis dampak impor sampah plastik terhadap masyarakat dan lingkungan hidup di Indonesia. *Jurnal UNISIA*. Retrieved April 7, 2025, from https://www.researchgate.net/Publication/339603074

Jabbar, U. F. (2017). *Pengaruh penambahan kitosan terhadap karakteristik bioplastik dari pati kulit kentang (Solanum tuberosum L.)* (Skripsi, Universitas Islam Negeri Alauddin Makassar).

Latupeirissa, J., Fransina, E. G., & Tanasale, M. F. (2019). Ekstraksi dan karakterisasi pektin kulit jeruk manis kisar (*Citrus* sp.). *Indonesian Journal of Chemical Research, 7*(1), 61–68.

Muryeti, M. (2024). Pengaruh penambahan pektin kulit jeruk, kitosan, dan peppermint oil terhadap karakteristik bioplastik. *Jurnal Chemurgy, 8*(2), 166–177.

Pooja, N., Chakraborty, I., Rahman, M. H., et al. (2023). An insight on sources and biodegradation of bioplastics: A review. *3 Biotech, 13,* 220. https://doi.org/10.1007/s13205-023-03638-4

Putri, F. A., Rianjanu, A., & Sipahutar, W. S. (2024). Cellulose impact on bioplastic performance: A study on mechanical strength, physical properties, and degradation of water hyacinth and kepok banana peel-derived materials. *Jurnal Teori dan Aplikasi Fisika, 12*(2).

Tambunan, A. Y., Azhari, A., Dewi, R., ZA, N., & Mulyawan, R. (2022). Pemanfaatan limbah kulit jeruk manis sebagai pektin dengan metode ekstraksi. *Jurnal Teknologi Kimia Unimal, 11*(1), 112–121.

Ursachi, V.-F., Oroian, M., & Spinei, M. (2024). Development and characterization of biodegradable films based on cellulose derivatives and citrus pectin: A comparative study. *Industrial Crops and Products, 219,* 119052. https://doi.org/10.1016/j.indcrop.2024.119052

Utami, A. P., Pane, N. N. A., & Hasibuan, A. (2023). Analisis dampak limbah/sampah rumah tangga terhadap pencemaran lingkungan hidup. *Cross-border, 6*(2), 1107–1112.

Van Rooyen, B., De Wit, M., Osthoff, G., Van Niekerk, J., & Hugo, A. (2023). Effect of pH on the mechanical properties of single-biopolymer mucilage (*Opuntia ficus-indica*), pectin and alginate films: Development and mechanical characterisation. *Polymers, 15*(24), 4640. https://doi.org/10.3390/polym15244640

Xu, Y., Wu, Z., Li, A., Chen, N., Rao, J., & Zeng, Q. (2024). Nanocellulose composite films in food packaging materials: A review. *Polymers, 16*(3), 423.

https://doi.org/10.3390/polym16030423