Volume 6 (2) July 2026, Pages: 278-287

Environmental Pollution Journal

https://doi.org/10.58954/epj.v6i2.493

Development of a Biodegradable Fishing Net Prototype Based on Pineapple Leaf Fiber as an Alternative to Reduce Microplastics in the Water

Kinara Zahwa As'ad[1✉], Elva Gracia Dinata Ginting[1], Rizqi Najma Delia[1], Agung Prastyo[1,2]

[1]SMA Unggulan Rushd

[2]Universitas Sebelas Maret

Keywords

Fishing net; Microplastic; Pineapple leaf fiber; Biopolymer; Biodegradable

Abstract

Fishing nets are generally made of synthetic materials that are difficult to decompose. When fishing nets are left behind in the waters, they trap aquatic life (ghost fishing), posing a serious threat to aquatic ecosystems. Globally, more than 50,000 tons of fishing nets drift away and become a major contributor to plastic, especially microplastics, in the water. This study aims to develop the use of pineapple leaf fibers as a base material for biodegradable fishing nets to reduce the phenomenon of ghost fishing. The method used is research and development by developing a prototype fishing net from pineapple leaf fibers with a layer of easily degradable biopolymer solution. This study tested the water content and density of pineapple fiber yarn as well as the compressive strength and biodegradability of pineapple fiber-based fishing nets. The results showed that pineapple leaf fiber-based fishing nets measuring 10x10 cm and 0.2 cm in diameter could withstand loads of up to 20 kg and were biodegradable, proving that the developed prototype had adequate mechanical properties and was environmentally friendly.

INTRODUCTION

Indonesia ranks second globally in plastic waste generation, producing around 3.2 million tons, of which 1.29 million tons enter the marine environment (Mainnah et al., 2016). This plastic waste primarily originates from land-based sources and is transported to the ocean through river flows, wind, rainfall, and flooding, particularly from household waste and single-use products such as plastic bags and packaging bottles. In addition, plastic waste is also generated from activities in aquatic environments, including fishing operations. Most fishers utilize synthetic materials for nets and ropes in their fishing gear due to their durability, strength, and low production cost. However, the benefits provided by synthetic fishing nets are not commensurate with the negative environmental impacts they impose.

When fishing nets are damaged and ropes break during operation, fishers often dispose of the damaged net fragments or broken ropes directly into the sea, a phenomenon known as ghost fishing. This practice contributes to the increasing accumulation of plastic waste in marine environments (Mainnah et al., 2016). Abandoned, lost, or discarded fishing gear accounts for a significant proportion of global marine plastic pollution, with an estimated 640,000 tons of fishing nets entering the ocean each year (Richardson et al., 2018).

The use of synthetic materials in fishing gear can trigger the accumulation of plastic waste, leading to significant environmental pollution (Mainnah et al., 2016). Synthetic fishing nets derived from petroleum-based materials possess complex polymer bonds, making them resistant to biodegradation by micro-organisms. Plastic waste that remains in the marine environment undergoes weathering processes that substantially alter its physical and chemical properties. Exposure to ultraviolet (UV) radiation reduces polymer stability, causing

✉ kinarazahwaa@gmail.com, Sragen, Jawa Tengah

fragmentation and compositional changes, which may facilitate the adsorption of hazardous substances from plastics into the surrounding marine environment (Sun et al., 2022).These processes result in the formation of microplastics, as larger plastic debris fails to fully decompose and instead breaks down into smaller particles that disperse widely in aquatic systems. Microplastics are defined as plastic particles measuring less than 5 mm in size and are capable of contaminating the environment. Consequently, microplastic pollution has emerged as a growing global threat. At present, nearly all aquatic environments worldwide have been contaminated by microplastics (Sharma et al., 2021).

Therefore, alternative materials are required to reduce the use of synthetic substances in the production of fishing nets, one of which is the utilization of natural resources such as pineapple. Pineapple is a major commodity with high economic value. However, not all parts of the pineapple plant are fully utilized, resulting in environmental waste. Pineapple leaves contain a high fiber content, with a cellulose concentration of 81.27% (Thahir et al., 2017), which contributes to their excellent tensile and flexural mechanical properties (Mainnah et al., 2023). Pineapple leaf fiber is considered to have significant potential as an alternative material for synthetic fishing nets due to its abundant availability, biodegradability, and favorable mechanical properties (Mainnah et al., 2023).

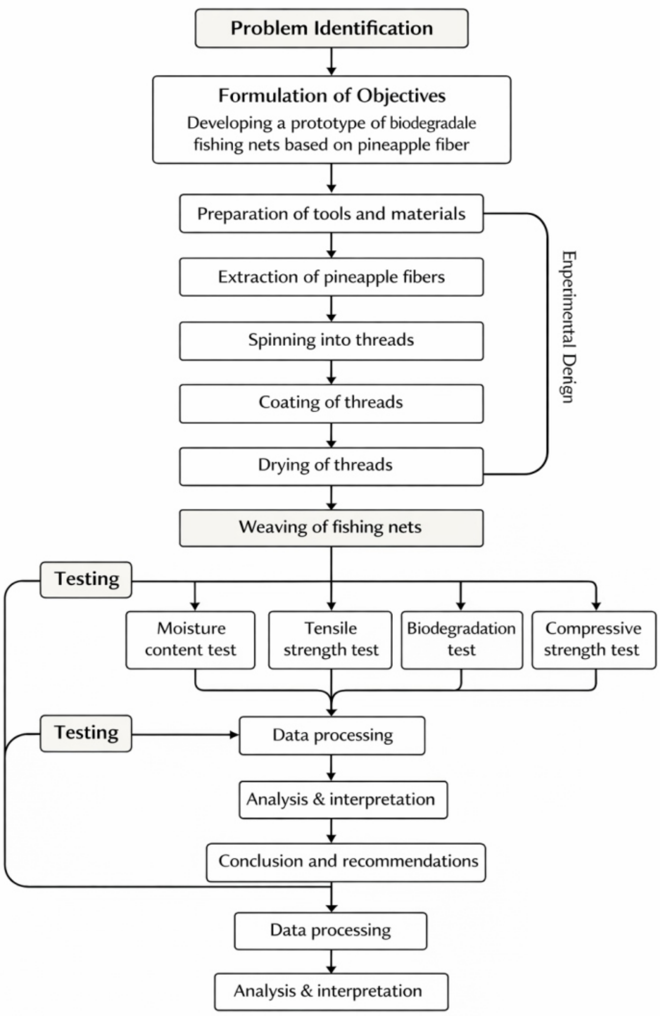
One of the primary limitations of natural fibers is their high water absorption capacity and susceptibility to biodegradation. Consequently, these fibers require additional protection to enhance their durability. Such protection can be provided in the form of a coating that functions to reduce water absorption while inhibiting the growth of decay-causing bacteria. One potential approach is the application of a coating derived from a biopolymer solution. Biopolymers are naturally occurring organic substances that exhibit biocompatible and biodegradable properties (Baranwal et al., 2022). In previous research by Mainnah et al. (2016), chitosan was utilized as the biopolymer. However, chitosan has been widely employed in numerous studies, making its application relatively common. Therefore, the present study seeks to introduce novelty by utilizing a biopolymer solution composed of a combination of carboxymethyl cellulose (CMC), sodium alginate, calcium lactate, and glycerin. Carboxymethyl cellulose is selected due to its excellent water-binding capacity, non-toxic nature, biodegradability, and antibacterial properties (Akhtar et al., 2023). Sodium alginate is employed for its thickening ability and its potential to form gel structures (Feng et al., 2023; Rahman et al., 2025). Calcium lactate functions as a crosslinking agent to enhance the strength of the protective layer and also serves as an environmentally friendly preservative (Zhang et al., 2024). Glycerin acts as a plasticizer, imparting elasticity to the fishing nets and preventing them from breaking easily (Goudali et al., 2025).The combination of these four natural compounds can produce an environmentally friendly biopolymer solution with enhanced characteristics. Carboxymethyl cellulose and glycerin contribute to improved flexibility, while sodium alginate and calcium lactate enhance water resistance, ensuring that the biopolymer coating remains stable under aquatic conditions. Therefore, fishing nets fabricated using this combination of biopolymers are expected to exhibit superior flexibility and durability compared to those utilizing a single biopolymer.

Based on the aforementioned background, this study aims to develop biodegradable fishing nets derived from pineapple leaf fibers that possess adequate strength, are readily degradable, and exhibit physical properties comparable to conventional synthetic nets. Through this research, it is expected to generate an innovation that not only provides a solution to reduce microplastic pollution in aquatic ecosystems but also supports sustainable fisheries practices.

RESEARCH METHODS

This study employed a Research and Development (R&D) approach aimed at producing a biodegradable fishing net derived from pineapple leaf fibers (Ananas comosus) coated with a biopolymer. The initial product draft utilized pineapple leaf fibers as the primary material. The research was conducted over a period of two months, from August to September 2025, and took place in the Chemistry and Physics Laboratories of SMA Unggulan Rushd.

The main material used in this study was pineapple leaf fiber. In the coating process, a biopolymer solution was formulated using 2 g of sodium alginate and 2 g of carboxymethyl cellulose (CMC) dissolved in 250 mL of distilled water, with the addition of 3 mL of glycerin as a plasticizer. Additionally, 3 g of calcium lactate, prepared in a separate solution, was used as a crosslinking agent. The formulation of this biopolymer solution represents a preliminary approach that has not been previously investigated, and thus its results may serve as a reference for future studies. The equipment utilized in this research included plastic containers, measuring instruments, beakers, stirrers, and an analytical balance.



Source: Processed Primary Data, (2025)

Figure 1

Research Procedure Flowchart

In the fabrication of biodegradable fishing nets, the initial stage involves twisting pineapple leaf fibers. A total of 15–20 fibers are twisted using a single-twist technique to form threads with a length of 40–60 cm and an initial diameter of 0.04–0.05 cm. The process of converting fibers into threads is carried out manually using a combination of S- and Z-twist directions. This combined S–Z twist is selected to produce threads with uniform bonding and enhanced structural strength (Thahir et al., 2017). After the twisting process, the diameter of the fiber threads increases to approximately 0.2 cm, with an average length of 25 cm.

The twisted yarn is then given a biopolymer coating process. Preparation begins by providing plastic containers that have been sterilized using distilled water. The threads are immersed in a homogeneous solution of sodium alginate, carboxymethyl cellulose, and glycerin dissolved in distilled water. Thereafter, the threads are immersed in a calcium lactate solution prepared separately in distilled water. This crosslinking step is intended to strengthen the structure of the biopolymer coating. Following the immersion process, the threads are dried under sunlight for 4 hours. Subsequently, the threads are manually woven into fishing nets measuring 10 × 10 cm with a mesh size of 1 cm.

The subsequent stage involves testing the moisture content and density of pineapple leaf fibers. These tests are conducted by first determining the initial mass of fiber threads with an average length of 10 cm and a diameter of 0.2 cm. This study evaluates the moisture content and density using three samples of pineapple leaf fiber threads. The test samples are weighed using an analytical balance. The volume of each thread is determined by measuring its length and radius to obtain its volume in cm³. Next, the dry mass of the test samples is determined by drying the fibers in an electric oven at a temperature of 100–105°C for 5 hours, followed by weighing.

The moisture content of the test samples is then analyzed using the formula as applied by Fathoni & Rohmawati (2023):

$$MC = (m_i - m_{od})/mk \; x \; 100 \qquad (1)$$

MC represents the moisture content (%), m_i denotes the initial mass (g), and m_{od} refers to the oven-dry mass (g). The density of the test sample is analyzed using the following formula:

$$\rho = m/v \qquad (2)$$

In this equation, ρ represents density, m denotes the mass of the pineapple leaf fiber (g), and V refers to the volume (cm³).

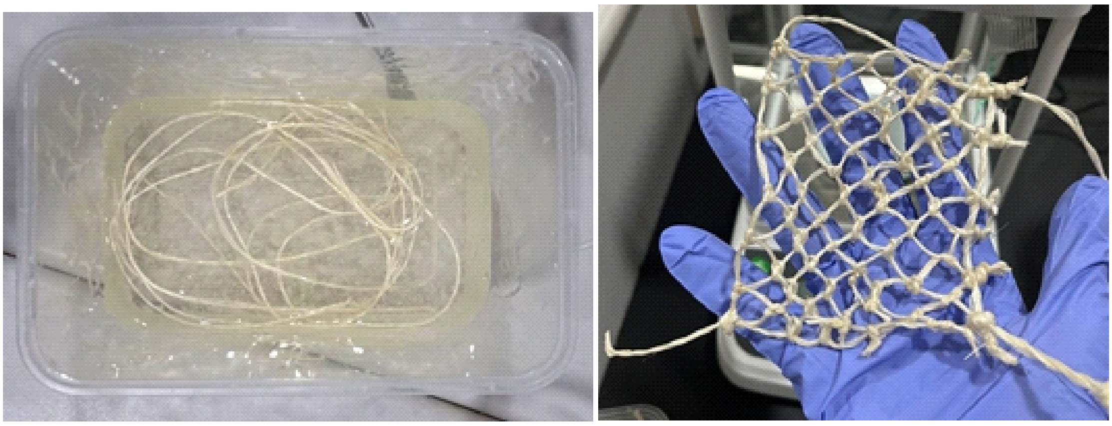
The subsequent test conducted in this study is the biodegradability test. This test is performed to determine the rate at which biodegradable fishing nets can be decomposed by microorganisms in the environment. The method employed is the soil burial test, which involves burying the samples in pots containing soil. This method is selected because microorganisms that act as natural decomposers are readily found in soil. In this study, the samples used were biodegradable fishing nets measuring 10 × 10 cm with a diameter of 0.2 cm. The biodegradation test was carried out by calculating the percentage of mass loss of the samples to evaluate the rate of decomposition in soil over a period of one month.

This study also evaluates the compressive strength of fishing nets made from pineapple fiber. The compressive strength test is conducted to determine the maximum force that the biodegradable fishing net can withstand before failure. The method employed is a compression test, which measures the magnitude of force sustained by biodegradable fishing nets measuring 10 × 10 cm with a diameter of 0.2 cm by incrementally adding loads during the testing process (Mainnah et al., 2016).

The biodegradability test is analyzed using the following formula:

$$MDP = (W_0 - W_1)/W_1 \; x \; 100 \qquad (3)$$

Where MDP is mass degradation percentage, W_0 represents the initial weight (g) and W_1 represents the final weight (g).



Source: Processed Primary Data, (2025)

Figure 2

Fabrication Results of Pineapple Leaf Fiber-Based Fishing Nets

RESULTS AND DISCUSSION

The results of this study indicate that pineapple leaf fibers can be processed into fishing nets with a mesh size of 1 cm and dimensions of 10 × 10 cm. The fabrication process was carried out in accordance with the procedures described in the research methodology. Figure 2 presents two images: the first illustrates the soaking process of pineapple leaf fibers, while the second shows the prototype fishing net produced from pineapple leaf fibers.

The resulting pineapple fiber nets exhibit a physical form similar to conventional fishing nets, although with a slightly coarser texture and the natural color of the fibers. This demonstrates that pineapple leaf fibers have strong potential to be applied as an environmentally friendly alternative to conventional fishing nets.

Physical Property Testing

The moisture content values of the test threads ranged from 10.28% to 11.11%, with an average value of 10.66%. The results of the moisture content test are presented in Table 1. The moisture content of the biopolymer-coated threads is relatively stable. These values fall within the range of natural pineapple fiber moisture content reported by Mainnah et al. (2023), which is 4.5455%–13.7931%. This indicates that the biopolymer coating process does not significantly alter the moisture content of pineapple fibers, but rather maintains it within a reasonable range. Moisture content is an important parameter as it influences the adhesion of the applied biopolymer. The inherent moisture in the fibers affects how the biopolymer interacts with the fiber surface (Dargaville & Hutmacher, 2022). This, in turn, impacts the absorption capacity of the fibers toward the biopolymer substances. Excessively high moisture content may promote fungal growth and reduce fiber strength, whereas excessively low moisture content can make the fibers

Table 1

Physical Properties of Pineapple Leaf Fiber Threads

Samp le	Initial Mass (g)	Dry Mass (g)	Volume (cm^3)	Moisture Conte nt (%)	Den sity (g/cm^3)
1	0.167	0.151	0.314	10.60	0.532
2	0.236	0.214	0.383	10.28	0.616
3	0.220	0.198	0.346	11.11	0.636
Average	0.208	0.188	0.348	10.66	0.595

Source: Processed Primary Data, (2025)

stiff and brittle (Fu et al., 2024). The moisture content values of the test threads in this study are considered stable. This condition supports their potential as a base material for biodegradable fishing nets, as stable moisture content helps maintain fiber flexibility while allowing natural degradation in aquatic environments.

The density values of the test threads ranged from 0.532 to 0.875 g/cm^3, with an average of 0.681 g/cm^3. The results of the density test are presented in Table 1. Based on data from the Food and Agriculture Organization (FAO), the density of synthetic nylon threads is approximately 1.14 g/cm^3. Therefore, the density of the test threads in this study is relatively lower than that of synthetic nylon threads. A lower density is associated with lighter thread properties, resulting in fishing nets that have a slower sinking rate. The behavior of the test threads in water can be analyzed based on Archimedes' principle. If the density of an object is greater than that of water, it will sink; if it is lower, it will float; and if it is equal, it will remain suspended. Based on the density values obtained in this study, the test threads tend to float in both freshwater (0.681 < 1.00) and seawater (0.681 < 1.025). Therefore, in practical applications, additional weights are required for the fishing nets to achieve functionality comparable to nylon nets. According to Abesho et al. (2025), the density of untreated pineapple fiber is 1.526 g/cm^3, whereas the density obtained in this study after treatment is 0.681 g/cm^3. This decrease in density may be attributed to the biopolymer coating, which creates inter-fiber spaces and consequently reduces the overall density (Liang et al., 2025). Although the formation of inter-fiber spaces reduces fiber compactness, the distribution of the biopolymer layer on the fiber surface results in a more uniform structure. This indicates that the addition of the biopolymer coating does not drastically alter the inherent properties of pineapple fibers, but rather enhances their homogeneity and inter-fiber bonding.

There are slight changes in the physical properties of the test threads that can be observed visually. This is due to the relatively small thread diameter of 0.2 cm. The observable changes include a smoother texture and reduced stiffness, while the color of the test threads does not exhibit any significant alteration.

Biodegradation Test Analysis

This study evaluates the biodegradation properties of fishing nets made from pineapple leaf fibers by burying both biopolymer-coated and uncoated pineapple fiber nets, measuring 12 × 2 cm, in soil-filled pots at a depth of 5 cm for a period of 4 weeks. The purpose of the biodegradation test is to assess the resistance of the bioplastic material to soil temperature, moisture, decomposing microorganisms, and other physico-chemical factors (Suryati et al., 2016). The biodegradation test is conducted in soil to utilize the activity of microorganisms such as bacteria and fungi in facilitating the degradation process. The biodegradation performance is evaluated by measuring the reduction in mass of the pineapple fiber nets before and after burial for 4 weeks (Mufida & Sigiro, 2024; Rizqia et al., 2022).

Source: Processed Primary Data, (2025)

Figure 3

Biodegradability Test

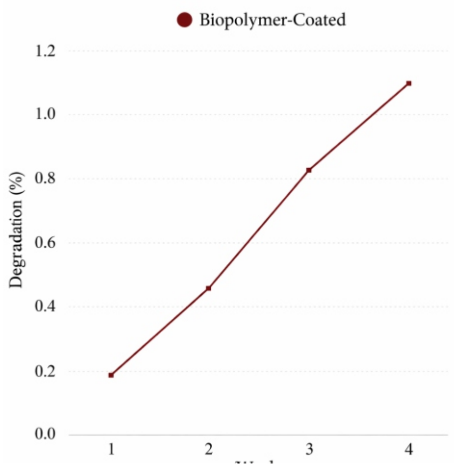
Based on the results of the biodegradation test presented in Table 2, the biopolymer-coated pineapple leaf fiber fishing nets exhibit an increasing percentage of degradation over time. The degradation rate shown in Figure 4 is

Table 2
Results of Biodegradation Test of Pineapple Leaf Fiber-Based Fishing Nets (After Biopolymer Coating)

Time	Initial weight (g)	Final weight (g)	MDP
Week 1	11.00	10.98	0.18%
Week 2	11.00	10.95	0.45%
Week 3	11.00	10.91	0.82%
Week 4	11.00	10.88	1.09%

Source: Processed Primary Data, (2025)

relatively slow, indicating that the biopolymer coating is effective in delaying the degradation process, thereby allowing the fishing nets to be used for a longer period. In comparison with the study by Ahmad (2025), it was reported that without chitosan, the degradation percentage was 0%, while a chitosan concentration of 0.5% resulted in the highest degradation percentage of 5%. In contrast, concentrations of 0.25% and 0.75% yielded negative degradation percentages of −3% and −1%, respectively. This suggests a slight increase in mass during the testing process at those concentrations. These findings indicate that chitosan influences the degradation rate inconsistently. Based on the comparison of these two studies, it can be concluded that pineapple leaf fiber fishing nets coated with a combination of biopolymers demonstrate superior performance in consistently controlling the degradation process and enhancing the durability of the nets during use.



Source: Processed Primary Data, (2025)

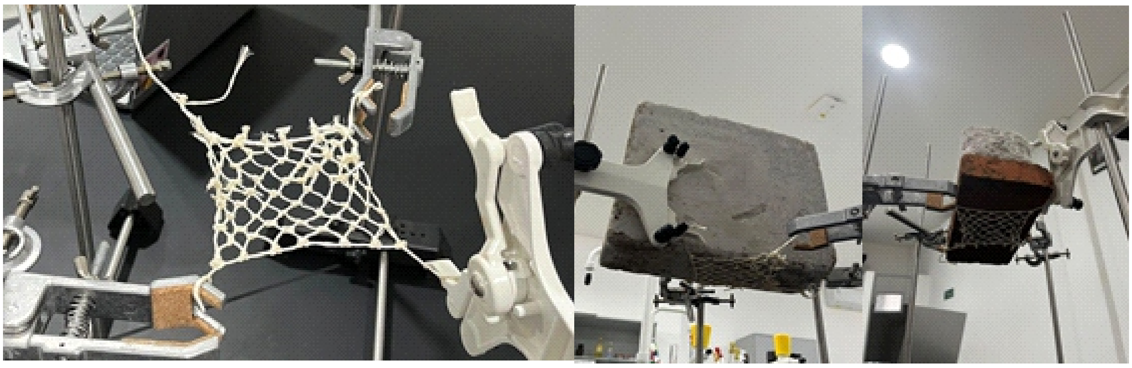
Figure 4
Degradation Rate of Pineapple Leaf Fiber-Based Fishing Nets as a Function of Time

Compressive Strength Test Analysis

This study evaluates the compressive strength of fishing nets made from pineapple leaf fibers measuring 10 × 10 cm under applied loads. The compressive strength test is conducted to determine the maximum strength that the pineapple leaf fiber nets can withstand, considering the effect of daily immersion treatment. The test is carried out over a period of 4 weeks by placing loads on the pineapple leaf fiber fishing nets (10 × 10 cm) until failure occurs.

Based on the results of the compressive strength test presented in Table 3, it can be observed that pineapple leaf fiber-based fishing nets measuring 10 × 10 cm with a diameter of 0.2 cm are capable of withstanding loads ranging from 18.5 to 20 kg. These values are relatively high and remain stable up to the fourth week, with only a slight decrease of approximately 0% to 7.5%. In comparison with the study by Mainnah et al. (2016), the average tensile strength of pineapple leaf fibers was reported to be approximately 1.018–1.825 kg/mm^2, with testing conducted only on individual fibers. This indicates that when pineapple leaf fibers are twisted and woven into a net structure, the maximum load-bearing capacity of the fishing net becomes greater than that of individual fiber testing reported in previous studies. These findings demonstrate that the pineapple leaf fiber-based fishing net prototype has strong potential as an alternative to synthetic fishing nets.

Based on the results of the compressive strength test presented in Table 3, it can be observed that the fishing nets experience a decrease in strength with

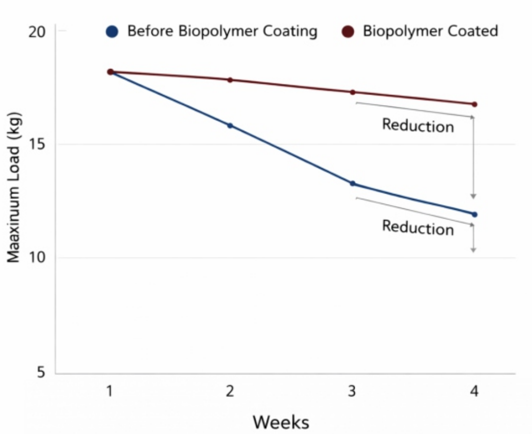


Source: Processed Primary Data, (2025)
Figure 5
Proses Uji Kuat Tekan

increasing immersion time. The uncoated fishing nets show a significant reduction in maximum load, decreasing from 20 kg in the first week to 13 kg in the fourth week, representing a 35% decline. In contrast, the biopolymer-coated nets are able to better maintain their strength, with the maximum load decreasing only from 20 kg to 18.5 kg, corresponding to a 7.5% reduction over the same period. This indicates that the biopolymer coating provides protection against the degradation of pineapple leaf fibers, thereby enhancing the nets' resistance to compressive loads and improving their overall durability compared to uncoated fishing nets.

CONCLUSION

Pineapple leaf fibers demonstrate strong potential as an environmentally friendly alternative material for fishing nets. The nets produced from pineapple leaf fibers are capable of withstanding loads of up to 20 kg. The coating of pineapple leaf fibers with a biopolymer solution composed of carboxymethyl cellulose (CMC), sodium alginate, calcium lactate, and glycerin has been proven to slow the degradation rate, allowing the nets to be used for a relatively longer period. In addition, immersion in the biopolymer solution



Source: Processed Primary Data, (2025)
Figure 6
Graph of the Comparison of Mechanical Strength Reduction of Pineapple Leaf Fiber Fishing Nets Before and After Biopolymer Coating Over 4 Weeks

Table 3
Compressive Strength Results of Biopolymer-Coated Pineapple Leaf Fiber Fishing Nets

Time	Maxim um Load Before Coating (kg)	Reduction (%)	Maxim um Load After Coating (kg)	Reduction (%)
Week 1	20.0	0%	20.0	0%
Week 2	17.5	12.5%	19.5	2.5%
Week 3	15.0	25.0%	19.0	5.0%
Week 4	13.0	35.0%	18.5	7.5%

Source: Processed Primary Data, (2025)

enhances the mechanical strength of pineapple leaf fiber-based fishing nets. These results indicate that the biodegradable fishing net prototype developed from pineapple leaf fibers possesses adequate strength, is biodegradable, and exhibits physical properties comparable to conventional synthetic nets. For large-scale implementation, further field testing is required to evaluate the durability of the nets under real aquatic conditions, including the effects of water currents and interactions with aquatic organisms.

REFERENCES

Abesho, K. W., Jiru, M. G., Lemu, H. G., & Alfeki, M. A. (2025). Study of Mechanical and Physical Properties of Pineapple Leaf Fiber and Coffee Husk Filler Reinforced Polymer Composite Using Response Surface Method. *Polymer Testing*, *150*, 1–28. https://www.sciencedirect.com/science/article/pii/S0142941825002296

Ahmad, L. (2025). Pengaruh Variasi Kitosan Terhadap Sifat Biodegradable Kertas dari Daun Nanas. *Jurnal Teknologi Kimia*, *14*(1). https://doi.org/10.29103/jtku.v14i1.21764

Akhtar, H. M. S., Ahmed, S., Olewnik-Kruszkowska, E., Gierszewska, M., Brzezinska, M. S., Dembińska, K., & Kalwasińska, A. (2023). Carboxymethyl Cellulose Based Films Enriched with Polysaccharides from Mulberry Leaves (Morus alba L.) as New Biodegradable Packaging Material. *International Journal of Biological Macromolecules*, *253*(8). https://www.sciencedirect.com/science/article/abs/pii/S0141813023045312

Baranwal, J., Barse, B., Fais, A., Delogu, G. L., & Kumar, A. (2022). Biopolymer : A Sustainable Material for Food and Medical Applications. *Polymers*, *14*(983),1–22.https://www.mdpi.com/2073-4360/14/5/983

Dargaville, B. L., & Hutmacher, D. W. (2022). Water as the Often Neglected Medium at the Interface between Materials and Biology. *Nature Communications*, *13*, 1–10. https://doi.org/10.1038/s41467-022-31889-x

Fathoni, N., & Rohmawati, L. (2023). Sifat Fisik dan Mekanik Komposit Berpenguat Serat Alami. *IFI: Inovasi Fisika Indonesia*, *12*(3), 63–69. https://ejournal.unesa.ac.id/index.php/inovasi-fisika-indonesia/article/view/54446

Feng, S., Tang, Q., Xu, Z., Huang, K., Li, H., & Zou, Z. (2023). Development of Novel Co-MOF Loaded Sodium Alginate Based Packaging Films with Antimicrobial and Ammonia-sensitive Functions for Shrimp Freshness Monitoring. *Food Hydrocolloids*, *135*. https://www.sciencedirect.com/science/article/abs/pii/S0268005X22007135

Fu, Z., Zhao, T., Wang, H., Wei, J., Liu, H., Duan, L., Wang, Y., & Yan, R. (2024). Study on the Mechanism and Law of Temperature, Humidity and Moisture Content on the Mechanical Properties of Molded Fiber Products. *Journal of Bioresources and Bioproducts*, *9* (April), 351–368. https://www.sciencedirect.com/science/article/pii/S2369969824000355

Goudali, L., Belouaggadia, N., Nagoor, B. S., Zamma, A., & Elfarissi, L. (2025). Innovative Whey Protein Isolate-based Biopolymer Film with Glycerol for Sustainable Food Packaging Applications. *Hybrid Advances*, *11* (Desember). https://www.sciencedirect.com/science/article/pii/S2773207X25001435

Liang, Z., Yan, C., Cao, Y., Shi, Y., Bao, H., & Li, H. (2025). Influence of Dry-wet Cycles on the Strength Behavior of Biopolymer and Fiber Composite Modified Loess.

Journal of Materials Research and Technology, *37*(May), 4800–4813.https://www.sciencedirect.com/science/article/pii/S2238785425017284

Mainnah, M., Diniah, & Iskandar, B. H. (2016). Perpaduan Serat Daun Nanas (Ananas Comosus) dan Kitosan Sebagai Material Alat Penangkapan Ikan Ramah Lingkungan. *Marine Fisheries*, *7*(2), 149–159. https://jurnal.utu.ac.id/jptropis/article/view/59

Mainnah, M., Jaya, M. M., & Iskandar, B. H. (2023). Pengaruh Perendaman Kitosan Terhadap Sifat Fisik dan Kekuatan Putus serta Kemuluran Tali Serat Daun Nanas untuk Material Alat Penangkap Ikan. *Jurnal Perikanan*, *13*(1), 244–253. http://doi.org/10.29303/jp.v13i1.468

Mufida, I., & Sigiro, O. N. (2024). Analisis Biodegradasi dan Ketahanan Air pada Plastik Biodegradable dari Kulit Singkong dengan Variasi Selulosa Serat Daun Nanas. *Journal of Food Security and Agroindustry*, 2(2), 61–68.https://pakisjournal.com/index.php/jfsa/article/view/357

Rahman, S., Konwar, A., Gurumayam, S., Borah, J. C., & Chowdhury, D. (2025). Sodium Alginate-chitosan-starch Based Glue Formulation for Sealing Biopolymer Films. *Next Materials*, *7*. https://www.sciencedirect.com/science/article/pii/S2949822825000255

Richardson, K., Gunn, R., Wilcox, C., & Hardesty, B. D. (2018). Understanding Causes of Gear Loss Provides a Sound Basis for Fisheries Management. *Marine Policy*, *96*(March), 278–284. https://doi.org/10.1016/j.marpol.2018.02.021

Rizqia, N., Rahayu, S., Sahda, N. T., & Sukreni, T. (2022). Pemanfaatan Alga Coklat Sargassum sp pada Pembuatan Kemasan Air Mineral yang Dapat Dikonsumsi. *Jurnal Jaring SainTek (JJST)*, *4*(1), 21–30. https://ejurnal.ubharajaya.ac.id/index.php/jaring-saintek/article/view/1912

Sharma, S., Sharma, V., & Chatterjee, S. (2021). Microplastics in the Mediterranean Sea: Sources, Pollution Intensity, Sea Health, and Regulatory Policies. *Frontier in Marine Science*, *8*(May), 1–15. https://doi.org/10.3389/fmars.2021.634934

Sun, J., Zheng, H., Xiang, H., Fan, J., & Jiang, H. (2022). The Surface Degradation and Release of Microplastics from Plastic Films Studied by UV Radiation and Mechanical Abrasion. *Science of the Total Environment*, *838*(3). https://www.sciencedirect.com/science/article/abs/pii/S0048969722034660

Suryati, S., Meriatna, M., & Marlina, M. (2016). Optimasi Proses Pembuatan Bioplastik dari Pati Limbah Kulit Singkong. *Jurnal Teknologi Kimia*, *5*(1),78.https://ojs.unimal.ac.id/jtk/article/view/81

Thahir, M. A., Syofyan, I., & Isnaniah. (2017). Pengujian Sinking Speed Serat Alami. *Jurnal Perikanan Tropis*, *4*(1),93–100.https://jurnal.utu.ac.id/jptropis/article/view/59

Zhang, Y., Kong, Q., Niu, B., Liu, R., Chen, H., Xiao, S., Wu, W., Zhang, W., & Gao, H. (2024). The Dual Function of Calcium Ion in Fruit Edible Coating: Regulating Polymer Internal Crosslinking State and Improving Fruit Postharvest Quality. *Food Chemistry*, *447*(Juli). https://www.sciencedirect.com/science/article/abs/pii/S0308814624006010