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Effect of Dip-Coating Immersion Time of Mangosteen Peel Extract on Alginate/Banana Fiber Biopolymer as a Biodegradable Antibacterial Absorbent Material

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Abstract

The increasing use of synthetic superabsorbent polymers in hygiene products has raised environmental and health concerns due to their non-biodegradable nature and potential chemical residues. This study investigated the effect of dip-coating immersion time on the physical, antibacterial, and biodegradable properties of an alginate/banana fiber biopolymer incorporated with mangosteen peel extract. The biopolymer films were prepared using sodium alginate and banana fiber obtained from the banana pseudostem at ratios of 10/90, 30/70, and 50/50, with untreated samples used as the control and coated samples treated with 15% mangosteen peel extract for 30, 60, and 90 minutes. The films were characterized by liquid absorption capacity, antibacterial activity against *Staphylococcus aureus*, biodegradability through the soil burial method, and FTIR analysis. The results showed that the 50/50 alginate/banana fiber ratio exhibited the highest absorption capacity among the coated samples at 90 minutes, reaching 5.88 times its initial weight. However, the absorption capacity did not fulfill the SNI standard. In contrast, the highest antibacterial activity was obtained at 30 minutes of immersion, with an inhibition zone of 9.3 mm against *S. aureus*. Biodegradation testing confirmed that the biofilms were degradable in soil, while FTIR analysis revealed characteristic functional groups and indicated physical interactions between the biopolymer components and mangosteen peel extract. Overall, the developed biofilm demonstrates potential as a biodegradable antibacterial absorbent material.

Keywords: Alginate, Banana fiber, Mangosteen peel extract, Dip-coating, Antibacterial

INTRODUCTION

The widespread use of synthetic superabsorbent polymers (SAPs) in hygiene products has attracted attention regarding environmental sustainability due to their poor biodegradability and resulting environmental impact. In addition, concerns have been raised regarding their potential effect on human reproductive health. Several synthetic polymer-based hygiene products have been reported to contain residues of hazardous chemicals, including chlorine-derived compounds, dioxins, and other synthetic additives, which may contribute to skin irritation, microflora imbalance, and reproductive health problems following prolonged exposure (Sadaf et al., 2025; Ketema & Worku, 2020).

These environmental and health concerns have increased interest in the development of safer absorbent materials from renewable resources. In this context, natural biopolymers have attracted considerable attention due to their biodegradability, good biocompatibility, and lower environmental impact. Among them, sodium alginate is widely applied because of its hydrophilic properties, good film-forming ability, and biocompatibility (Fan, 2023). Alginate-based films have been developed for various applications, including biomedical, packaging, and absorbent materials. However, pure alginate films generally have limited mechanical stability and strength, which may restrict their application in hygienic materials. Previous studies have shown that alginate-based biopolymer films combined with natural extracts can exhibit improved functional properties and hold potential for various applications (Riyandari & Multazam, 2023; Rahayu et al., 2024). Therefore, reinforcing agents are needed to enhance the structural stability and functional performance of alginate-based films.

Banana fiber is a lignocellulosic material with high cellulose content, biodegradability, and abundant availability as an agricultural waste resource

(Büyüküstün et al., 2020). Previous studies have reported the potential of banana-derived fibers as reinforcement in composite materials due to their ability to improve material properties. However, studies focusing on alginate-based absorbent biofilms reinforced with banana fiber for hygiene-related applications remain limited.

In addition to physical properties, biological safety is an important consideration for materials intended for hygienic applications. Mangosteen peel extract (*Garcinia mangostana* L.) contains bioactive compounds that exhibit antibacterial activity against *Staphylococcus aureus* (Indrianingsih et al., 2021; Poeloengan & Praptiwi, 2010). Similarly, various natural plant extracts, such as pineapple peel, nutmeg leaves, and *Lannea coromandelica*, have been reported to exhibit antibacterial activity against *Staphylococcus aureus*, demonstrating the potential of plant-derived bioactive compounds as natural antibacterial agents (Ramadani et al., 2022; Kapelle et al., 2022; Syamsurya et al., 2016). Consequently, the incorporation of natural antibacterial agents into a biopolymer matrix may enhance the protective function of absorbent materials while utilizing bioactive compounds derived from renewable resources. Furthermore, dip-coating is a simple and effective technique for depositing active compounds onto the surface of biopolymer materials. The duration of immersion during the dip-coating process can influence the amount and distribution of active compounds deposited, as well as their interaction with the polymer matrix, thereby affecting the functional properties of the resulting biofilm (Pawar et al., 2024).

Therefore, this study aims to investigate the effect of dip-coating immersion time on the absorption capacity, antibacterial activity, functional groups, and biodegradability of sodium alginate/banana fiber biopolymer films incorporated with 15% mangosteen peel extract as a biodegradable antibacterial absorbent material.

METHODOLOGY

Materials and Instruments

The materials used in this study were banana fiber obtained from the banana pseudostem as a natural reinforcing material, sodium alginate as a biopolymer matrix, and mangosteen peel extract (*Garcinia mangostana* L.) as a natural antibacterial agent. Carboxymethyl cellulose (CMC), glycerol, and citric acid were used as additives in the preparation of the biopolymer film. Antibacterial activity was evaluated against *Staphylococcus aureus* using the disc diffusion method.

Crosslinking was carried out through chemical and physical interactions: CMC served to strengthen the film structure, glycerol acted as a plasticizer to increase flexibility, and citric acid acted as an additional crosslinking agent that formed ester bonds with the hydroxyl groups in sodium alginate and CMC. This combination produced a biopolymer film that was mechanically stable while remaining biodegradable.

The equipment used included an analytical balance, magnetic stirrer, beaker, measuring cup, stirring rod, and hot plate. The dip-coating process was carried out using several beakers and sample clamps. Antibacterial activity testing was carried out using microbiology laboratory equipment such as Petri dishes, incubators, autoclaves, and laminar airflow. The inhibition zone was measured using a vernier caliper or digital ruler.

Methods

Material Preparation

Banana fiber obtained from the banana pseudostem was used as a natural reinforcing material, while sodium alginate was used as the biopolymer matrix. The banana fiber was first subjected to an alkaline treatment using 10% NaOH solution at a material-to-solution ratio of 1:7 (w/v). After the alkaline treatment, the fiber was cleaned and dried before being cut into approximately ±1-inch pieces. The prepared banana fiber was then incorporated into the sodium alginate solution at alginate-to-banana fiber ratios of 10/90, 30/70, and 50/50 (w/w).

Mangosteen peel extract was prepared by maceration using 96% ethanol as the extraction solvent. Dried mangosteen peel powder was extracted using 700 mL of 96% ethanol at a material-to-solvent ratio of 1:7 (w/v). The maceration process was conducted at room temperature for 3 × 24 h with occasional stirring to facilitate the extraction of bioactive compounds. The resulting extract was filtered, and the solvent was subsequently evaporated to obtain a concentrated mangosteen peel extract. The extract was then incorporated into the biopolymer system at a concentration of 15% (w/v) (Fitriana et al., 2024). Carboxymethyl cellulose (CMC), glycerol, and citric acid were added during the crosslinking process. The mixture was stirred using a magnetic stirrer until homogeneous before biofilm formation.

Liquid Absorption Testing *(In Vitro)*

The absorption capacity of the biofilm was evaluated according to SNI 16-6363-2000 and the method reported by Miraningtyas et al. (2024), with a minimum absorption requirement of ≥ 10 times the initial weight. The samples were cut into 2.5 × 8 cm

and weighed to obtain the initial weight (W_0). Each sample was placed on a dressing layer, followed by the gradual addition of artificial blood until no further absorption occurred. After approximately 1 min, the samples were reweighed to obtain the final weight (W_t), and the absorption capacity was subsequently calculated.

Antibacterial Biopolymer Film Production

The solution was poured on a flat casting mold and dried to form a biofilm. The resulting dry biofilm was then treated using the dip-coating method with mangosteen peel extract solution following the method reported by Abdurrohman et al. (2025). The immersion times were varied at 30, 60, and 90 min, followed by oven drying.

Antibacterial Activity Test

Antibacterial activity against *Staphylococcus aureus* was evaluated using the disc diffusion method on agar media. The biofilm samples were cut into circular shapes and placed on agar plates inoculated with the test bacteria, followed by incubation at 37°C for 24 hours. The diameter of the inhibition zone formed around the samples was measured using a vernier caliper or digital ruler (Pratiwi, 2008).

Fourier Transform Infrared (FTIR) Spectroscopy

The functional groups of the samples were analyzed using an Attenuated Total Reflectance (ATR) FTIR spectrometer (Nicolet™ iS™ 5). The samples were measured over a wavenumber range of 4000–500 cm^{-1}.

Biodegradability Testing

The biodegradability of the biofilm was tested using the soil burial method. The biofilm samples were buried in moist soil containing EM4 fertilizer for two weeks. After the burial period, the samples were removed, dried, and weighed to determine the difference between the initial and final masses, which was used to calculate the percentage of degradation.

Data Analysis

The data obtained from testing absorption capacity, antibacterial activity, and biodegradability were analyzed quantitatively. The absorption capacity was determined from the ratio between the sample weight after liquid absorption and its initial weight using the Equation:

$$Absorption\ Capacity = \frac{W1}{W0} \quad (1)$$

where W_0 represents the initial sample weight (g), and W_1 represents the sample weight after absorbing artificial blood (g).

Antibacterial activity was evaluated based on the diameter of the inhibition zone formed around the sample on agar medium and measured in millimeters (mm).

The mass loss of the biofilm samples was determined from the reduction in sample weight after the soil burial test using the following Equation:

$$Mass\ Loss\ (\%) = \left[\frac{W_0 - W_1}{W_0}\right] \times 100\% \quad (2)$$

where W_0 is the initial weight of the sample before burial (g), and W_1 is the final weight of the sample after soil burial and drying (g). The final weight (W_1) was expected to be lower than the initial weight (W_0) due to the degradation and loss of biodegradable components during the soil burial process.

All experiments were conducted in triplicate (n = 3), and the results are presented as mean ± standard deviation (SD). Statistical analysis of the absorption capacity was performed using two-way analysis of variance (ANOVA) at a 95% confidence level (α = 0.05) to determine the effects of the alginate/banana fiber ratio, dip-coating immersion time, and their interaction. When significant effects were observed, Tukey's honestly significant difference (HSD) post hoc test was performed for pairwise comparisons.

RESULTS AND DISCUSSION

Liquid Absorption Testing *(In Vitro)*

The absorption capacity of the biofilms treated with 15% mangosteen peel extract varied depending on the alginate/banana fiber biopolymer ratio (Figure 1). In addition, the dip-coating immersion time influenced the absorption performance of the resulting material. A dip-coating time of 0 min was used as the control (without dip-coating treatment). At the 10/90 alginate/banana fiber ratio, the absorption capacities were 3.75, 3.24, 4.18, and 4.49 times the initial weight at immersion times of 0, 30, 60, and 90 min, respectively. These values were lower than those observed for the other composition ratios, which may be attributed to differences in matrix structure and pore development that influenced liquid uptake and swelling behavior.

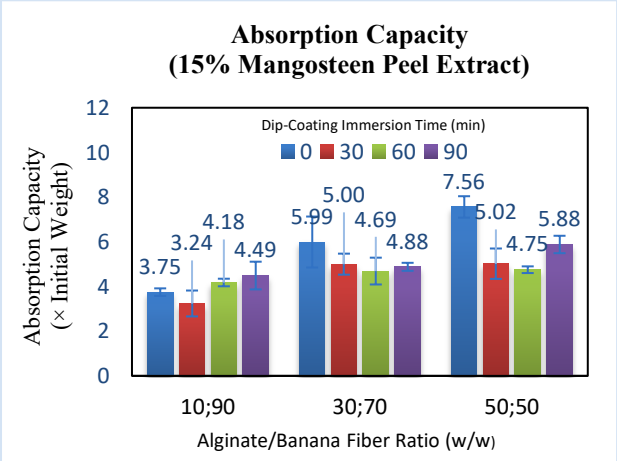

Figure 1. Absorption capacity of the biofilms incorporated with 15% mangosteen peel extract at different alginate/banana fiber ratios and dip-coating immersion times. Data are presented as mean ± standard deviation (SD), n = 3.

The 30/70 alginate/banana fiber ratio exhibited absorption capacities of 5.99, 5.00, 4.69, and 4.88 times the initial weight at immersion times of 0, 30, 60, and 90 min, respectively. The relatively higher absorption capacity compared with the 10/90 ratio may be associated with differences in the alginate/fiber composition and the resulting biofilm structure, which may provide more accessible pathways for liquid penetration. However, the dip-coating treatment generally reduced the absorption performance, likely due to the deposition of mangosteen peel extract on the biofilm surface and partial obstruction of liquid-accessible pores.

The highest numerical absorption capacity was observed at the 50/50 alginate/banana fiber ratio, with absorption capacities of 7.56, 5.02, 4.75, and 5.88 times the initial weight at immersion times of 0, 30, 60, and 90 min, respectively. The balanced proportion of alginate and banana fiber may have contributed to a biofilm structure with more favorable pathways for liquid penetration and swelling. Although the dip-coating treatment reduced the absorption capacity compared with the untreated control, the increase observed at 90 min compared with 30 and 60 min suggests that the deposited extract layer did not completely hinder liquid diffusion through the biofilm structure. Overall, the absorption capacity was lower after dip-coating than in the untreated control for all composition ratios. These results indicate that the dip-coating treatment affects the internal structure of the biofilm in addition to forming a coating layer on its surface. The surface characteristics of the biofilm, particularly its hydrophilicity or hydrophobicity, can influence liquid wettability and penetration into the material. A hydrophilic surface generally facilitates liquid spreading and penetration, whereas a hydrophobic surface tends to hinder liquid uptake. Therefore, the deposition of mangosteen peel extract on the biofilm surface may alter its surface characteristics and consequently contribute to the observed changes in absorption performance.

Two-way analysis of variance (ANOVA) showed that the alginate/banana fiber ratio, dip-coating immersion time, and their interaction significantly affected the absorption capacity, with p-values of 4.40×10^{-8}, 4.72×10^{-5}, and 0.000937, respectively. The significant interaction between the alginate/banana fiber ratio and immersion time indicates that the effect of dip-coating immersion time on absorption capacity depended on the alginate/banana fiber ratio.

Compared with the requirements of SNI 16-6363-2000, which specifies a minimum absorption capacity of 10 times the initial weight, the highest value obtained in this study (7.56 times the initial weight) did not meet the standard. Nevertheless, the material evaluated in this study consisted of a single-layer biofilm rather than the multilayer structure commonly used in commercial absorbent products. These findings indicate the potential for further development through structural and formulation optimization to improve liquid absorption performance.

Antibacterial Activity Test

The antibacterial activity of the alginate/banana fiber biofilm against *Staphylococcus aureus* was evaluated using the disc diffusion method at dip-coating immersion times of 30, 60, and 90 min. *S.*

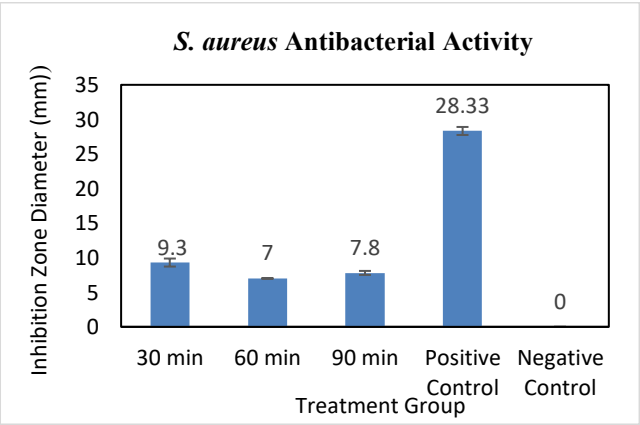

Figure 2. Antibacterial activity of the biofilms against *Staphylococcus aureus* at different dip-coating immersion times. Data are presented as mean ± standard deviation (SD), n = 3.

aureus was selected as the test microorganism because it is a common pathogenic bacterium associated with skin infections and is widely used to evaluate materials intended for hygiene and healthcare applications (Wijaya et al., 2021).

As shown in Figure 2, the average inhibition zone diameters were 9.3 ± 0.58 mm, 7.0 ± 0 mm, and 7.8 ± 0.29 mm at 30, 60, and 90 min of immersion, respectively. The 0-minute sample was not included in the antibacterial testing. The positive and negative controls showed inhibition zone diameters of 28.33 ± 0.58 mm and 0 mm, respectively. The highest antibacterial activity was obtained at 30 min of immersion, as indicated by the largest inhibition zone diameter. The extension of dip-coating immersion time from 30 to 60 and 90 min resulted in a reduction in antibacterial activity. This behavior may be attributed to the accumulation or agglomeration of mangosteen peel extract components during prolonged immersion, which could result in a less uniform distribution of bioactive compounds within or on the surface of the biofilm. In addition, the biofilm matrix may approach saturation with extract components at longer immersion times, limiting the effective incorporation and subsequent release of additional bioactive compounds. These conditions may reduce the accessibility and diffusion of antibacterial compounds into the agar medium, resulting in a smaller inhibition zone. Based on these results, all biofilm formulations exhibited antibacterial activity against *S. aureus.* Overall, dip-coating immersion time influenced the antibacterial activity of the biofilm, with the 30 min treatment showing the highest inhibition effectiveness.

Fourier Transform Infrared Spectroscopy

FTIR analysis was performed to identify the functional groups in the 50/50 alginate/banana fiber biofilms after treatment with 15% mangosteen peel extract at coating times of 0, 30, 60, and 90 minutes. The spectrum showed an –OH (hydroxyl) absorption band in the 3339–3343 cm^{-1} region originating from cellulose, alginate, and phenolic compounds in mangosteen extract. The width of this band indicated the presence of hydrogen bonds between polymer chains, which contributed to the hydrophilic properties of the biofilm. Aliphatic C–H groups appear at 2933.98 cm^{-1} (60 minutes) and 2927.74 cm^{-1} (90 minutes), while at 0 and 30 minutes they are not clearly detected, possibly due to overlap with the –OH band.

The bands at 1631–1640 cm^{-1} and 1412–1433 cm^{-1} indicate asymmetric and symmetric COO^- stretching vibrations, respectively, which are characteristic of sodium alginate. Aromatic C=C groups are detected at 1598–1606 cm^{-1}, which are associated with phenolic compounds in mangosteen extract. In addition, the phenolic C–O band appears at 1280–1282 cm^{-1}, while the band at 1033–1036 cm^{-1} indicates the presence of C–O–C/C–O alcohol groups from the polysaccharide structure.

Overall, the FTIR spectrum shows that the biofilm functional groups are consistent with the constituent materials. Variations in coating time only cause minor shifts and changes in the intensity of the absorption bands, indicating physical interactions between the mangosteen peel extract and the biopolymer matrix without the formation of new functional groups.

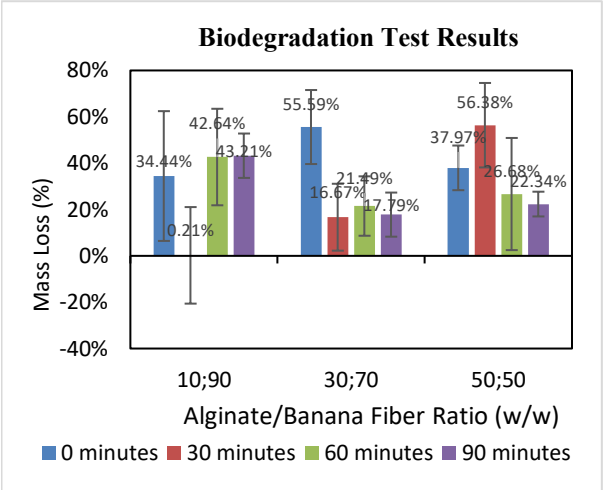

Figure 3. Mass loss of the biofilms after two weeks of soil burial. Data are presented as mean ± standard deviation (SD), n = 3.

Biodegradability Testing

Biodegradation testing was conducted for two weeks using the soil burial method with the addition of EM4 as a source of effective microorganisms, following the method reported by Cut Masyithah & Mariyanti (2024). The biodegradation behavior of the biofilms was evaluated based on the percentage of mass loss before and after soil burial. After two weeks, the biofilm samples were retrieved from the soil, and adhering soil residues were removed. The samples were then dried to remove residual moisture before the final weight (W_1) was measured. The percentage of mass loss was calculated based on the initial weight (W_0) and final weight (W_1) using Equation (2).

Figure 3 presents the biodegradation results of the biofilms after two weeks of soil burial. At the alginate/banana fiber ratios of 10/90, 30/70, and 50/50, the mass loss values at immersion times of 0, 30, 60, and 90 min were 34.44 ± 28.00%, 0.21 ± 20.83%,

42.64 ± 20.82%, and 43.21 ± 9.57%; 55.59 ± 15.97%, 16.67 ± 14.43%, 21.49 ± 12.82%, and 17.79 ± 9.52%; and 37.97 ± 9.64%, 56.38 ± 18.22%, 26.68 ± 24.20%, and 22.34 ± 5.34%, respectively.

Table 1. Initial and final weights and mass loss of biofilms after soil burial

Alginate/Banana Fiber Ratio	Immersion Time (min)	W_0 (g), Mean ± SD	W_1 (g), Mean ± SD	Mass Loss (%), Mean ± SD	n
10/90	0	0.403 ± 0.101	0.247 ± 0.071	34.44 ± 28.00	3
30/70	0	0.270 ± 0.036	0.117 ± 0.029	55.59 ± 15.97	3
50/50	0	0.223 ± 0.060	0.140 ± 0.053	37.97 ± 9.64	3
10/90	30	0.260 ± 0.046	0.247 ± 0.012	0.21 ± 20.83	3
30/70	30	0.077 ± 0.006	0.063 ± 0.006	16.67 ± 14.43	3
50/50	30	0.340 ± 0.151	0.130 ± 0.017	56.38 ± 18.22	3
10/90	60	0.137 ± 0.032	0.077 ± 0.031	42.64 ± 20.82	3
30/70	60	0.273 ± 0.171	0.200 ± 0.087	21.49 ± 12.82	3
50/50	60	0.230 ± 0.115	0.153 ± 0.032	26.68 ± 24.20	3
10/90	90	0.370 ± 0.056	0.207 ± 0.006	43.21 ± 9.57	3
30/70	90	0.157 ± 0.076	0.133 ± 0.006	17.79 ± 9.52	3
50/50	90	0.163 ± 0.084	0.127 ± 0.061	22.34 ± 5.34	3

The results indicate that the mass loss varied with both the alginate/banana fiber ratio and dip-coating immersion time. The highest mass loss was observed at the 50/50 alginate/banana fiber ratio with a 30-min immersion time, reaching 56.38 ± 18.22%, followed by the 30/70 ratio without dip-coating treatment, which showed a mass loss of 55.59 ± 15.97%. In contrast, the lowest mean mass loss was observed at the 10/90 ratio with a 30-min immersion time, at 0.21 ± 20.83%.

The positive mass loss values indicate a reduction in sample mass after soil burial, suggesting that degradation occurred under the tested conditions. However, one replicate of the 10/90 ratio at 30 min showed a slight increase in measured mass after soil burial, resulting in a negative mass-loss value for that individual replicate. This variation may have been caused by residual soil particles or moisture retained by the sample despite the cleaning and drying procedures. The negative value contributed to the relatively large standard deviation for this treatment. It caused the lower error bar in Figure 3 to extend below zero, although the mean mass loss remained positive.

The variation in mass loss indicates that the degradation behavior of the biofilms was influenced by both the alginate/banana fiber composition and dip-coating immersion time. The presence of banana fiber may contribute to biodegradation because natural fibers are susceptible to microbial degradation under soil burial conditions. However, the effect of dip-coating immersion time was not consistent across the different alginate/banana fiber ratios, suggesting that differences in biofilm structure, fiber distribution, and mangosteen peel extract deposition may influence water penetration and microbial interaction with the biofilm matrix. Overall, the alginate/banana fiber biofilms exhibited mass loss under soil burial conditions, indicating degradation under the tested conditions. This finding is consistent with previous studies reporting microbial degradation of alginate- and natural fiber-based materials (Pawar et al., 2024; Zinina et al., 2023). These results further support the potential of biopolymer-based materials as environmentally friendly alternatives to conventional synthetic materials (Cut Masyithah, 2024).

CONCLUSION

This study successfully developed sodium alginate/banana fiber biopolymer films incorporated with 15% mangosteen peel extract through a dip-coating treatment for potential application as biodegradable antibacterial absorbent materials. The absorption capacity was affected by the alginate/banana fiber ratio, dip-coating immersion time, and their interaction. Two-way analysis of variance (ANOVA) showed that the alginate/banana fiber ratio, immersion time, and their interaction significantly affected the absorption capacity, with p-

values of 4.40×10^{-8}, 4.72×10^{-5}, and 0.000937, respectively. The highest numerical absorption capacity was obtained at an alginate/banana fiber ratio of 50/50 without dip-coating, reaching 7.56 ± 0.48 times the initial weight. Among the dip-coated samples, the highest absorption capacity was obtained at the 50/50 ratio with a 90-minute immersion time, reaching 5.88 ± 0.39 times. However, the highest absorption capacity remained below the minimum requirement of 10 times the initial weight specified in SNI 16-6363-2000.

The antibacterial test against *Staphylococcus aureus* showed that the 30-minute dip-coating treatment produced the highest inhibition zone diameter, with an average of 9.3 ± 0.58 mm, compared with 7.0 ± 0 mm at 60 minutes and 7.8 ± 0.29 mm at 90 minutes. FTIR analysis confirmed the presence of characteristic functional groups associated with the sodium alginate/banana fiber matrix and mangosteen peel extract, including hydroxyl, C–H, carboxylate, aromatic C=C, phenolic C–O, and C–O–C/C–O groups. No new functional groups were observed after dip-coating, indicating that the treatment primarily involved physical interactions. The biodegradation test demonstrated that the biofilms underwent mass loss after two weeks of soil burial, with the highest mass loss observed for the 50/50 ratio at 30 minutes, reaching 56.38 ± 18.22%. The variation in mass loss among treatments indicates that the biodegradation behavior was influenced by the alginate/banana fiber ratio and dip-coating immersion time.

Although the developed biofilms demonstrated absorption, antibacterial, and biodegradation properties, their absorption capacity did not yet meet the SNI requirement. Therefore, further optimization is recommended to improve liquid absorption by optimizing the alginate/banana fiber ratio, increasing the porosity and liquid-accessible structure of the biofilm, improving banana fiber dispersion within the polymer matrix, and controlling the amount and distribution of mangosteen peel extract deposited during dip-coating. Optimization of film thickness and coating conditions may also be considered to achieve a better balance between antibacterial functionality and liquid absorption. These improvements may increase the absorption capacity toward the minimum requirement specified in SNI 16-6363-2000 while maintaining the functional and biodegradable characteristics of the biofilm.

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