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Effect of Immersion Media on the Swelling Degree of Banana Peel Extract-Based Biofilm

Muthia Muthmainnah Ismail*, Mira Setiana

Department of Biomedical Engineering, Faculty of Science and Technology, Universitas PGRI Yogyakarta, Yogyakarta, Indonesia
*e-mail: muthiamuthmainnahh@gmail.com

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Abstract: The waste from banana peels has bioactive chemicals that could be exploited as natural biomaterials for wound dressings. The amount of swelling in a biofilm is one of the most crucial things that impacts how effectively it works for wound care. This is because it changes how much water it can hold and how solid its structure is. The purpose of this study is to determine the impact of immersion media on the swelling of banana peel extract-based biofilms. We mixed banana peel extract with gelatin at 0.1, 0.3, and 0.5 mL to form biofilms. We tested for swelling in distilled water and a 0.9% NaCl solution for 10 to 30 minutes. We calculated out how much the swelling changed by comparing the weights before and after immersion. After that, we looked at the data by finding the average swelling numbers. The findings indicated that biofilms immersed in NaCl solution exhibited greater swelling than those immersed in pure water. This means that ionic interactions affect how polymer networks grow. The biofilm with 0.3 mL of extract swelled the most, although greater concentrations of extract made the swelling more controllable. These findings indicate that the concentration of the extract and the nature of the immersion medium significantly influence the swelling behavior of banana peel extract-based biofilms. This work provides scientists with insights into enhancing natural biofilm compositions for use as stable and absorbent, eco-friendly wound dressings.

Keywords: Banana Peel; Biofilm; Immersion Media; Swelling Degree; Wound Dressing.

Introduction

Biofilms based on natural materials are increasingly being developed as environmentally friendly and biocompatible alternatives to medical materials [1]. Banana peel is one such potential biomaterial because it contains pectin, polyphenols, flavonoids, and other active compounds that can form a flexible and stable film matrix [2]. These compounds enable the biofilm to have good mechanical properties, water-binding ability, and biological activity that supports wound healing [3]. With these characteristics, banana peel extract-based biofilm is an attractive candidate for development as a safe and economical natural wound dressing [4].

One important parameter in the development of wound dressings is the degree of swelling, which is the ability of the biofilm to absorb fluid from its surroundings [5]. In the context of wound care, swelling plays a very important role because it is directly related to the dressing's ability to absorb exudate, maintain appropriate moisture, and protect wound tissue from conditions that are too wet or too dry [6]. Excessive swelling can cause the film to lose its mechanical integrity, while insufficient swelling can inhibit the healing process [7]. Therefore, understanding swelling behavior is a key aspect in characterizing biofilms for medical applications [8].

The immersion medium is one of the significant external factors in determining the degree of biofilm swelling [9]. Distilled water, which contains no ions, allows for more hydrogen interactions between water and hydrophilic groups on the film, thereby triggering greater swelling [10]. Conversely, NaCl solutions can inhibit water absorption through ionic effects that stabilize the polymer structure and reduce the attractive forces between polymer chains and water molecules [11]. Understanding these differences in response is important because wound conditions can have varying exudate environments, including in terms of salinity and electrolyte composition [12].

This phenomenon has been reported in natural polymer-based biofilms such as pectin, gelatin, and carrageenan, where changes in the immersion medium have been shown to affect the internal structure and fluid absorption capacity of the film [13]. Although banana peel is rich in pectin and has the potential to exhibit similar behavior, studies that specifically evaluate the response of banana peel extract biofilms in different immersion media are still very limited, especially regarding their application as wound dressings. In fact, understanding how films behave in various media is very important for determining the durability, stability, and functionality of biofilms in real conditions on the skin [14]. This data gap highlights the need for comprehensive swelling characterization of banana peel-based biofilms.

Based on this, this study was conducted to evaluate the effect of immersion media, namely distilled water and NaCl solution, on the degree of swelling of banana peel extract-based biofilms. The results of this characterization are expected to provide relevant scientific information regarding the performance of biofilms as wound dressings,

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particularly in terms of absorbency, structural stability, and film interaction with fluids [15]. This study also has the potential to serve as a basis for optimizing biofilm formulations so that they can be developed into effective, safe, and sustainable wound care materials.

Research Methods

This study is an experimental investigation conducted through a series of procedures in the laboratory to examine the characteristics of a biofilm based on kepok banana peel extract, with gelatin added as a film matrix reinforcement. The research stages include material preparation, biofilm formulation and printing, drying, and testing of physical properties, particularly swelling degree, in various immersion media. All procedures were carried out in accordance with laboratory standards to ensure data validity and reproducibility. The research stages included material preparation, biofilm formulation, printing, drying, and testing of the biofilm's physical and functional properties. All procedures were carried out in accordance with laboratory standards to ensure data validity and reproducibility.

Materials

Biofilm formulation prepared using microbiological gelatin (2 g), glycerol (0.3 mL), acetic acid PA (0.2 mL), aquades (10 mL), and banana peel processed kepok. Two types of soaking media are used: aquades and a 0.9% NaCl solution. All chemicals used have analytical purity to ensure the validity of the process and research results.

Equipment and Instruments

The equipment used includes stainless steel spoons, glass beakers, stirring rods, Whatman filter paper, and vials for extract and sample storage. The instruments used include analytical scales, digital pH meters, magnetic stirrers, and hot plates. All instruments were calibrated before the study began.

Research Chronological

The research phase began with the collection and cleaning of kepok banana peels, followed by natural drying in sunlight to achieve optimal dryness. The dried banana peel is further mashed into a powder. Banana peel powder is then macerated in an aqueous solution to obtain the extract. The resulting extract is used to manufacture gelatin-based biofilms. The formed Biofilm is further dried, then cut to the size of the test. Biofilm samples were then tested for swelling using two types of soaking media, namely aqueous and 0.9% sodium chloride solution. The data obtained from the swelling test were then analyzed to determine the characteristics of biofilm development.

Research Procedures

Kepok Banana Peel Extraction

Banana peel kepok washed thoroughly, then cut into small portions. The sample is then dried in the sun until it reaches a perfectly dry state through natural drying. The dried banana peel is then blended until a powder forms. Banana peel powder soaked in aqueous at a ratio of 1: 10 W/v for 24 hours using the maceration method [16]. The macerated mixture is then filtered using filter paper to obtain the extract filtrate. The filtrate obtained is stored in vials before use in the biofilm manufacturing process.

Making Biofilms

A total of 2 g of gelatin PA dissolved in 10 mL of water using a hot plate magnetic stirrer at a temperature of about 80℃ until a homogeneous solution [17]. Then, glycerol was added as much as 0.3 mL as a plasticiser and homogenized again. After that, 0.2 mL of acetic acid PA is added to adjust the pH and increase the stability of the gelatinous Matrix. Kepok banana peel extract is then added according to the formulation variations (0.1 mL, 0.3 mL, or 0.5 mL), and the mixture is stirred until the solution is completely homogeneous. The biofilm solution is then poured into a flat mold and dried at room temperature for 24 hours until a stable biofilm is formed [18]. The dried Biofilm is removed from the mold and cut to a Test size of 1 x 2 cm.

Swelling Test

The biofilm samples were cut into uniform pieces and subsequently weighed using an analytical balance to determine their initial weight before the immersion treatment [19]. The samples were immersed in two media, namely water and a 0.9% NaCl solution, for 10, 15, 20, 25, and 30 minutes, respectively. After each soaking time interval, the sample is slowly removed and dried using filter paper without compressing the biofilm structure [20]. The sample is then weighed again to obtain the weight after immersion. The swelling degree was calculated by subtracting the initial dry weight of the biofilm (W_o) from the swollen weight after immersion (W_t), dividing by the initial weight (W_o), and multiplying by 100% [15]. The swelling test was conducted in triplicate for each formulation and immersion medium, and ed descriptively by calculating the mean swelling degree[21].

$$\text{Swelling Degree } (\%) = \frac{\text{Wt} - \text{Wo}}{\text{Wo}} \times 100\%$$

The swelling test was performed three times for each formulation and immersion medium. We analysed the swelling data by calculating the average swelling degree. The results were displayed graphically to demonstrate the swelling behavior as a function of immersion time. This study did not use any kind of inferential statistical analysis.

Results and Discussion

Swelling Behavior in Distilled Water (Aquades)

A swelling degree test in aqueous media was conducted to evaluate the biofilm's ability to absorb pure in a non-ionic environment. The swelling value increased gradually from the 10th to the 25th minute in all samples, both control and sample with the addition of banana peel extract, as shown in Fig. 1. This indicates that the biofilm matrix contains hydrophilic functional groups capable of interacting with water molecules through hydrogen bonding. Biofilms with higher extract concentrations (0.5 mL) showed a tendency toward slightly larger swelling values than those with lower concentrations (0.1 mL), possibly due to the increased content of polysaccharides and phenolics, which attract water molecules [22].

Table 1. Polymer film swelling test result with variation of kepok banana peel extract in aqueous

Volume Extract (mL)	Time (Minute)	Average swelling ratio
0	10	1.057 ± 0.134
0	15	1.534 ± 0.277
0	20	1.259 ± 0.438
0	25	1.819 ± 0.120
0	30	1.612 ±0.487
0.1	10	1.039 ± 0.046
0.1	15	1.242 ± 0.126
0.1	20	1.274 ± 0.412
0.1	25	1.383 ± 0.086
0.1	30	1.467 ± 0.312
0.3	10	1.048 ± 0.139
0.3	15	1.541 ± 0.388
0.3	20	1.193 ± 0.092
0.3	25	1.259 ± 0.355
0.3	30	1.353 ± 0.083
0.5	10	0.994 ± 0.204
0.5	15	1.230 ± 0.100
0.5	20	1.211 ± 0.132
0.5	25	1.727 ± 0.329
0.5	30	1.636 ± 0.173

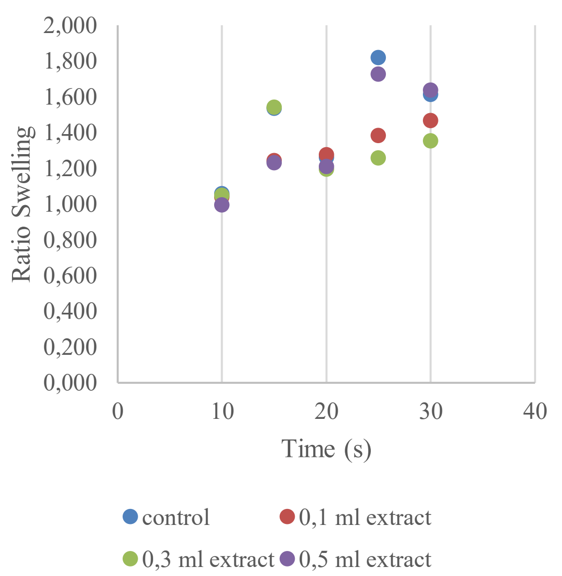

Figure 1. Swelling aquades results chart

Figure 1 shows that swelling worsens similarly across all extract concentrations. This rise is due to water moving into the biofilm matrix via hydrogen bonding. After 30 minutes of immersion, some samples showed a small decrease in swelling. This could be because the water-absorption capacity was saturated or the polymer network was relaxed. These results show that biofilms made from banana peel extract stay hydrated in non-ionic media.

The swelling behavior observed in non-ionic media further reflects the intrinsic characteristics of natural polymer-based biofilms. In the absence of dissolved ions, water diffusion into the biofilm matrix is predominantly governed by hydrogen bonding between water molecules and hydrophilic functional groups such as hydroxyl, carboxyl, and amino groups present in gelatin and banana peel extract components [23]. This mechanism allows gradual matrix expansion without significant disruption of the polymer network.

Variations in extract concentration also influence the swelling response, with higher extract content increasing the availability of hydrophilic sites, thereby enhancing water affinity. However, excessive polymer content may simultaneously increase matrix density, thereby limiting further expansion at longer immersion times. This balance between hydrophilicity and network compactness explains the observed plateau or slight decrease in swelling after prolonged immersion [24].

Other natural biofilms and hydrogel systems have exhibited analogous swelling behaviors in non-ionic solutions. This means that the behavior seen here is what happens when biodegradable polymer matrices are hydrated without any ions. These results show that the biofilm remains stable and can absorb sufficient water, which is important for applications that require controlled hydration performance.

Swelling Behavior in NaCl Solution

Testing on NaCl media provides a general idea of how biofilms behave in ionic conditions, which better reflects the conditions in biological fluids such as wound exudate. The swelling value in this medium exhibits a similar pattern of increase, although it is typically elevated at specific immersion durations. This can happen when Na^+ ions interact with ionic and hydroxyl functional groups in the biofilm matrix. This makes the polymer network grow and makes it easier for water to move through. This is often called the ionic shielding effect, which happens when electrostatic interactions between polymer chains are lessened. This makes the matrix more flexible and lets it take in more water. [25].

Figure 2 shows that in some samples, particularly at an extract concentration of 0.3 mL, the swelling increased markedly at the 25th and 30th minutes. This behavior indicates the presence of an ionic shielding effect, in which Na^+ ions reduce electrostatic interactions between polymer chains, resulting in a looser matrix structure [26]. In contrast, at an extract concentration of 0.5 mL, the observed increase in swelling was relatively limited, indicating that the polymer network's higher density provides strong resistance to ionic penetration. These findings suggest that the internal structure of biofilms plays an important role in the swelling response in ionic environments [27].

The swelling behavior seen in NaCl medium is similar to how biofilms made of natural polymers react in ionic environments. Na^+ ions in the immersion medium help charged functional groups in the polymer chains screen each other electrically. This makes the matrix expand and makes it easier for water to move through it. This ionic interaction is very different from non-ionic media, where hydrogen bonding is the main way that swelling happens [28].

Table 1. Polymer film Swelling test result with variation of kepok banana peel extract on NaCl

Volume Extract (mL)	Time (Minute)	Average swelling ratio
0	10	0.877 ± 0.036
0	15	1.671 ± 0.243
0	20	1.487 ± 0.230
0	25	1.767 ± 0.176
0	30	1.907 ± 0.353
0.1	10	1.018 ± 0.145
0.1	15	1.159 ± 0.137
0.1	20	1.288 ± 0.101
0.1	25	1.741 ± 0.271
0.1	30	1.781 ± 0.257
0.3	10	1.223 ± 0.143
0.3	15	1.244 ± 0.257
0.3	20	1.668 ± 0.294
0.3	25	1.580 ± 0.476
0.3	30	2.016 ± 0.402
0.5	10	1.260 ± 0.153
0.5	15	1.579 ± 0.055
0.5	20	1.547 ± 0.254
0.5	25	1.829 ± 0.375
0.5	30	1.737 ± 0.326

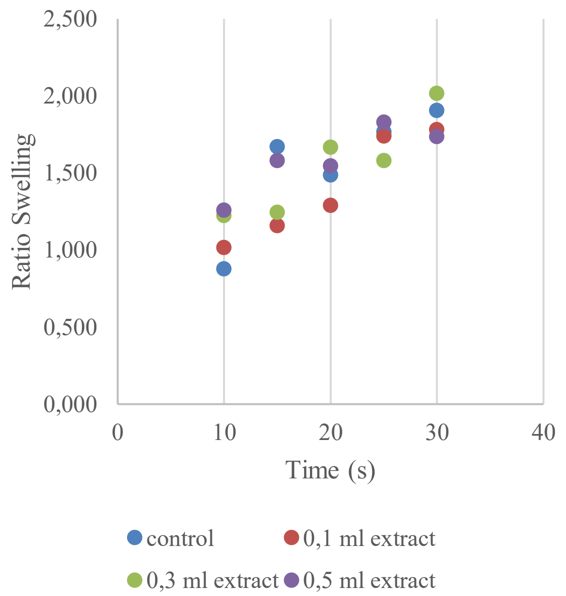

Figure 2. Graph Of NaCl Swelling Results

At an intermediate extract concentration (0.3 mL), the polymer network remains sufficiently flexible to respond to ionic shielding, leading to a pronounced increase in swelling at longer immersion times. Conversely, a higher extract concentration (0.5 mL) results in a more compact, densely crosslinked matrix that restricts ion penetration and limits further expansion despite prolonged soaking.

Such behavior is consistent with previous reports on gelatin- and polysaccharide-based biofilms, where an optimal polymer concentration enables maximum swelling in ionic media, while excessive polymer content enhances mechanical stability at the expense of swelling capacity. These findings confirm that the swelling response of the developed biofilm in ionic environments is governed by the interplay between ionic interactions and polymer network density [29], [30].

Comparative Analysis of Aquades and NaCl Media

Comparison of biofilm swelling in aqueous media and NaCl solution revealed a clear difference in hydration response, both quantitatively and in kinetic patterns (Table 1 and Table 2). In general, swelling values in NaCl media tend to be higher than in aqueous media across almost all variations in extract concentration and soaking time, especially during the 20th to 30th minute. This trend is also confirmed by the charts in Fig. 1 and Fig. 2.

In the control sample (0 mL of extract), the swelling value of NaCl media increased from 0.877 ° 0.036 (10 minutes) to 1.907 ° 0.353 (30 minutes) (Table 2; Fig. 2), whereas in aquades only reached about 1.612 ° 0.487 (30 minutes) (Table 1; Fig. 1). This difference indicates that the presence of ions enhances the hydration capacity of the biofilm through ionic interactions with hydrophilic functional groups in the polymer matrix, a behavior commonly reported for natural polymer-based biofilms. Similar observations have been reported in previous studies on gelatin- and polysaccharide-based biofilms, where ionic media promoted higher swelling compared to non-ionic media due to electrostatic screening effects [29], [30].

At an extract concentration of 0.1 mL, the swelling value of NaCl media increased from 1.018 ± 0.145 (10 minutes) to 1.781 ± 0.257 (30 minutes) (Table 2; Fig. 2), whereas in aquades, it only reached approximately 1.467 ± 0.312 at the 30th minute (Table 1; Fig. 1). This result indicates that ionic interactions significantly contribute to polymer network expansion, even at low extract concentrations, in contrast to hydrogen-bond-driven swelling in non-ionic environments.

The biofilm showed the most swelling in NaCl medium at an intermediate extract concentration of 0.3 mL, reaching 2.016 ± 0.402 at 30 minutes (Table 2; Fig. 2). This was much higher than the value in aquades (1.353 ± 0.083; Table 1; Fig. 1). This phenomenon indicates the existence of an optimal equilibrium between polymer network density and ionic responsiveness, facilitating maximal matrix expansion in the presence of ionic shielding effects. Previous studies on natural biofilms have shown that they swell optimally at intermediate polymer concentrations. This is because the matrix is flexible enough to let more water in without breaking down [29], [30].

In contrast, at a concentration of 0.5 mL of extract, the swelling difference between the two media decreases. The maximum swelling in NaCl reached 1.737 ± 0.326 (30 minutes), while in aqueous solutions, around 1.636 ± 0.173 (30 minutes). This relatively small difference indicates that increasing the density of the biofilm tissue causes greater resistance to the penetration of ions and water molecules, so that the expansion ability of the structure becomes more limited [31].

This difference in swelling characteristics is very important for using biofilm as a wound dressing, as it affects its performance. NaCl Media that mimic the state of the wound fluid offer a more accurate depiction of the biofilm's efficacy in exudate absorption. The 0.3 mL extract concentration has the highest swelling value, indicating that this formulation is best suited for wound fluid-absorbent applications. The 0.5 mL concentration, on the other hand, is better for applications that need higher mechanical stability and more controlled absorption.

Conclusion

This study demonstrates that the soaking medium significantly influences the extent of swelling of biofilm derived from banana peel extract. Biofilms have a greater ability to retain water in NaCl media than in aqueous solutions because ionic interactions alter the polymer matrix's internal structure. The swelling response also depends on the concentration of the extract. For example, 0.3 mL has the best absorption capacity, while 0.5 mL yields a more stable structure with better-controlled absorption. This result shows that a biofilm made from banana peel extract can adjust its hydration properties to match the ionic environment. This means it could be a good material for wound dressings because it can absorb exudate well and is structurally stable enough.

Author's Contribution
M. M. Ismail: as the main researcher and main author, responsible for research design, data collection, data processing and analysis, as well as the preparation and processing of the Article script language; M. Setiana: as a mentor, providing direction, scientific input, and supervision during the research process and preparation of articles.

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