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Research Article

Polyvinyl alcohol/Chitosan/Gelatin Hydrogel incorporated with betel leaves for enhanced wound care management

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ABSTRACT

In the rapidly advancing medical field, there is a significant demand for efficient, safe, and cost-effective wound healing solutions that address both infection control and tissue regeneration. Traditional wound dressings often fall short in managing complex wounds, particularly those susceptible to microbial contamination or inflammation. For these critical healthcare needs, the development of innovative material systems that facilitate rapid wound recovery is essential. This research explores the potential of a composite biomaterial based on Polyvinyl Alcohol (PVA), Chitosan, and Gelatin—three biocompatible and biodegradable polymers known for their unique physicochemical and biological properties. The blend is further enhanced by incorporating betel leaf extract, a natural antibacterial agent widely used in traditional medicine in Southeast Asia, including Vietnam. The synergistic combination of these components aims to create an optimized wound dressing that promotes faster healing, moisture retention, reduced inflammation, and antimicrobial protection. Chitosan contributes to hemostatic activity and antimicrobial resistance, Gelatin supports cellular adhesion and proliferation, while PVA improves structural integrity and flexibility. Betel leaf extract, rich in bioactive compounds like chavicol and eugenol, imparts potent antibacterial and anti-inflammatory properties. A series of formulations were prepared by varying the ratios of PVA, Chitosan, and Gelatin, and introducing different concentrations of betel leaf extract to evaluate mechanical properties, swelling behavior and degradation rate. Surface morphology was examined using digital microscopy to assess homogeneity and distribution of betel particles. Among all combinations, a 2:1:1 ratio of PVA/Chitosan/Gelatin with 15% betel leaf content exhibited the most favorable characteristics. This study highlights the potential of using sustainable, natural resources to develop advanced wound dressings that are accessible, effective, and environmentally friendly, offering promising applications in biomedical and clinical settings.

Key words: Betel leaves, Hydrogel, Wound healing

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INTRODUCTION

Wound care management is crucial in healthcare, prompting the development of advanced materials to facilitate effective healing. Researchers efficiently prepared the PVA/Chitosan/Gelatin hydrogel, thoroughly examining its physicochemical properties. Overall, this innovative hydrogel holds promise for wound care strategies. Furthermore, the hydrogel exhibited excellent compatibility with human cells, supporting its potential for *in vivo* applications. Animal studies further evaluated its effectiveness in promoting wound closure, tissue regeneration, and reducing inflammation [1–5].

The betel leaves, known for their antimicrobial and anti-inflammatory properties, enhance the hydrogel's therapeutic potential [6–8]. Rigorous assessments confirm the hydrogel's suitability for wound care applications, including structural integrity, swelling behavior, porosity, and biodegradability. Additionally, *in vitro* studies demonstrate sustained release of bioactive compounds from the betel leaves, creating an antimicrobial environment conducive to wound healing [4,7,9].

There has been a surge of interest in wound care materials, particularly PVA/Chitosan/Gelatin hydrogels enriched with natural additives. This trend represents a deliberate fusion of traditional medicinal knowledge with modern biomaterial science, all aimed at enhancing wound healing practices. The therapeutic potential of indigenous plants, particularly betel leaves, is gaining recognition in the scientific community. Traditionally employed in local medicinal practices for their antimicrobial and anti-inflammatory properties, betel leaves are now garnering attention for their significant benefits. The integration of betel leaves into Chitosan/PVA-Gelatin hydrogels is a significant effort to combine traditional remedies with contemporary healthcare solutions. Therefore, this study focuses on creating and understanding a flexible hydrogel. The hydrogel is made

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up of Chitosan, PVA and Gelatin, with the additional inclusion of betel leaves as natural additives. The study aims to optimize the hydrogel's formulation to achieve a balance of mechanical strength, biocompatibility, and enhanced wound-healing properties. Optimized PVA/Chitosan/Gelatin hydrogels are expected to accelerate healing, possess anti-inflammatory effects, and reduce inflammation. Additionally, betel leaf, known for its potent antimicrobial properties against various pathogens, holds promise as an antimicrobial option for enhancing wound care. These findings highlight the promising potential of the PVA/Chitosan/Gelatin hydrogel incorporated with betel leaves as a versatile material for advanced wound care management. The integration of natural additives with biocompatible polymers offers a comprehensive approach to expedite the healing process, presenting a promising avenue for future advancements in biomaterials and wound care in Vietnam.

MATERIALS AND METHOD

Preparation

Polyvinyl alcohol (PVA), with a hydrolysis degree of 98–100 mol% and an average molecular weight ranging from 60,000 to 125,000 KDa, was obtained from HiMedia Laboratories, Mumbai, India. Gelatin derived from porcine skin, possessing a molecular weight (Mn) of 260 kDa, was supplied by Fuchen (Tianjin) Chemical Reagent Co., Ltd, China. Betel leaves were obtained from Tay Ninh province, Vietnam. Betel leaves were dried in an oven at 90°C for 1 hour. Then, the dried leaves were ground into powder. For dehydration, the betel powder was immersed in ethanol solutions at concentrations of 30 wt.%, 50 wt.% and 70 wt.%, respectively. The obtained betel powder was filtered and then dried in the oven at 90°C for 1 hour. PVA powder was gradually added to distilled water at 90°C to create PVA solutions with concentrations of 7 wt.%, 10 wt.% and 15 wt.%, followed by continuous stirring for 1 hour at the same temperature to ensure complete dissolution. Gelatin was stirred in distilled water at 60°C for 1 hour to form a solution with a concentration of 5 wt.%. Chitosan (CS), with a molecular weight (Mn) of 120 kDa and a deacetylation degree of at least 75%, was procured from VietnamFood Co., Vietnam. Chitosan was dissolved in a 3% v/v acetic acid solution at a concentration of 3% w/v, utilizing magnetic stirring for 24 hours at 37°C. During this process, the pH of the solution was monitored hourly, aiming to maintain it within the range of 3 to 5 and it was adjusted by adding dropwise NaOH 0.1N to the polymer solution. Hydrogels composed of PVA/Chitosan and PVA/Gelatin were prepared using a similar method, with variations in the mass ratios between Chitosan/Gelatin and PVA. Different ratios were tested, where the mass of Chitosan/Gelatin ranged from 0 wt.% to 50 wt.% of the total PVA mass. The components were mixed using magnetic stirring for a duration of 1 hour to ensure proper homogenization. This systematic approach allowed for the investigation of how varying ratios of Chitosan/Gelatin to PVA affected the properties and characteristics of the resulting hydrogels. Following the characterization of the previously obtained samples, the optimal ratio of PVA, Chitosan, and Gelatin was selected to create the base sample for PVA/Chitosan/Gelatin. Once the background sample was opted, a mixture comprising PVA, Chitosan, Gelatin, and betel powder was stirred for 1 hour, with variations in the proportions of betel powder. The mass of betel powder was adjusted to 0 wt.%, 5 wt.%, 15 wt.%, and 30 wt.% in comparison to the mass of the base sample PVA/Chitosan/Gelatine. Type of samples is described in Table 1.

Microstructure properties

Digital Microscope (Bysameyee USB Microscope, Digital Handheld 40X-1000X Magnification Endoscope Mini Video Camera with 8 Adjustable LED Lights) was used to analyze the structure and size of the pores. The images of four samples after adding betel powder were analyzed using ImageJ and HiView software.

Mechanical properties

Mechanical properties were evaluated in term of tensile strength by Universal Tensile Tester (MTC-500 PTA Group) according to ASTM D882-18 standards. The samples are prepared with dimensions according to ASTM D882-18 standard (Figure 1). In this context: L_0 represents the sample length (where L_0 must be greater than or equal to 100 mm). WO represents the sample width (with a range of 20-15 mm). G corresponds to the length of the measuring interval (specifically, G = 50 mm). D denotes the distance between the two clamps (which is D = 80 mm). Finally, T signifies the sample thickness (where T should not exceed 1 mm). Five samples were tested to take the average value.

Degradation

Each hydrogel film (1cm x 1cm) was weighed on a 4-digit weighing device with an accuracy of 0.1 mg to determine the initial sample mass. The samples were soaked in 50ml NaCl 0.9 wt.% solution at 37^{o}C. After

Table 1: Type of samples

Raw materials	Sample name	Component of hydrogels			Ratio of hydrogels component	Betel powder (%wt)
		PVA (%wt)	Chitosan (%wt)	Gelatin (%wt)		
PVA	PVA 7%	7	0	0	0	0
	PVA 10%	10	0	0	0	0
	PVA 15%	15	0	0	0	0
PVA/Chitosan	CS 10%	10	2	0	9:1	0
	CS 20%	10	2	0	8:2	0
	CS 40%	10	2	0	6:4	0
	CS 50%	10	2	0	5:5	0
PVA	Gel 10%	10	0	5	9:1	0
/Gelatin	Gel 20%	10	0	5	8:2	0
	Gel 40%	10	0	5	6:4	0
	Gel 50%	10	0	5	5:5	0
PVA/Chitosan	Betel 0%	10	2	5	2:1:1	0
/Gelatin + Betel	Betel 5%	10	2	5	2:1:1	5
	Betel 15%	10	2	5	2:1:1	15
	Betel 30%	10	2	5	2:1:1	30

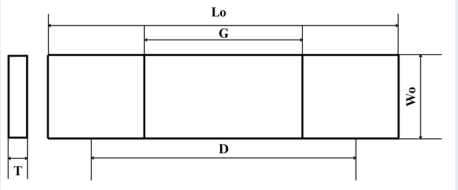

Figure 1: Illustration of hydrogel film following ASTMD882-18 standard

a period of 1, 2, 3, 4, 5 and 6 days, the samples were removed from the solution and weighed. Five samples were tested to take the average value.

Gel fraction

The dried hydrogel samples were cut into 1 cm × 1 cm pieces and the initial mass (W_f) was weighed, then they were soaked in 50 ml of distilled water for 24 h at room temperature. The submerged samples were removed from the water and dried under vacuum at room temperature until they reached a consistent weight (W_i). Five samples were tested to take the average value. The gel fractions of the hydrogels, determined based on the dry weights for both washed and unwashed conditions, were calculated as follows:

$$Gel\ fraction\ (\%) = \frac{W_f - W_i}{W_i}\ x\ 100$$

Swelling fraction

Initially, dried hydrogel samples measuring 1 cm x 1 cm were weighed to determine their initial mass. These samples were then immersed in distilled water for a duration of 30 hours at room temperature. After the swelling process, the hydrogel samples were removed from the water, and their weight (W_s) was measured again following gentle blotting to dry the surface. Afterward these tests were dried and weighed once more to get W_d. Five samples were tested to take the average value. The swelling fraction was calculated by the following formula:

$$Swelling\ fraction\ (\%) = \frac{W_s - W_d}{W_d}\ x100$$

where W_s and W_d are hydrogel weight in swollen and dry states, respectively.

Statistical analysis

A one-way factorial ANOVA was performed, followed by Fisher's LSD post hoc test, using OriginPro 2023 (OriginLab Corporation, Northampton, MA, USA). Statistical significance was set at $p < 0.05$.

RESULTS AND DISCUSSION

Characterization of PVA

The degree of swelling of PVA was shown in Figure 2. When PVA hydrogels were submerged in distilled water for 30 hours, their weight increased as the concentration of PVA was raised. During the initial 5 hours, there was some fluctuation in the weight of the hydrogels, particularly observed in the case of PVA 10%. However, after the full 30 hours, the weight tended to stabilize [1,2].

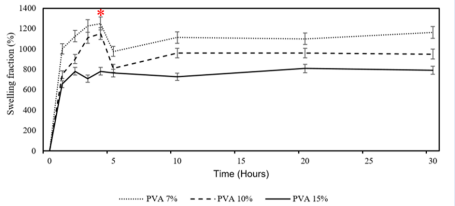

Figure 2: The swelling fraction of PVA hydrogels (*p <0.05)

The gel fraction of PVA as shown in Figure 3 (which represents the crosslinked network within the hydrogel) showed an interesting relationship with swelling.

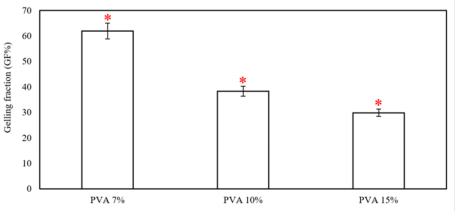

Figure 3: The gel fraction of PVA hydrogels (*p < 0.05)

It was inversely proportional to the degree of swelling. Additionally, the gel fraction was directly proportional to both the thickness and concentration of the PVA solution. After a certain period, PVA 7% hydrogels exhibited a significantly larger gel fraction compared to those made from PVA 10% and PVA 15% solutions. In fact, the gel fraction was almost twice as much for PVA 7% [1–5]. These findings highlight the importance of PVA concentration in controlling the swelling behavior and network structure of PVA hydrogels. The relationship between gel fraction, swelling, and concentration can have implications for various applications of these hydrogels. After immersing PVA hydrogels in 0.9 wt.% NaCl solution for 6 days, the weight of the hydrogels (as shown in Figure 4) exhibits a decrease across all samples [6–8]. Notably, the 10% PVA hydrogel experiences the most significant decomposition compared to the other samples, which achieve varying degrees of expansion.

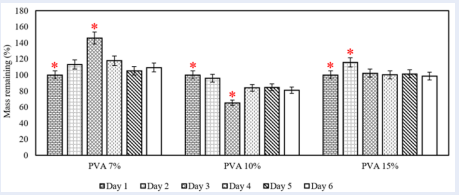

Figure 4: The degradation of PVA hydrogels (*p < 0.05)

Figure 5 illustrates the tensile strength of the PVA hydrogels, which is influenced by the PVA concentration in each sample. Interestingly, the greater the PVA content, the lower the tensile strength. Consequently, the order of tensile strength from lowest to highest corresponds to PVA 15%, PVA 10%, and PVA 7%. In summary, for selecting the foundational concentration of hydrogels in our research, PVA 10% emerges as the most stable choice. Its suitability as a base for the material system is attributed to its favorable characteristics, including swelling behavior, gel fraction, degradation, and tensile strength properties [1–7].

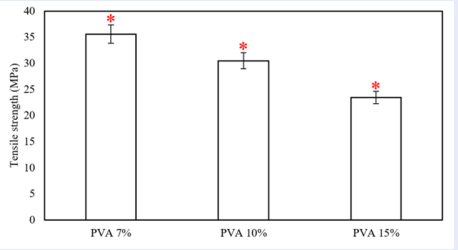

Figure 5: The tensile strength of the PVA hydrogels (*p < 0.05)

Characterization of PVA/ Chitosan and PVA/Gelatin mixtures

Figure 6 and Figure 7 illustrates the swelling behavior of PVA/Chitosan and PVA/Gelatin mixtures. These mixtures exhibit a similar pattern, with swelling gradually increasing as the concentration rises. Specifically, at a 10% concentration, both samples display

minimal swelling during the initial 5 hours, remaining relatively stable over the subsequent 30 hours [1–3]. However, concentrations of 20% and higher result in significant swelling within the first 5 hours, reaching maximum levels by that time and subsequently stabilizing over the next 30 hours. Furthermore, at higher concentrations, swelling increases significantly, with 50% of the samples displaying the highest swelling levels and subsequent stability. The presence of Chitosan and Gelatin enhances swelling, particularly at the 50% concentration, likely due to increased wettability and hydrophilicity.

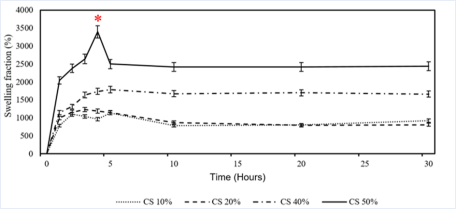

Figure 6: The swelling fraction of PVA/Chitosan hydrogels (*p < 0.05)

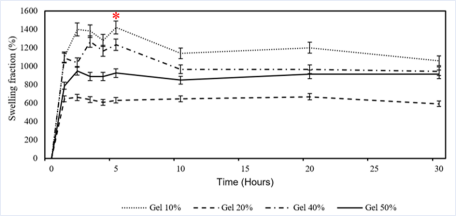

Figure 7: The swelling fraction of PVA/Gelatin hydrogels (*p< 0.05)

Figure 8 and Figure 9 illustrate the gelling fraction of PVA/Chitosan and PVA/Gelatin mixtures. PVA/Gelatin exhibits high gelling levels across various concentrations (10%, 40%, and 50%), gradually increasing to 110.26%, 122.09%, and 141.62%, respectively. Notably, the 20% sample demonstrates the lowest gelling degree at 54.69%. Similarly, in PVA/Chitosan blends, the gelling degree correlates positively with concentration. Specifically, the values range from 73.57% at 10% concentration to 182.2% at 50% concentration. The presence of higher Chitosan and Gelatin content contributes to the formation of softer and more flexible samples. These findings are crucial for optimizing material systems and tailoring their properties to specific applications [10–13].

Figure 10 and Figure 11 describe the degradation of PVA/Chitosan and PVA/Gelatin hydrogels. It can be

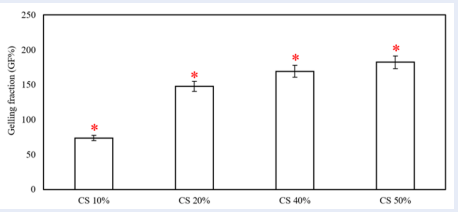

Figure 8: The gel fraction of PVA/Chitosan hydrogels (*p < 0.05)

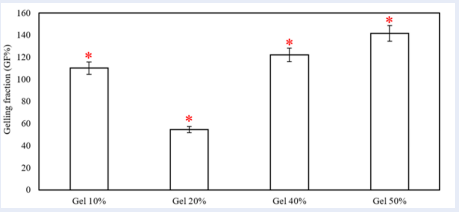

Figure 9: The gel fraction of PVA/Gelatin hydrogels (*p < 0.05)

seen that the degradation primarily occurs after the 4^{th} day, following an initial swelling period within the first 3 days. Gelatin samples containing 10% and 20% content begin decomposing as early as day 3. However, there is no significant decomposition observed in the 40% and 50% gelatin samples. In contrast, for PVA/Chitosan, decomposition starts on day 4 and becomes more pronounced with higher proportions. Notably, samples with 20% and 50% concentrations of PVA/Chitosan exhibit noticeable weight loss from day 4 onward.

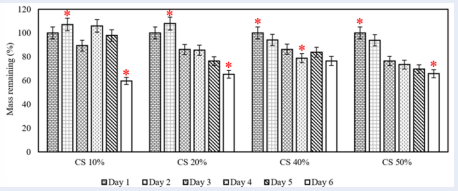

Figure 10: The degradation of PVA/Chitosan hydrogels (*p <0.05)

Figure 12 and Figure 13 illustrate the tensile strength of PVA/Chitosan and PVA/Gelatin mixtures. In PVA/Gelatin blends, tensile strength declines as concentrations increase, showing values of 37.83 MPa (10%), 23.62 MPa (20%), 21.27 MPa (40%), and 17.32 MPa (50%). Notably, the 10% and 50% PVA/Chitosan samples present the highest tensile strength, with

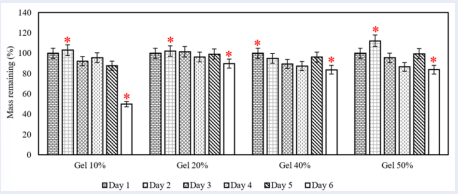

Figure 11: The degradation of PVA/Gelatin hydrogels (*p < 0.05)

36.84 MPa and 37.68 MPa, respectively. In contrast, the 20% and 40% samples demonstrate lower tensile strength. In PVA/Chitosan blends, the presence of PVA facilitates crosslinking between chitosan chains. This crosslinking enhances the tensile strength of the blend. However, in PVA/Gelatin blends, the crosslinking is less prominent. This difference arises from the distinct reactive groups present in gelatin. As the concentration of gelatin increases in the PVA/Gelatin blends, the plasticization effect becomes more pronounced. Plasticizers can reduce the crystallinity and increase the amorphous nature of the polymer, which can lead to a decrease in tensile strength. This effect may not be as significant in PVA/Chitosan blends due to the different interactions between PVA and chitosan compared to PVA and gelatin. Generally, tensile strength in PVA/Gelatin and PVA/Chitosan blends depends on the properties of both gelatin and chitosan because these two components significantly influence the overall structure, interactions, and mechanical properties of the blend. Gelatin results from the partial hydrolysis of collagen proteins, leading to its denatured form. Chitosan, in contrast, is a linear polysaccharide obtained by deacetylating chitin, which is present in crustacean exoskeletons. These unique molecular structures give rise to diverse interactions and bonding within the blend, ultimately influencing its tensile strength. Additionally, the tensile strength of a material is influenced by the interactions between its constituent polymers. Gelatin and chitosan, in particular, form hydrogen bonds, Van der Waals forces, and electrostatic interactions, which contribute to their overall bonding and performance. These interactions impact the overall tensile strength, influenced by component concentration. The gelatin and chitosan concentrations significantly shape the morphology and network structure of the material. An optimal balance between both components is expected to result in uniform polymer distribution and formation of a robust interconnected network. This network effectively distributes stress, leading to higher tensile strength. However, excessive concentration of one component weakens the network, resulting in lower tensile strength [3,5,9–18].

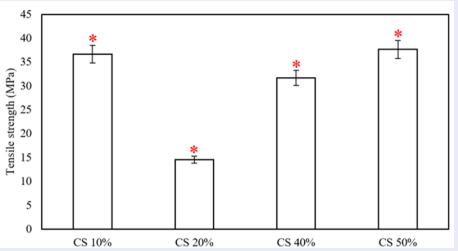

Figure 12: The tensile strength of the PVA/Chitosan hydrogels (*p < 0.05)

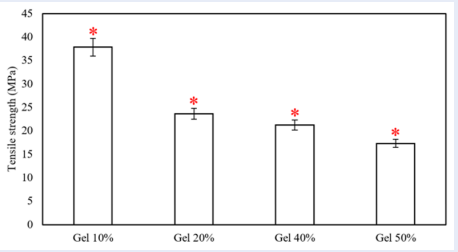

Figure 13: The tensile strength of the PVA/Gelatin hydrogels (*p< 0.05)

According to the results, a 50% ratio of PVA/Chitosan and PVA/Gelatin blends presents favorable sensory attributes, such as adaptable flexibility and a moderate level of softness. In these mixtures, the Gelatin 50% sample exhibits substantial gelling and swelling capabilities. However, it has relatively lower tensile strength. This drawback can be counterbalanced by the higher tensile strength of the Chitosan 50% sample, in relation to PVA. Furthermore, the elevated Chitosan content in the blend ensures additional benefits, including antibacterial and antifungal properties.

Characterization of PVA/Chitosan/Gelatin + Betel powder mixtures

Figure 14 illustrates the swelling capacity of the PVA/Chitosan/Gelatin hydrogel upon incorporating betel powder (0% to 5%, 15%, and 30%). As the betel powder concentration decreases, the swelling percentage of each sample rises but remains lower than the base without betel powder.

Analyzing the results alongside the gel fraction data (Figure 15) reveals a logical correlation between the

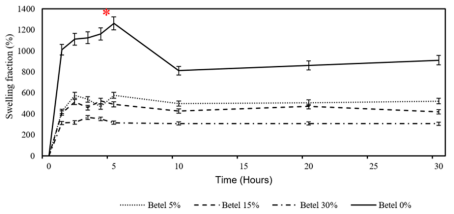

Figure 14: The swelling fraction of the PVA/Chitosan/Gelatin hydrogels upon incorporating betel powder (*p < 0.05)

swelling and gel fraction, where a higher gel fraction corresponds to a lower swelling percentage. The swelling capacity of the PVA/Chitosan/Gelatin composite decreases when betel powder is added, compared to the pure composite hydrogel. However, these materials still exhibit a notable swelling ability, making them potentially useful for wound healing applications. For instance, Betel 0% had a gelling fraction of 48.02%, while Betel 15% had 86.67%. Interestingly, although Betel 30% had the highest betel concentration, its gelling fraction was the lowest at 37.67%. The relationship between the gel fraction of hydrogels and the fraction of betel appears to be almost linear, suggesting that the presence of betel powder within the hydrogel's three-dimensional network can increase cross-linking in the structure, leading to a higher cross-link density. However, this effect is significant only at suitable betel concentrations [7,8].

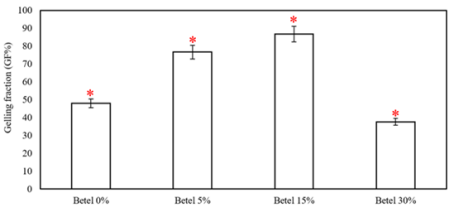

Figure 15: The gel fraction of the PVA/Chitosan/Gelatin hydrogels upon incorporating betel powder (*p < 0.05)

Figure 16 demonstrates that the weight of the betel-added samples reduced over time during the saltwater decomposition test. Initially, all samples experienced a weight increase due to their swelling properties, which lasted for the first two days. Afterward, the weight began to decrease, particularly on the fourth day. The change in weight was more significant for Betel 15% to 30%, while there was a slight variation in Betel 0% to 5%. This phenomenon occurred because the betel powder, being made entirely from natural cellulose, allowed microorganisms in saltwater to easily decompose the fiber membranes, generating biomass. Consequently, the added betel samples underwent rapid weight loss compared to the original sample, eventually getting completely decomposed within a week. This experiment confirms that betel-based biomaterials are biodegradable with time.

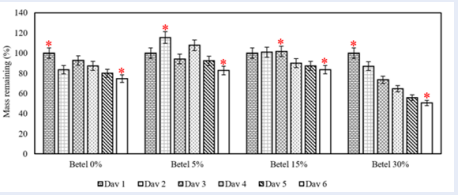

Figure 16: The degradation of the PVA/Chitosan/Gelatin hydrogels upon incorporating betel powder (*p < 0.05)

Figure 17 indicates the strength in the betel composite biopolymer compared to the pure PVA/Chitosan/Gelatin hydrogel. When the betel powder concentration was increased to 15%, the strength reached 0.53 MPa. Surprisingly, this level of strength was sustained even when the betel powder loading was doubled to 30%. The mechanical strength of the betel samples suggests a strong compatibility between the PVA/Chitosan/Gelatin matrix and the betel leaves themselves.

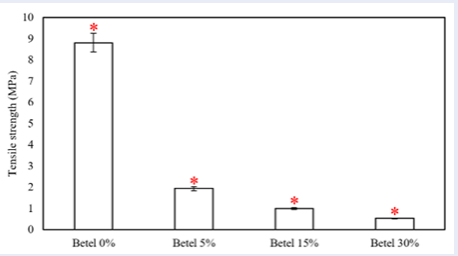

Figure 17: The tensile strength of the PVA/Chitosan/Gelatin hydrogels upon incorporating betel powder (*p < 0.05)

Figure 18 presents the surface morphology of the pure PVA/Chitosan/Gelatin hydrogel and the betel-added hydrogels with 5%, 15%, and 30% betel content.

In the provided images, the white spots correspond to the betel powder embedded within the PVA/Chitosan/Gelatin matrix. Initially, all samples contained a few betel aggregates. As the betel

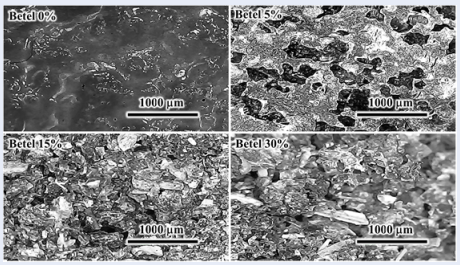

Figure 18: The surface morphology of the pure PVA/Chitosan/Gelatin hydrogel and the betel-added hydrogels with 5%, 15%, and 30% betel content.

powder content increased, the dispersion and distribution of the powder particles within the PVA/Chitosan/Gelatin matrix significantly improved. It was attributed to the sample preparation method that larger betel aggregates experienced greater shear stress during processing, leading to a more efficient breakdown of these aggregates. This observation aligns with the findings in studies on PVA morphology when incorporating additives, providing further support for our conclusion [3–5,7,15]. It was observed that the dispersion of betel particles in the 15% sample exhibited the most optimal distribution.

CONCLUSIONS

In conclusion, through a comprehensive analysis of various properties such as tensile strength, swelling, gel fraction, biodegradability, and surface structure, this study has determined that the blend of PVA/Chitosan/Gelatin in a ratio of 2:1:1, with an addition of 15% betel particles, stands out as a suitable and stable choice in comparison to other concentrations. This material is anticipated to exhibit improved properties such as enhanced wound healing efficacy and antibacterial qualities. Its ability to shield wounds from external irritants makes it a potential contender for facilitating skin regeneration. Furthermore, the material possesses sufficient durability to maintain the overall effectiveness of the healing process.

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COMPETING INTERESTS

The authors declare no conflict of interest.

AUTHORS' CONTRIBUTIONS

Conceptualization, Nguyen Xuan Thanh Tram; Methodology, Tran Tam Nha; Investigation, Tran Huynh Thien Phu; Data curation, Dao Minh Khanh Tuyen; Writing—original draft preparation, Tran Tam Nha; Writing—review and editing, Nguyen Xuan Thanh Tram; Visualization, Tran Tam Nha; Supervision, Nguyen Xuan Thanh Tram. All authors have read and agreed to the published version of the manuscript.

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Bài nghiên cứu

Hydrogel Polyvinyl Alcohol/Chitosan/Gelatin kết hợp với lá trầu không ứng dụng lành vết thương

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TÓM TẮT

Trong bối cảnh ngành y tế đang phát triển nhanh chóng, nhu cầu về các giải pháp điều trị vết thương hiệu quả, an toàn và tiết kiệm chi phí, đồng thời kiểm soát nhiễm trùng và thúc đẩy tái tạo mô, đang ngày càng gia tăng. Các loại băng vết thương truyền thống thường không đáp ứng được yêu cầu xử lý những vết thương phức tạp, đặc biệt là các vết thương dễ bị nhiễm khuẩn hoặc viêm. Trước nhu cầu cấp thiết này, việc phát triển các hệ vật liệu mới hỗ trợ quá trình phục hồi vết thương một cách nhanh chóng là rất cần thiết. Nghiên cứu này khám phá tiềm năng của vật liệu sinh học tổ hợp bao gồm Polyvinyl Alcohol (PVA), Chitosan và Gelatin — ba loại polymer có tính tương thích sinh học và khả năng phân hủy sinh học, nổi bật với các đặc tính lý – hóa và sinh học riêng biệt. Hệ vật liệu còn được tăng cường bằng cách bổ sung chiết xuất từ lá trầu không – một chất kháng khuẩn tự nhiên được sử dụng phổ biến trong y học cổ truyền ở Đông Nam Á, trong đó có Việt Nam. Sự kết hợp hiệp lực giữa các thành phần này nhằm tạo ra một loại băng vết thương tối ưu, giúp thúc đẩy quá trình lành vết thương nhanh hơn, duy trì độ ẩm, giảm viêm và tăng khả năng bảo vệ khỏi vi khuẩn. Trong đó, chitosan hỗ trợ cầm máu và kháng khuẩn, gelatin hỗ trợ kết dính và tăng sinh tế bào, trong khi PVA tăng độ bền cơ học và tính linh hoạt của vật liệu. Chiết xuất lá trầu không giàu các hợp chất hoạt tính sinh học như chavicol và eugenol, có tác dụng kháng khuẩn và chống viêm mạnh. Nhiều thành phần khác nhau đã được chuẩn bị bằng cách thay đổi tỷ lệ giữa PVA, Chitosan và Gelatin, đồng thời thêm vào các nồng độ chiết xuất lá trầu khác nhau để đánh giá các đặc tính cơ học, khả năng hút nước và độ phân huỷ. Hình thái bề mặt của các mẫu được quan sát bằng kính hiển vi kỹ thuật số nhằm đánh giá độ đồng nhất và sự phân bố của các hạt lá trầu. Trong số các công thức thử nghiệm, tỷ lệ PVA:Chitosan:Gelatin là 2:1:1 với 15% chiết xuất lá trầu thể hiện các đặc tính ưu việt nhất. Nghiên cứu này cho thấy tiềm năng ứng dụng của các nguồn nguyên liệu tự nhiên, bền vững để phát triển các loại băng vết thương tiên tiến, thân thiện với môi trường, hiệu quả và dễ tiếp cận, phù hợp với nhiều ứng dụng trong y học lâm sàng và công nghệ sinh học.

Từ khoá: Lá trầu không, Hydrogel, Làm lành vết thương

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