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Research Article

Innovation of Fish Scale Gelatin-Based Hydrogel Wound Dressings Combined with Banana Pith Extract and Turmeric for Hemostasis and Antibacterial Activity

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Abstract: *Wounds with active bleeding and high infection risk remain a major clinical challenge, particularly when complicated by bacterial pathogens such as Staphylococcus aureus. This study developed a novel hydrogel wound dressing fabricated from Nile tilapia (Oreochromis niloticus) fish scale gelatin combined with banana pith (Musa sapientum) juice and turmeric (Curcuma longa L.) extract. Gelatin was extracted via alkaline-acid treatment (Bloom strength 185 ± 12 g; yield 8.4%). Hydrogel films at ratio 1:2:2 (gelatin:banana pith:turmeric extract) were fabricated and evaluated for antibacterial activity against S. aureus ATCC 25923 (Disc Diffusion) and hemostatic activity (in vitro Clotting Time Assay). The hydrogel exhibited a Zone of Inhibition of 15.7 ± 0.9 mm and reduced blood clotting time by 38.4 ± 2.8% versus control (p < 0.01). Water absorption reached 312.5 ± 18.3% with structural stability maintained for 14 days. These findings demonstrate the potential of this eco-friendly, low-cost formulation as a dual-function hemostatic and antibacterial wound dressing.*

1. INTRODUCTION

Traumatic wounds with active haemorrhage and concurrent bacterial infection represent a critical clinical problem worldwide. Staphylococcus aureus is among the most prevalent wound pathogens, responsible for 20–30% of nosocomial infections and capable of producing biofilms resistant to conventional antibiotics (Crossley et al., 2009; Lowy, 1998). Rapid haemostasis combined with antimicrobial protection are therefore essential requirements for an effective wound dressing.

Hydrogel dressings have attracted considerable attention because they maintain a moist wound environment, absorb exudate, facilitate gaseous exchange, and can serve as a carrier for bioactive molecules (Boateng et al., 2008). However, most commercial hydrogels rely on synthetic polymers, carry a significant cost burden, and may provoke hypersensitivity reactions.

Fish scales a high-volume by-product of the aquaculture and fish-processing industries are an underutilised source of type-I collagen that can be converted to gelatin through alkaline-acid hydrolysis (Wang et al., 2009; Arnesen & Gildberg, 2002). Curcumin, the principal polyphenol of turmeric (Curcuma longa L.), disrupts bacterial cell membranes and inhibits the cell-division protein FtsZ, conferring potent activity against S. aureus at minimum inhibitory concentrations of 25–50 µg/mL (Aggarwal et al., 2003; Mahady et al., 2002). Banana pith (Musa sapientum) contains tannins and coagulation-promoting proteins that accelerate platelet aggregation and reinforce the fibrin clot (Kaur & Kaur, 2018; Aurore et al., 2009).

The present study aimed to (i) extract and characterise gelatin from Nile tilapia scales, (ii) quantify the antibacterial activity of turmeric extract and the haemostatic activity of banana pith juice, and (iii) fabricate and evaluate a composite hydrogel film incorporating all three bio-based materials as a dual-function wound dressing.

2. LITERATURE REVIEW

2.1 Fish Scale Gelatin

Gelatin is a denatured collagen derivative composed of polypeptide chains rich in glycine, proline, and hydroxyproline. Fish-derived gelatin (Type A) produced by acid treatment has an isoelectric point of 7.0–9.0 and a Bloom strength range of 50–300 g (Wang et al., 2009). Fish-scale collagen is predominantly type I, which promotes fibroblast proliferation and extracellular-matrix remodelling during wound healing (Arnesen & Gildberg, 2002). Unlike bovine or porcine gelatins, fish gelatin carries no risk of prion-related disease transmission and is acceptable to consumers with religious dietary restrictions.

2.2 Curcumin and Its Antibacterial Mechanism

Curcumin ($C_{21}H_{20}O_6$) is a lipophilic polyphenol isolated from C. longa rhizomes. Its antibacterial mechanism against Gram-positive organisms, including S. aureus, involves membrane depolarisation, inhibition of the bacterial cytokinesis protein FtsZ, and suppression of virulence gene expression (Aggarwal et al., 2003). Curcumin also exhibits anti-inflammatory and antioxidant effects that accelerate wound re-epithelialisation (Mahady et al., 2002).

2.3 Banana Pith and Haemostasis

Banana pith is rich in condensed tannins, pectin, and bioactive amines. Tannins exert an astringent effect by precipitating surface proteins of endothelial cells, inducing vasoconstriction and stimulating platelet aggregation. Coagulation proteins identified in banana pith have been reported to activate the intrinsic coagulation cascade, thereby shortening clotting time significantly compared with saline controls (Kaur & Kaur, 2018; Aurore et al., 2009).

2.4 Hydrogel Wound Dressings

Hydrogel dressings are three-dimensional polymer networks capable of absorbing more than 90% of their dry weight in water. Key performance criteria include water absorption capacity (≥ 200%), moisture-vapour transmission rate, pH compatibility with wound fluid (5.5–7.5), mechanical integrity, and sustained release of incorporated bioactives (Boateng et al., 2008; Liu et al., 2020). Bio-based hydrogels derived from gelatin, chitosan, or alginate are biodegradable and biocompatible, making them attractive alternatives to fully synthetic matrices.

2.5 Related Research

Patel and Shah (2021) demonstrated that fish-gelatin/curcumin composite hydrogels produced a Zone of Inhibition (ZOI) against S. aureus significantly superior to controls ($p < 0.01$) and accelerated wound closure in a murine excision model. Liu et al. (2020) identified 10% w/v gelatin as the optimal concentration for achieving tensile strength in the range 0.8–1.2 MPa while maintaining adequate flexibility. A school-level investigation by Dan Khun Thot School (2020) confirmed that banana pith preparations significantly reduced clotting time relative to distilled water, validating its traditional haemostatic use.

3. METHODOLOGY

3.1 Materials

Fresh Nile tilapia (Oreochromis niloticus) scales were obtained from Warorot Market, Chiang Mai. Fresh banana pith (Musa sapientum var. Pisang Awak) and turmeric rhizomes (Curcuma longa L.) were purchased locally. Reagents included NaOH (98%), acetic acid (99.5%), ethanol (95%), DMSO (≥ 99.5%), Mueller-Hinton Agar/Broth (MHA/MHB), S. aureus ATCC 25923, and fresh porcine blood (without anticoagulant) from a licensed abattoir.

3.2 Experimental Design

A Completely Randomised Design (CRD) was applied with $n = 3$ independent replicates per treatment group. Positive controls (PC) and negative controls (NC) were included in every assay. Statistical analysis used one-way ANOVA followed by Tukey's Honest Significant Difference (HSD) post-hoc test at $\alpha = 0.05$.

3.3 Gelatin Extraction from Fish Scales

Scales were washed, dried at 60 °C for 2 h, then demineralised in 0.1 M NaOH (1:10 w/v, room temperature, 2.5 h) and subsequently in 0.5 M acetic acid (1:10 w/v, room temperature, 2.5 h), with distilled water washes to neutrality between steps. Gelatin was extracted in distilled water at 60 °C for 4 h, filtered through Whatman No. 1, and vacuum-dried at 40 °C. The resulting powder was characterised for Bloom strength, viscosity, and purity by SDS-PAGE.

3.4 Turmeric Extraction and Antibacterial Assay

Dried turmeric rhizomes were extracted in 95% ethanol (1:10 w/v) for 24 h, filtered, and concentrated by rotary evaporation at 40 °C. Stocks of 200 mg/mL in DMSO were serially diluted to 25, 50, and 100 mg/mL. Antibacterial activity was evaluated by Disc Diffusion on MHA inoculated with S. aureus at 0.5 McFarland standard (1.5×10^8 CFU/mL); discs (6 mm) loaded with 10 µL of each concentration were incubated at 37 °C for 24 h, and ZOI diameters measured with Vernier callipers. Amoxicillin (10 µg) served as PC; DMSO as NC.

3.5 Banana Pith Extraction and Haemostatic Assay

Fresh pith was blended, pressed, and filtered through four layers of cheesecloth. Clotting time was determined using a 24-well plate: 1 mL of each test solution (banana pith juice, distilled water [NC], 0.9% NaCl, 0.025 M $CaCl_2$ [PC]) was combined with 100 µL fresh porcine blood. Clotting time was recorded when a pipette tip drawn through the well produced no trailing filament; observations were made every 30 s up to 20 min. Blood smears were Giemsa-stained and examined at ×400 for platelet aggregation and fibrin formation.

3.6 Hydrogel Fabrication and Characterisation

Gelatin (10% w/v) was dissolved in a mixture of banana pith juice and turmeric extract (2:2 v/v) in a water bath at 60 °C with gentle stirring. The homogeneous solution was cast into 5 × 5 cm silicone moulds (target thickness 2 mm), cured at 25 °C for 24 h, then sterilised by autoclaving at 121 °C, 15 psi, 15 min. Physical properties assessed included thickness (Vernier calliper), water absorption (gravimetric, immersion in distilled water for 24 h), light transmittance (%), and surface pH. Antibacterial and haemostatic assays were repeated on film discs as described in Sections 3.4 and 3.5.

4. FINDINGS

4.1 Gelatin Characterisation

The alkaline-acid extraction yielded 8.4 ± 0.6% (w/w) of pale-yellow, odourless gelatin powder. Bloom strength was 185 ± 12 g, well above the pharmaceutical-grade threshold of 100 g. Viscosity measured 32.5 ± 2.1 mPa·s (specification: 20–50 mPa·s). SDS-PAGE produced principal bands at 95–130 kDa, consistent with α-chains of collagen type I, confirming the identity and purity of the extract.

Table 1. Antibacterial activity (Zone of Inhibition, ZOI) of turmeric extract against S. aureus ATCC 25923

Treatment Group	Run 1 (mm)	Run 2 (mm)	Run 3 (mm)	Mean ± SD (mm)
Turmeric extract 100 mg/mL	18.0	19.0	18.0	18.3 ± 1.2[a]
Turmeric extract 50 mg/mL	14.5	15.0	14.5	14.7 ± 0.6[b]
Turmeric extract 25 mg/mL	10.0	10.5	10.5	10.3 ± 0.6[c]
Amoxicillin 10 µg (PC)	28.0	27.5	28.5	28.0 ± 0.5[d]
DMSO (NC)	0.0	0.0	0.0	0.0 ± 0.0[e]

Superscripts (a–e) denote statistically distinct groups (Tukey's HSD, $p < 0.05$). PC = Positive control; NC = Negative control.

4.2 Haemostatic Activity of Banana Pith Juice

Table 2. In vitro blood clotting time of banana pith juice versus controls

Treatment Group	**Run 1 (s)**	**Run 2 (s)**	**Run 3 (s)**	**Mean ± SD (s)**
Banana pith juice	412	428	418	419.3 ± 8.1[a]
Distilled water (NC)	723	738	729	730.0 ± 7.6[b]
0.9% NaCl	695	710	701	702.0 ± 7.6[b]
0.025 M $CaCl_2$ (PC)	285	291	288	288.0 ± 3.0[c]

Banana pith juice reduced clotting time by 42.6 ± 3.1% relative to distilled water ($p < 0.001$). Giemsa-stained smears confirmed dense platelet aggregation and fibrin meshwork formation in the banana pith group, substantiating activation of both platelet and coagulation pathways.

4.3 Physical Properties of the Hydrogel Film

Table 3. Physical characterisation of the fish scale gelatin hydrogel film

Property	**Measured Value (Mean ± SD)**	**Acceptance Criterion**
Thickness (mm)	2.12 ± 0.08	1.5–3.0 mm
Water absorption (%)	312.5 ± 18.3	≥ 200%
Light transmittance (%T)	68.4 ± 3.2	≥ 50%
Surface pH	6.8 ± 0.2	5.5–7.5
Structural stability (days)	14 ± 1	≥ 7 days

4.4 Dual-Function Performance of the Hydrogel Film

Table 4. Antibacterial and haemostatic performance of the composite hydrogel film

Group	**ZOI Mean ± SD (mm)**	**Clotting Time Mean ± SD (s)**	**p-value**
Hydrogel film	15.7 ± 0.9[a]	446.0 ± 12.5[a]	< 0.01
Amoxicillin disc (PC)	28.0 ± 0.5[b]	—	< 0.001
$CaCl_2$ (PC – haemostasis)	—	288.0 ± 3.0[b]	< 0.001
DMSO disc (NC)	0.0 ± 0.0[c]	—	—
Distilled water (NC)	—	730.0 ± 7.6[c]	—

The hydrogel film achieved a ZOI of 15.7 ± 0.9 mm (classified as Sensitive per CLSI breakpoints) and reduced blood clotting time by 38.4 ± 2.8% versus the NC ($p < 0.01$). Both outcomes exceeded the pre-specified minimum thresholds (ZOI ≥ 10 mm; clotting-time reduction ≥ 30%), confirming the validity of the study hypotheses.

5. DISCUSSION

The Bloom strength of 185 g obtained from tilapia scales is within the range reported for fish-skin gelatins (150–250 g; Arnesen & Gildberg, 2002) and satisfies pharmaceutical-grade specifications. The relatively low yield (8.4% vs. 15–25% for fish skin) is attributable to the lower collagen content of scales compared with dermis; however, since scales are a zero-cost industrial waste stream, the economic argument for their use remains compelling.

The concentration-dependent antibacterial activity of turmeric extract is consistent with the mechanistic data of Aggarwal et al. (2003), who demonstrated FtsZ inhibition and membrane disruption at curcumin concentrations equivalent to those used here. Although the ZOI values were lower than those for amoxicillin, the purpose of incorporating turmeric extract in the hydrogel is prophylactic surface antibacterial coverage rather than systemic therapy, for which the achieved ZOI is clinically meaningful.

The haemostatic effect of banana pith juice corroborates Kaur and Kaur (2018), who attributed accelerated clotting to tannin-mediated vasoconstriction and platelet activation. Microscopic evidence of fibrin meshwork formation confirmed dual-pathway (platelet plug + coagulation cascade) activation, a mechanistically robust haemostatic profile.

The modest reduction in both antibacterial and haemostatic efficacy observed for the hydrogel film compared with the pure extracts is explained by (i) dilution of active molecules within the polymer matrix, (ii) potential interaction between gelatin and polyphenolic curcumin reducing bioavailability, and (iii) rate-limited diffusion of actives through the hydrogel network. Paradoxically, this slow-release behaviour is beneficial for chronic wound management, providing sustained protective activity over the 14-day stability period. The water absorption of 312.5% is particularly advantageous for exudate-heavy wounds, as the hydrogel can absorb substantial fluid without structural disintegration, maintaining a moist microenvironment conducive to re-epithelialisation (Boateng et al., 2008; Liu et al., 2020). Surface pH of 6.8 is optimal for wound-healing enzyme activity and avoids the alkaline conditions that inhibit epidermal growth factor receptor signalling.

Limitations of the current study include: restriction to a single ATCC reference strain (not clinical isolates or MRSA), absence of in vivo wound-healing models, lack of HPLC quantification of curcumin retained in the film, and no formal cytotoxicity evaluation (MTT assay on HaCaT keratinocytes). These gaps define the priority agenda for subsequent investigations.

6. CONCLUSION

A novel hydrogel wound dressing was successfully fabricated from Nile tilapia scale gelatin combined with banana pith juice and turmeric extract. The composite film demonstrated statistically significant antibacterial activity against S. aureus (ZOI 15.7 ± 0.9 mm) and haemostatic activity (38.4 ± 2.8% reduction in clotting time), alongside favourable physical properties including 312.5% water absorption and 14-day structural stability. The formulation valorises fish-processing waste (scales) and locally available medicinal plants, yielding an eco-friendly, low-cost alternative to synthetic wound dressings. Future work should encompass in vivo wound-healing studies, cytotoxicity profiling, HPLC quantification of curcumin release, and scale-up under GMP-compliant conditions.

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