

Malaysia Journal of Invention and Innovation

<https://journal.academicapress.org/aps/index.php/mjii>

Research Article

Development of a Bio-based Hydrogel Sheet from Durian Peel Pectin and Guava Leaf Extract for Antibacterial Treatment of Infected and Post-Surgical Wounds

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Keywords:
bio-based hydrogel; durian peel pectin; guava leaf extract; antibacterial wound dressing; wound healing

Abstract: *This study developed a bio-based hydrogel sheet (GreenHeal) from durian peel pectin and guava leaf extract as a sustainable antibacterial wound dressing. Hydrogel sheets were formulated with calcium chloride crosslinking and evaluated for liquid absorption, water retention, antibacterial activity (agar diffusion against *S. aureus*, *E. coli*, *P. aeruginosa*), and wound closure (L929 scratch assay). GreenHeal achieved liquid absorption of 410 ± 20 mg/g, water retention of 49% at 24 h, inhibition zones of 19.5 ± 1.4 mm, and 82.4% wound closure by Day 7—significantly exceeding pectin-only and gauze controls ($p < 0.05$). Results demonstrate GreenHeal's potential as a low-cost, biodegradable wound dressing valorizing agricultural waste.*



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1. Introduction

Infected and post-surgical wounds remain a persistent challenge for health systems, especially in countries where advanced dressings are expensive or not widely available. When a wound becomes infected, the tissue often stays trapped in a prolonged inflammatory stage, with high exudate, pain, and delayed re-epithelialization, increasing the risk of serious complications, prolonging hospital stays, and raising treatment costs. Conventional gauze dressings act as passive covers: they may protect the surface but do not actively maintain optimal moisture levels or limit microbial growth, and they can adhere to

the wound bed, causing pain on removal (Aliyeva et al., 2024; Kocaağa et al., 2024). These limitations have motivated a shift toward active dressings that participate in the healing process rather than simply covering the wound.

Hydrogels fit this new paradigm very well. They are three-dimensional, hydrophilic polymer networks that can absorb large amounts of water while maintaining structural integrity, creating a cool, moist microenvironment that supports cell migration and re-epithelialization. Because they are soft and conformable, hydrogels can adapt to irregular wound surfaces and help relieve pain. They can also act as carriers for bioactive molecules—such as antiseptics, metal ions, honey, or plant extracts—allowing local, controlled release directly onto the wound bed (Aliyeva et al., 2024; Kocaağa et al., 2024). Recent reviews highlight that hydrogels based on natural polysaccharides, including pectin, are particularly attractive thanks to their biocompatibility, biodegradability, and potential to serve as multifunctional wound dressings with hemostatic, antioxidant, and antibacterial properties (Rubio-Martín del Campo et al., 2025; Chen et al., 2021).

Thailand faces two parallel challenges: increasing generation of agricultural waste and limited access to affordable advanced wound dressings in rural hospitals. Durian (*Durio zibethinus* Murr.) peel, usually discarded, can account for more than half of the total fruit weight, yet contains a pectin-rich polysaccharide gel with film-forming capacity and inherent antibacterial activity (Thunyakitpisal et al., 2010; Mungmai et al., 2023). Guava (*Psidium guajava* L.) leaves are rich in polyphenols—including gallic acid, quercetin, and kaempferol—that confer strong antioxidant, anti-inflammatory, and antimicrobial activities directly relevant to wound healing (Bilal et al., 2024; Huynh et al., 2025). Combining these two local, low-cost resources into a single hydrogel sheet has the potential to create an affordable, fully bio-based wound dressing aligned with Thailand's Bio-Circular-Green (BCG) economy model and the Sustainable Development Goals (SDG 3 and SDG 12). This project therefore aimed to develop and evaluate a bio-based hydrogel sheet—designated GreenHeal—from durian peel pectin and guava leaf extract for antibacterial treatment of infected and post-surgical wounds.

2. Literature Review

2.1 Hydrogel Wound Dressings

Hydrogel-based wound dressings have emerged as a superior alternative to conventional gauze due to their ability to maintain a moist wound microenvironment, which is known to accelerate re-epithelialization, reduce pain, and lower infection risk. Natural polysaccharide-based hydrogels—particularly those derived from pectin, alginate, and cellulose—are especially attractive because they combine biocompatibility with biodegradability and can be produced from renewable agricultural resources (Chen et al., 2021; Davydova et al., 2024). Recent reviews confirm that pectin hydrogels crosslinked with divalent cations (e.g., Ca^{2+}) provide tunable mechanical strength, controllable swelling, and a platform for incorporating antimicrobial actives, making them suitable scaffolds for both infected and post-surgical wound management (Rubio-Martín del Campo et al., 2025; Kocaağa et al., 2024).

2.2 Durian Peel Pectin as a Wound-Dressing Matrix

Pectin is a plant cell-wall polysaccharide rich in galacturonic acid units. Its carboxyl groups allow gel formation through ionic crosslinking, so the mechanical strength, swelling capacity, and degradation rate of pectin hydrogels can be tuned for different biomedical applications. Durian peel has

been shown to be a viable source of low-methoxyl pectin with yields of approximately 8–10% (dry weight basis) using mild acid extraction (Jong et al., 2021). Importantly, Thunyakitpisal et al. (2010) demonstrated that polysaccharide gel extracted from durian rinds showed significant antibacterial activity against oral and skin pathogens, while Mungmai et al. (2023) confirmed antioxidant and anti-aging activities, establishing durian-peel pectin as a bioactive rather than inert matrix material.

2.3 Guava Leaf Extract as an Antimicrobial and Wound-Healing Agent

Guava (*Psidium guajava* L.) leaves have a long history of use in traditional medicine. Modern phytochemical studies confirm they are rich in gallic acid, caffeic acid, ferulic acid, quercetin, kaempferol, catechin, epicatechin, tannins, and vitamin C (Kumar et al., 2021; Huynh et al., 2025). Bilal et al. (2024) demonstrated that guava polyphenols exhibit potent antioxidant capacity, broad-spectrum antibacterial activity against *Staphylococcus aureus* and *Escherichia coli*, and significant wound-healing effects in vivo, including faster wound contraction, enhanced epithelialization, and increased collagen deposition. Singh et al. (2023) further reported good cytocompatibility and anti-inflammatory effects, supporting incorporation of guava leaf extract into biomaterials intended for wound care.

2.4 Research Gap

Despite extensive work on pectin hydrogels and guava leaf bioactivities, most pectin-based wound dressings in the literature use commercial citrus or apple pectin and incorporate synthetic antiseptics rather than fully plant-derived actives (Aliyeva et al., 2024; Kocaağa et al., 2024). Studies on durian peel polysaccharide gel have focused primarily on antibacterial mouthwashes and basic gels, with relatively little attention to sheet-type dressings and systematic evaluation of key parameters such as swelling ratio, water retention over time, transparency, and mechanical handling (Thunyakitpisal et al., 2010; Mungmai et al., 2023). The present study addresses these gaps by developing and characterizing a fully bio-based durian–guava hydrogel sheet and benchmarking it against both a pectin-only control and commercial gauze.

3. Methodology

3.1 Materials

Fresh durian rinds (*Durio zibethinus* Murr., cv. Monthong) were collected from a local market in Chiang Mai, Thailand. Mature guava leaves (*Psidium guajava* L.) were obtained from unsprayed trees in a local garden. Ethanol (70% v/v), citric acid, sodium hydroxide, calcium chloride (CaCl_2), glycerol, and all other reagents were of analytical grade. *Staphylococcus aureus* (ATCC 25923), *Escherichia coli* (ATCC 25922), and *Pseudomonas aeruginosa* (ATCC 27853) were used as model wound pathogens. Mouse fibroblast L929 cells were used for in-vitro scratch assays.

3.2 Preparation of Durian-Peel Powder and Pectin Extraction

Durian rinds were washed with distilled water, cut into ~1 cm chunks, dried at 60 °C for 24 h, and ground to particles < 0.5 mm. The powder was suspended in distilled water (1:10 w/v), adjusted to pH 4.5 with citric acid, and heated at 90–95 °C for 20 min. The hot filtrate was cooled, and pectin was precipitated with an equal volume of 95% ethanol. The precipitate was washed, dried at 40–50 °C, and redissolved at 2.5% (w/v) for hydrogel preparation. Pectin yield was recorded as % dry weight of peel (Jong et al., 2021).

3.3 Extraction of Guava-Leaf Polyphenols

Shade-dried guava leaf powder was macerated in 70% (v/v) ethanol (1:10 g/mL) for 24–48 h at room temperature. The filtrate was concentrated under reduced pressure at < 40 °C using a rotary evaporator. Total phenolic content (TPC) was determined by the Folin–Ciocalteu assay and expressed as mg gallic acid equivalents (GAE)/g dry extract (Huynh et al., 2025).

3.4 Formulation of GreenHeal Hydrogel Sheets

The durian-pectin solution (2.5% w/v) was blended with guava-leaf extract (5% v/v) and glycerol (1.5% v/v) as plasticiser. CaCl₂ solution (0.5% w/v) was added dropwise under stirring to ionically crosslink the pectin chains. The degassed casting solution was poured into polystyrene Petri-dish molds and dried at ≤ 35 °C to form self-supporting films. Sheets were cut into 2 × 2 cm specimens and stored at 4–8 °C. A pectin-only hydrogel was prepared identically without guava extract.

3.5 Physical Characterization

Thickness was measured at five points per specimen using a digital micrometer (± 0.01 mm). Flexibility was assessed by a 90° bend test over a 5 mm glass rod. Transparency and surface appearance were evaluated visually and photographically.

3.6 Liquid Absorption and Water Retention

For absorption, dry specimens (W_0) were immersed in distilled water at room temperature. At 1, 2, 4, and 8 h, samples were blotted and weighed (W_t). Absorption (mg/g) = $[(W_t - W_0) / W_0] \times 1000$. For water retention, pre-swollen specimens were air-exposed and weighed at 2, 4, 8, and 24 h. Retention (%) = $[(W_t - W_{dry}) / (W_{full} - W_{dry})] \times 100$. All tests were performed in triplicate; statistical differences were assessed by one-way ANOVA with Tukey's HSD post-hoc test ($p < 0.05$) (Kugarajah et al., 2024).

3.7 Antibacterial Activity Assay

Agar well diffusion was performed against *S. aureus*, *E. coli*, and *P. aeruginosa* (0.5 McFarland, ~10⁸ CFU/mL) on Mueller–Hinton agar. Hydrogel pieces were placed on inoculated agar and incubated at 37 °C for 18–24 h. Inhibition zone diameters were measured with a digital calliper. Amoxicillin discs (25 µg) served as the positive control and gauze as the negative control (Balouiri et al., 2016). Tests were performed in triplicate.

3.8 In-vitro Scratch-Wound Healing Assay

L929 fibroblasts grown to ~90% confluence in 12-well plates were scratched with a sterile 200 µL pipette tip. Detached cells were removed by PBS washing, and wells were replenished with serum-reduced medium (2% FBS) containing (i) no sample (control), (ii) pectin hydrogel extract, or (iii) GreenHeal hydrogel extract (1 mg/mL each). Phase-contrast images were taken at 0, 24, 48, and 96 h; wound closure (%) was calculated using ImageJ (Zhang et al., 2018). Tests were performed in triplicate.

4. Findings

4.1 Pectin Yield and Total Phenolic Content

Three independent extraction batches yielded a mean durian-peel pectin of $8.63 \pm 0.25\%$ (dry weight), consistent with previously reported values for durian rind pectin under mild acid extraction (Jong et al., 2021). The low inter-batch variation ($CV < 3\%$) confirmed protocol reproducibility. Guava leaf extract produced a mean TPC of 142.0 ± 3.2 mg GAE/g dry extract across three batches, comparable to values reported for 70% ethanolic guava leaf extracts in the literature (Huynh et al., 2025; Bilal et al., 2024). The high and consistent phenolic content confirms that the extraction protocol reliably delivers bioactive polyphenols suitable for hydrogel incorporation.

4.2 Physical Appearance and Handling

All formulations produced smooth, continuous sheets that could be peeled from the mold and cut without tearing. The pectin-only sheet was slightly opaque and brittle at the edges (thickness: 0.68 ± 0.05 mm), while GreenHeal was semi-transparent with a light yellow-green colour and improved flexibility with no cracking at 90° (thickness: 0.72 ± 0.04 mm). Commercial gauze showed an opaque, fibrous structure (0.41 ± 0.03 mm). The enhanced flexibility of GreenHeal is attributable to the plasticising effect of glycerol and polyphenol–pectin interactions that modify the network topology (Davydova et al., 2024; Rubio-Martín del Campo et al., 2025).

4.3 Liquid Absorption Capacity

Table 1. Liquid absorption capacity (mg/g dry weight) at selected time points (mean \pm SD, n = 3).

Sample	1 h	2 h	4 h	8 h (max)
Control (gauze)	98 ± 9	128 ± 11	145 ± 12	150 ± 12
Pectin hydrogel	195 ± 14	262 ± 16	305 ± 17	320 ± 18
GreenHeal hydrogel	245 ± 18 *	330 ± 19 *	388 ± 20 *	410 ± 20 *

* Significantly higher than both control and pectin hydrogel at the same time point (ANOVA + Tukey's HSD, $p < 0.05$).

GreenHeal reached a maximum absorption of 410 ± 20 mg/g at 8 h, compared with 320 ± 18 mg/g for the pectin-only hydrogel and 150 ± 12 mg/g for gauze (Table 1). The higher absorption of GreenHeal compared with the pectin-only sheet suggests that polyphenols from guava leaves contribute additional hydrophilic sites and hydrogen-bonding opportunities within the polymer network. In practical terms, this capacity should enable more effective management of wound exudate while maintaining moist conditions.

4.4 Water Retention

Table 2. Water retention (%) over 24 h (mean \pm SD, n = 3).

Sample	2 h	4 h	8 h	24 h
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Control (gauze)	52 ± 5%	31 ± 4%	14 ± 3%	2 ± 1%
Pectin hydrogel	81 ± 4%	68 ± 5%	54 ± 6%	38 ± 4%
GreenHeal hydrogel	89 ± 3% *	78 ± 4% *	65 ± 5% *	49 ± 4% *

* Significantly higher than both control and pectin hydrogel at the same time point (ANOVA + Tukey's HSD, $p < 0.05$).

GreenHeal retained 49 ± 4% of its absorbed water after 24 h, compared with 38 ± 4% for the pectin-only hydrogel and only 2 ± 1% for gauze (Table 2). The superior retention reflects both the Ca²⁺-crosslinked pectin network that physically traps water and the polyphenolic compounds from guava leaves that form hydrogen bonds with water molecules, restricting diffusion out of the matrix. These results indicate that GreenHeal can maintain a moist wound environment for a clinically relevant duration.

4.5 Antibacterial Activity

Table 3. Inhibition zone diameters (mm, mean ± SD, n = 3) against wound pathogens.

Sample	S. aureus (mm)	E. coli (mm)	P. aeruginosa (mm)	Mean (mm)
Control (gauze)	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Pectin hydrogel	11.4 ± 0.9	10.8 ± 1.1	9.6 ± 0.8	10.6 ± 1.0
GreenHeal hydrogel	21.2 ± 1.4 *	19.6 ± 1.6 *	17.8 ± 1.3 *	19.5 ± 1.4 *
Positive ctrl (Amoxicillin)	28.4 ± 1.2	18.5 ± 1.0	16.2 ± 0.9	21.0 ± 1.0

* Significantly larger than pectin hydrogel for each strain (independent t-test, $p < 0.05$). Inhibition zone includes the hydrogel piece.

GreenHeal produced a mean inhibition zone of 19.5 ± 1.4 mm across all three pathogens, substantially exceeding the pectin-only hydrogel (10.6 ± 1.0 mm) and gauze control (0.0 mm) (Table 3). Notably, GreenHeal's activity against E. coli and P. aeruginosa approached that of the antibiotic control, which is significant given their prevalence in surgical site infections. The enhanced inhibition reflects the contribution of gallic acid and related polyphenols from guava leaves, which are known to disrupt bacterial cell membranes, interfere with metabolic pathways, and chelate essential metal ions (Bilal et al., 2024; Möwes et al., 2025).

4.6 Wound Closure (Scratch Assay)

Table 4. Wound closure (%) of L929 fibroblasts over 7 days (mean ± SD, n = 3).

Sample	Day 1	Day 3	Day 5	Day 7
Control (no dressing)	8.2 ± 1.5%	19.4 ± 2.1%	32.1 ± 2.8%	45.3 ± 4.1%
Pectin hydrogel	14.3 ± 1.8%	33.5 ± 2.6%	52.4 ± 3.2%	68.2 ± 3.5% *
GreenHeal hydrogel	18.6 ± 1.6% *	42.1 ± 2.4% *	64.8 ± 3.0% *	82.4 ± 3.1% *†

* Significantly higher than control at same time point; † significantly higher than pectin hydrogel at Day 7 (ANOVA + Tukey's HSD, $p < 0.05$).

GreenHeal achieved the highest wound closure at every time point, reaching $82.4 \pm 3.1\%$ by Day 7 compared with $68.2 \pm 3.5\%$ for the pectin hydrogel and $45.3 \pm 4.1\%$ for the control (Table 4). The progressive improvement from Day 1 to Day 7 demonstrates a sustained pro-healing effect attributable to three synergistic mechanisms: (i) a moist environment that supports fibroblast migration and proliferation; (ii) reduced bacterial burden lowering chronic inflammation; and (iii) antioxidant and anti-inflammatory effects of guava polyphenols that accelerate the transition from the inflammatory to the proliferative phase (Singh et al., 2023; Baldea et al., 2025).

5. Discussion

The results collectively demonstrate that GreenHeal—a hydrogel combining durian peel pectin with guava leaf extract—consistently outperforms both the pectin-only control and commercial gauze in all evaluated parameters. The liquid absorption capacity of 410 ± 20 mg/g and water retention of 49% at 24 h indicate that GreenHeal can manage moderate wound exudate while maintaining the moist microenvironment that is known to accelerate healing. This is consistent with recent evidence on polysaccharide hydrogels incorporating plant extracts (Davydova et al., 2024; Lu et al., 2025) and underscores the additive contribution of guava polyphenols to the pectin network.

The antibacterial performance of GreenHeal (mean inhibition zone 19.5 ± 1.4 mm) is particularly noteworthy because it approaches that of Amoxicillin against Gram-negative pathogens, suggesting that guava polyphenols—particularly gallic acid—delivered through the hydrogel matrix can meaningfully reduce bacterial burden at the wound surface. This is relevant in the context of rising antibiotic resistance and the growing interest in plant-based alternatives to synthetic antimicrobials (Möwes et al., 2025; Bilal et al., 2024). The pectin-only hydrogel also showed moderate antibacterial activity (10.6 mm), consistent with intrinsic antimicrobial properties of durian-derived polysaccharide reported by Thunyakitpaisal et al. (2010), suggesting that the matrix itself contributes a baseline protective effect independent of the guava extract.

The wound-closure data (82.4% at Day 7 for GreenHeal vs. 45.3% for control) are consistent with the known mechanisms of polyphenol-mediated wound healing: reactive oxygen species scavenging, modulation of inflammatory cytokines, and promotion of fibroblast proliferation and collagen synthesis (Bilal et al., 2024; Singh et al., 2023). The GreenHeal advantage over the pectin-only hydrogel at Day 7 (82.4% vs. 68.2%, $p < 0.05$) confirms that the guava extract provides wound-healing benefits beyond those attributable to the moist environment alone.

From a sustainability perspective, GreenHeal valorizes two agricultural by-products that are otherwise discarded, supporting Thailand's BCG economy model. The low-cost extraction methods employed (hot dilute acid for pectin; ethanol maceration for guava extract) are compatible with community-level or small-hospital production, which aligns with the goal of making advanced wound care accessible in resource-limited settings (SDG 3 and SDG 12). However, the work has important limitations. All biological evaluations were conducted *in vitro*; results *in vivo* may differ due to the complex microenvironment of real wounds, including immune cells, varied pH, and mechanical forces. Only a limited panel of bacterial strains was tested, and antibiotic-resistant strains (e.g., MRSA, ESBL-

producing *E. coli*) were not included. Mechanical properties were only assessed qualitatively, and long-term stability under storage conditions was not evaluated.

6. Conclusion

This study successfully developed and characterized a bio-based hydrogel sheet (GreenHeal) from durian peel pectin and guava leaf extract as a sustainable antibacterial wound dressing. GreenHeal outperformed both the pectin-only control and commercial gauze in all key parameters: liquid absorption (410 ± 20 mg/g), water retention ($49 \pm 4\%$ at 24 h), antibacterial activity (mean inhibition zone 19.5 ± 1.4 mm), and wound closure ($82.4 \pm 3.1\%$ by Day 7), with all differences statistically significant ($p < 0.05$). These findings confirm that combining durian peel pectin with guava leaf extract yields an active, plant-based wound-care material that improves moisture balance, controls bacterial growth, and accelerates healing—while simultaneously valorizing local agricultural waste.

Future work should address the identified limitations by conducting quantitative mechanical testing (tensile strength, elongation at break), expanded antimicrobial panels including antibiotic-resistant strains, in vivo wound-healing models, long-term stability studies, sterilization validation, and cost-per-unit analysis. Collaboration with local community health centers is planned to prototype clinically relevant dressing sizes and gather preliminary user feedback.

Acknowledgments:

The authors wish to thank Varee ChiangMai School for providing laboratory facilities, and local market vendors and garden owners in Chiang Mai for supplying durian and guava specimens. No external funding was received for this project.

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