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Chitosan and Red Ginger Extract Patches for Diabetic Foot Ulcers: An Alternative for Urban Healthcare Challenges

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ABSTRACT

Diabetic foot ulcers (DFUs) are a severe complication of diabetes, particularly in urban areas where healthcare access and infection risks pose significant challenges. This study investigates the potential of transdermal patches combining chitosan and red ginger (*Zingiber officinale var. rubrum*) extract to improve DFU care. Patches were formulated with varying concentrations of chitosan (2%, 3%, and 4%) and red ginger extract (0%, 5%, 10%, and 15%) and evaluated for physical properties, moisture retention, durability, and antimicrobial activity against *Staphylococcus aureus*. Results identified 3% chitosan with 5% red ginger extract as the optimal formulation, offering superior water retention, balanced durability, and moderate antimicrobial efficacy. These findings highlight the potential of chitosan-red ginger patches as cost-effective, adaptable solutions for DFU care, addressing critical needs for infection control, hydration, and patient comfort in resource-limited urban healthcare settings. Future studies should validate clinical efficacy and investigate scalability for broader implementation.

Keywords: Diabetic foot ulcers, Chitosan, Red ginger, Wound Dressing, Antimicrobial

INTRODUCTION

Diabetes is one of the leading causes of disability worldwide, with urban populations being particularly at risk due to delayed access to healthcare and limited wound care facilities [1]. Factors like sedentary lifestyles, high-calorie diets, and stress contribute to the growing number of diabetes cases in cities [2]. Diabetic foot ulcers (DFUs) are one of the most serious complications of diabetes, a condition that create an infection problem in addition of the already on going diabetic metabolic syndrome [3].

DFUs are especially challenging to manage because they are often infected with bacteria like *Staphylococcus aureus*, a pathogen that has become increasingly resistant to antibiotics in densely populated urban settings [4], [5]. Infections can quickly worsen, leading to severe complications and even amputations. Effective treatment for DFUs requires a combination

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of infection control, moisture management, and wound healing—needs that are often unmet in resource-constrained urban healthcare systems [6].

Red ginger (*Zingiber officinale var. rubrum*), a medicinal plant known for its antibacterial and anti-inflammatory properties, offers a natural alternative to synthetic antibiotics. Compounds like gingerol and shogaol found in red ginger have shown the ability to kill bacteria and reduce inflammation, both of which are crucial for healing chronic wounds [7], [8]. Chitosan, a natural polymer derived from crustacean shells, also holds great promise in wound care. It has antimicrobial properties and helps wounds heal by keeping them moist and supporting cell growth [9].

By combining red ginger extract with chitosan into a transdermal patch, this study seeks to create a localized therapy for DFUs that addresses key urban healthcare challenges which is targeted infection control, moisture management, and cost-effectiveness. This study aims to create a solution that addresses the growing need for innovative, cost-effective treatments for DFUs in urban populations. By combining red ginger's natural antibacterial properties with chitosan's wound-healing potential, this patch has the potential to improve wound care while addressing some of the biggest challenges faced by urban healthcare systems.

METHODS

The study utilized an experimental design to evaluate the antimicrobial efficacy and physical properties of chitosan-based transdermal patches containing red ginger (*Zingiber officinale* var. rubrum) extract. The research was conducted at the microbiology and pharmacy laboratories of the Faculty of Medicine and Health Sciences, Atma Jaya University, Indonesia.

Preparation of Red Ginger Extract

Red ginger was sourced from a local market and processed to obtain its essential oil. The rhizomes were washed, dried at 55°C for 48 hours, and ground into a fine powder. Extraction was performed using the Soxhlet method with *n*-hexane as the solvent at 80°C for 8 hours. The resulting extract was purified using a rotary evaporator at 40°C and further processed in a water bath to remove residual solvents.

Preparation of Chitosan-Based Hydrogel

Chitosan solutions at concentrations of 2%, 3%, and 4% were prepared by dissolving chitosan powder in 1% acetic acid. Tween 80 was added to enhance homogenization, followed by calcium chloride for cross-linking. Red ginger extract was incorporated into the chitosan solution at varying concentrations (0%, 5%, 10%, and 15%). The mixtures were stirred using a magnetic stirrer for 2 hours, then poured into petri dishes and dried in an oven at 55°C for 48 hours to form thin film-like transdermal patches.

Physical and Chemical Characterization of Patches

Visual and physical properties is done by visually inspecting each patch for clarity, color, and texture. Thickness and mass were measured using a micrometer screw gauge and a precision balance, respectively. Moisture absorption and fluid retention is measured by exposing patch to controlled humidity in a desiccator and evaluated for weight changes. Fluid absorption tests were conducted by immersing patches in water and potassium chloride solutions for 24 hours. Durability test is done by assessing the fold endurance, we repeatedly folded the patches at the same point until breakage occurred.

Antimicrobial Evaluation

The antimicrobial properties of the patches were tested against *Staphylococcus aureus* (ATCC 25923) using the disc diffusion method on Mueller-Hinton agar plates. Bacterial suspensions were prepared to match the 0.5 McFarland standard and uniformly spread on the agar surface. Sterile discs soaked in patch solutions were placed on the agar and incubated at 37°C for 18-24 hours. Zones of inhibition were measured to determine the effectiveness of the patches.

RESULTS AND DISCUSSION

Physical Properties and Applicability

The physical characteristics of the patches revealed a balance between structural integrity and practical usability. Lower chitosan concentrations (2%) produced thinner, smoother patches, making them suitable for irregular wound surfaces like those in DFUs. Smooth, flexible patches can significantly enhance patient adherence, an essential factor in urban settings where inconsistent healthcare access often limits treatment efficacy. Furthermore, the natural transparency and light weight of these patches add to their practicality, aligning with urban health goals of comfort and convenience for patients managing comorbid conditions in active lifestyles [10].

Table 1. Physical Properties Evaluation

Chitosan Concentration (%)	Red Ginger Extract Concentration (%)	Mass (g)	Thickness (mm)	Texture	Appearance
2	0-15	0.39-0.54	1.5-1.8	Smooth	Clear
3	0-15	0.54-0.73	1.5-2.0	Moderate	Yellowish
4	0-15	0.68-0.80	1.3-2.0	Rough	Yellowish

Moisture Absorption, Fluid Retention, and Durability

The findings reveal that moisture absorption remains stable across all formulations, regardless of chitosan or ginger extract concentrations. This stability ensures that the patches can adapt to diverse urban climatic conditions without compromising their ability to draw air moisture. Water and KCl retention, which reflect the patch's capacity to maintain hydration and balance electrolytes in exudative wounds, peaked with 3% chitosan and 5% red ginger extract. This formulation demonstrated superior water retention (5.29 times) and adequate ionic retention, making it ideal for managing moderate to highly exudative wounds, a common characteristic of DFU.

Durability is critical for wound dressing in urban environments, where patients often have limited access to medical supplies. The 2% chitosan patches with 15% red ginger extract exhibited the highest fold endurance, sustaining up to 8.33 folds. This resilience could supports prolonged wear, reducing the frequency of replacements and associated healthcare costs. Durability also ensures consistent therapeutic effects, which is essential for urban populations where mobility and economic constraints influence treatment adherence.

Table 2. Moisture Absorption, Fluid Retention, and Durability Evaluation

Chitosan Concentration (%)	Red Ginger Extract Concentration (%)	Moisture Absorption (Times)	Water Retention (Times)	KCl Retention (Times)	Fold Endurance (Times)
2	0	1.27	2.31	1.52	7.33
	5	1.17	3.38	2.13	6.33
	10	1.19	3.07	1.98	5.67
	15	1.23	2.48	1.65	8.33
3	0	1.15	3.65	2.14	6.67
	5	1.13	5.29	3.05	3.67
	10	1.13	4.50	2.57	4.67
	15	1.13	4.12	2.38	4.00
4	0	1.12	3.56	2.11	4.67
	5	1.12	3.94	2.34	3.33
	10	1.12	3.31	2.01	3.33
	15	1.13	3.01	2.29	3.33

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Antimicrobial Efficacy and Resistance Mitigation

The patches demonstrated moderate antimicrobial activity against *Staphylococcus aureus*, with inhibition zones up to 1.03 cm observed in patches containing 15% red ginger extract. While the effect was not extensive, the localized action is possible in combating infections in urban healthcare contexts. The antimicrobial activity of red ginger (Zingiber officinale var. rubrum) extract is attributed to bioactive compounds such as gingerols, shogaols, zingiberene, and phenolic and terpenoid compounds. Key agents like [10]-gingerol, [12]-gingerol, (6)-shogaol, zingiberene, and zingerone effectively inhibit bacterial growth, particularly against gram-positive bacteria like *Staphylococcus aureus* and pathogens associated with periodontal diseases. Phenolic compounds and terpenoids enhance these effects by disrupting bacterial cell walls and biofilms [11], [12]. Urban settings face high antimicrobial resistance due to widespread antibiotic overuse. Localized antimicrobial therapies like these patches reduce systemic antibiotic reliance, mitigating resistance development while targeting the infection site directly. The antimicrobial properties of red ginger are well-documented, with phenolic compounds such as gingerol and shogaol shown to inhibit bacterial growth and suppress inflammatory mediators like COX-2 [13], [14]. However, the observed inhibition zones suggest the need for further optimization, such as enhancing extract purity or combining it with other natural antimicrobials for synergistic effects like black turmeric that is easily found and had antimicrobial potential as well [15].

Table 3. Antimicrobial Activity of patch against *S. aureus*

Chitosan Concentration (%)	Ginger Extract Concentration (%)	Inhibition Zone (cm)
2	0	0.73
	5	0.80
	10	1.00
	15	1.03
3	0	0.97
	5	0.93
	10	0.93
	15	0.83
4	0	0.87
	5	0.90
	10	0.97
	15	0.93

Potential Patch Applications for Diabetic Foot Ulcer in Urban Health

The success of wound care patches in managing diabetic foot ulcers (DFU) hinges on balancing hydration, infection control, durability, and patient comfort. Among the tested formulations, **3% chitosan with 5% red ginger extract** stands out as the optimal choice. This formula achieves superior water retention, essential for maintaining a moist wound environment, and demonstrates robust fold endurance, making it suitable for wounds in mobile patients. Its moderate antimicrobial efficacy is sufficient for most DFU cases without compromising other properties. These characteristics make it versatile for urban healthcare settings, where diverse patient needs and dynamic lifestyles require adaptable and effective solutions. In contrast, **4% chitosan with 10% red ginger extract** offers maximum durability, making it appropriate for managing severe or heavily exudative wounds. However, its rigidity and rough texture may limit patient comfort, particularly for wounds in sensitive or high-mobility areas. Therefore, for more specialized cases—such as infections or wounds requiring structural support—tailored formulations with possible higher red ginger extract or chitosan concentrations should be prioritized. This adaptive approach ensures effective DFU management across urban healthcare scenarios, reducing complications and improving patient outcomes [16], [17].

CONCLUSION

This study demonstrates the potential of chitosan-red ginger patches as an innovative solution for DFU management, particularly in urban healthcare. The chitosan with red ginger extract formulation provides the balance of hydration, antimicrobial efficacy, and durability, making it ideal for most DFU cases. However, the low to moderate antimicrobial activity indicates the need for a combination herbal agent for a better activity. These patches offer a potentially cost-effective, localized therapy that aligns with urban healthcare challenges, promising improved outcomes and reduced systemic antibiotic reliance. Future studies should validate clinical efficacy and scalability.

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CONFLICT OF INTEREST

Authors declare no conflict of interest.

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