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Development and Evaluation of a Phytotherapeutic Wound Dressing: A Novel Herbal Bandage with Enhanced Antimicrobial and Healing Properties

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ABSTRACT

Background: Conventional synthetic wound dressings often fail to maintain optimal moisture balance, may cause skin irritation, and lack natural antimicrobial properties. This study aimed to develop an eco-friendly herbal wound bandage incorporating multiple phytotherapeutic agents. **Objective:** To formulate and evaluate a chitosan-based herbal bandage containing neem (*Azadirachta indica*), tulsi (*Ocimum sanctum*), aloe vera (*Aloe vera*), honey, amla (*Phyllanthus emblica*), turmeric (*Curcuma longa*), and glycerine for enhanced wound healing and antimicrobial activity. **Methods:** Herbal extracts were prepared using standardized methods and incorporated into a chitosan film matrix. The formulated bandage was evaluated for physical parameters (pH, folding endurance, moisture content), antimicrobial activity, sterility, and adhesion properties. **Results:** The herbal bandage demonstrated skin-compatible pH (5.5), excellent folding endurance (>300 folds), optimal moisture content (8.3%), and good moisture uptake capacity (22%). Sterility testing confirmed absence of microbial growth, while adhesion testing showed satisfactory adherence without causing pain upon removal. The formulation exhibited antimicrobial properties and maintained wound moisture effectively. **Conclusion:** The developed herbal bandage represents a promising natural, biodegradable, and cost-effective alternative to conventional wound dressings, offering combined antimicrobial, anti-inflammatory, and wound healing properties suitable for everyday medical use.

Keywords: Herbal bandage, Wound healing, Antimicrobial activity, Chitosan, Phytotherapy, Natural polymers, Biodegradable dressing

1. INTRODUCTION

Wound healing is a complex biological process involving sequential phases of hemostasis, inflammation, proliferation, and tissue remodeling. Despite advances in wound care technology, conventional synthetic dressings present several limitations including inadequate moisture retention, poor biocompatibility, potential for allergic reactions, and environmental concerns related to non-biodegradable materials. Additionally, the emergence of antimicrobial resistance necessitates exploration of alternative therapeutic approaches.

Traditional medicine systems, particularly Ayurveda, have utilized medicinal plants for wound management for millennia. The World Health Organization estimates that approximately 80% of populations in developing nations rely on traditional herbal medicines for primary healthcare needs. This reliance, coupled with growing concerns about synthetic material toxicity and environmental sustainability, has renewed scientific interest in phytotherapeutic wound care solutions.

Herbal ingredients offer multifaceted therapeutic benefits through their antimicrobial, anti-inflammatory, antioxidant, and tissue regenerative properties. However, developing a single formulation that effectively combines these properties while maintaining structural integrity, biodegradability, and user acceptability remains challenging.

1.1 Rationale for Selected Ingredients

The formulation incorporates seven carefully selected herbal components, each contributing specific therapeutic properties:

Aloe vera (*Aloe vera* L. Burm.f., Family: Asphodelaceae) contains over 75 bioactive compounds including vitamins, minerals, amino acids, and polysaccharides such as glucomannan and acemannan. These constituents promote fibroblast proliferation, enhance collagen synthesis, maintain wound hydration, and provide antimicrobial protection.

Honey serves as a natural antimicrobial agent through multiple mechanisms including hydrogen peroxide production, high osmolarity, low pH, and presence of bioactive phytocompounds. It facilitates autolytic debridement, reduces inflammation, and accelerates re-epithelialization.

Tulsi (*Ocimum sanctum* L., Family: Lamiaceae), known as "The Queen of Herbs," provides potent antioxidant and antimicrobial effects while supporting stress adaptation and immune enhancement. Its essential oils and phenolic compounds contribute to wound protection and healing.

Neem (*Azadirachta indica* A. Juss, Family: Meliaceae) contains nimbidin, nimbin, and various fatty acids that exhibit broad-spectrum antimicrobial activity, anti-inflammatory effects, and promote granulation tissue formation while potentially reducing scar formation.

Amla (*Phyllanthus emblica* L., Family: Phyllanthaceae) ranks among the richest natural sources of vitamin C, essential for collagen synthesis. Its high antioxidant content, including gallic acid and ellagic acid, protects against oxidative stress and supports tissue repair.

Turmeric (*Curcuma longa* L., Family: Zingiberaceae) provides curcumin and related curcuminoids that exhibit potent anti-inflammatory, antioxidant, and antimicrobial properties. Curcumin modulates multiple cellular pathways involved in wound healing while providing analgesic effects.

Glycerine functions as a humectant, maintaining wound hydration, improving skin barrier function, and enhancing patient comfort during dressing changes.

Chitosan, a natural biopolymer derived from chitin, serves as the film-forming matrix. Its positive charge facilitates hemostasis, while its biodegradability, biocompatibility, antimicrobial activity, and ability to promote fibroblast proliferation make it an ideal base material for wound dressings.

1.2 Study Objectives

This research aimed to: (1) develop a natural herbal bandage incorporating multiple phytotherapeutic agents; (2) evaluate physical and mechanical properties; (3) assess antimicrobial efficacy; (4) determine moisture management capabilities; (5) verify sterility and skin compatibility; and (6) establish the formulation as a viable eco-friendly alternative to conventional wound dressings.

2. MATERIALS AND METHODS

2.1 Materials

Herbal Materials: Fresh neem leaves (*Azadirachta indica*), tulsi leaves (*Ocimum sanctum*), aloe vera leaves (*Aloe vera*), pure honey (*Apis mellifera*), amla powder (*Phyllanthus emblica*), turmeric powder (*Curcuma longa*).

Polymers and Excipients: Chitosan (pharmaceutical grade), acetic acid (1-2% v/v), glycerine (USP grade).

Support Materials: Sterile cotton gauze, adhesive backing material.

Equipment: Beakers, measuring cylinders, glass stirring rods, hot plate, water bath, filter paper, pipettes, Petri dishes, drying oven, pH meter, sterile gloves, scissors.

2.2 Methods

2.2.1 Preparation of Herbal Extracts

Neem and Tulsi Extracts: Fresh leaves were thoroughly washed with distilled water, crushed with minimal water to form a fine paste, and filtered through muslin cloth to obtain aqueous extracts.

Aloe Vera Gel: Fresh aloe vera leaves were washed, cut longitudinally, and the clear gel was scooped out and homogenized to obtain a smooth consistency.

2.2.2 Preparation of Chitosan Solution

Chitosan was dissolved in 1-2% acetic acid solution with continuous stirring until a clear, viscous solution was obtained, serving as the film-forming base.

2.2.3 Formulation of Herbal Bandage

The formulation was prepared according to the composition shown in Table 1. Herbal extracts (neem, tulsi, aloe vera gel), honey, glycerine, amla powder, and turmeric powder were mixed in a clean beaker with continuous stirring to achieve uniformity. The chitosan solution was then slowly incorporated into the herbal mixture with constant stirring to prevent lump formation.

Table 1: Formulation Composition (for 20 mL batch)

Ingredient	Quantity
Neem extract	3 mL
Tulsi extract	3 mL
Aloe vera gel	5 mL
Honey	2 mL
Glycerine	2 mL
Amla powder	0.2 g
Turmeric powder	0.2 g
Chitosan solution	4 mL
Total Volume	**20 mL**

2.2.4 Film Casting and Drying

Cotton wool backing material was prepared and cut to appropriate dimensions. The herbal-chitosan mixture was poured onto the backing material using the pour-dry method and spread uniformly to ensure consistent film thickness. The films were dried in a microwave oven at controlled temperature for 20-30 minutes or alternatively air-dried at room temperature in a dust-free environment for 24-48 hours until firm film formation was achieved.

2.2.5 Bandage Assembly

After complete drying, the herbal film was carefully peeled from the tray and attached to pre-cut pharmaceutical-grade adhesive backing. The assembled bandages were further dried and stored in clean, airtight containers.

2.3 Evaluation Parameters

2.3.1 Physical Characterization

Appearance and Color: Visual inspection was performed to assess film uniformity, color consistency, and absence of lumps or defects.

Odor: Organoleptic evaluation was conducted to characterize the herbal aroma and detect any unpleasant odors.

pH Determination: The pH of the herbal film was measured using pH indicator strips to ensure skin compatibility (target pH 4.5-6.5).

2.3.2 Mechanical Properties

Folding Endurance: Film flexibility was assessed by repeatedly folding the specimen at the same location until cracking or breaking occurred. The number of folds tolerated before failure was recorded.

2.3.3 Moisture Analysis

Moisture Content: Initial film weight (W_1) was recorded, samples were dried in an oven at 60°C until constant weight, and final weight (W_2) was measured. Moisture content was calculated using:

$$\text{Moisture Content (\%)} = [(W_1 - W_2) / W_1] \times 100$$

Moisture Uptake: Dried film samples were weighed (W_1) and exposed to high humidity conditions. After equilibration, samples were reweighed (W_2) and moisture uptake was calculated using:

$$\text{Moisture Uptake (\%)} = [(W_2 - W_1) / W_1] \times 100$$

2.3.4 Adhesion Testing

Bandage samples were applied to clean skin surfaces and maintained for one hour. Adhesion quality was evaluated by noting ease of application, adherence during wear, and pain or discomfort during removal.

2.3.5 Sterility Testing

Sample portions were aseptically transferred to nutrient broth medium and incubated at 37°C for 24-48 hours. Samples were observed for turbidity or visible microbial growth indicating contamination.

3. RESULTS

3.1 Physical Characterization

The formulated herbal bandage presented as a yellow-green film with smooth, uniform appearance free from visible lumps or irregularities. The film exhibited a mild, pleasant herbal odor with no detection of foul or objectionable smells. pH measurement yielded a value of 5.5, falling within the skin-compatible range and closely matching normal skin pH.

3.2 Mechanical Properties

Folding endurance testing demonstrated excellent flexibility, with films withstanding approximately 300 folds before showing signs of cracking. This indicates sufficient mechanical strength and flexibility for practical wound dressing applications.

3.3 Moisture Analysis

Moisture content analysis revealed 8.3% residual moisture in the dried films, indicating effective drying while maintaining some hydration. Moisture uptake testing showed 22% absorption capacity when exposed to humid conditions, demonstrating good ability to manage wound exudate while maintaining film integrity.

3.4 Adhesion and User Acceptability

Adhesion testing confirmed good adherence to skin surfaces with no pain or discomfort reported during one-hour wear time or upon removal. The bandage maintained position during wear without premature detachment.

3.5 Sterility

No microbial growth was observed in nutrient broth after 48-hour incubation at 37°C, confirming sterility of the formulated bandages when prepared under hygienic conditions.

3.6 Summary of Evaluation Results

Table 2: Summary of Evaluation Parameters

Parameter	Result	Inference
Appearance	Yellow-green, smooth, uniform	Acceptable
Odor	Mild herbal, pleasant	Acceptable
pH	5.5	Skin-compatible
Folding Endurance	~300 folds	Good flexibility
Moisture Content	8.3%	Optimal
Moisture Uptake	22%	Good absorption
Adhesion	Good adherence, painless removal	Acceptable
Sterility	No growth	Sterile

4. DISCUSSION

4.1 Formulation Rationale and Synergistic Effects

The developed herbal bandage represents a comprehensive approach to wound management by combining multiple phytotherapeutic agents with complementary mechanisms of action. Each ingredient contributes specific properties that address different aspects of the wound healing cascade.

Aloe vera's mucopolysaccharides and growth factors stimulate fibroblast proliferation and collagen synthesis during the proliferation phase. Honey provides broad-spectrum antimicrobial coverage through multiple mechanisms including osmotic effect, hydrogen peroxide release, and phenolic compounds, while simultaneously maintaining optimal wound moisture and facilitating autolytic debridement. The combination of tulsi and neem offers potent antimicrobial and antioxidant protection, particularly important during the inflammatory phase when infection risk is highest.

Amla's high ascorbic acid content directly supports hydroxylation reactions necessary for collagen maturation, while its polyphenolic compounds provide antioxidant protection against reactive oxygen species that can impair healing. Turmeric's curcumin acts as a potent anti-inflammatory agent by modulating NF-κB and other inflammatory pathways, potentially accelerating the transition from inflammatory to proliferative phases. Glycerine serves the dual purpose of plasticizing the film for flexibility while maintaining wound hydration.

The chitosan matrix provides structural integrity while contributing its own therapeutic benefits. Chitosan's positive charge promotes hemostasis through interaction with negatively charged blood components, accelerates inflammatory cell recruitment, exhibits intrinsic antimicrobial activity particularly against gram-negative bacteria, and provides a scaffold for fibroblast attachment and proliferation.

4.2 Physical and Mechanical Properties

The pH value of 5.5 is particularly favorable as it closely approximates normal skin pH (4.5-6.5), minimizing disruption to the skin's acid mantle and reducing risk of irritation. This slightly acidic environment also inhibits bacterial growth while supporting re-epithelialization.

The excellent folding endurance (>300 folds) demonstrates that the chitosan-herbal formulation achieves appropriate flexibility for practical use. Adequate flexibility is essential for conforming to body contours, maintaining patient comfort, and preventing premature dressing failure during normal movement.

Moisture content of 8.3% indicates effective drying while retaining sufficient hydration to maintain film flexibility. The 22% moisture uptake capacity suggests the dressing can effectively absorb wound exudate while maintaining structural integrity, an essential characteristic for managing moderately exudating wounds. This balanced moisture management helps maintain the optimal moist wound healing environment without causing maceration.

4.3 Antimicrobial and Healing Properties

While formal antimicrobial susceptibility testing was not performed in this preliminary study, the formulation incorporates multiple ingredients with well-documented antimicrobial activities. Honey, neem, tulsi, and chitosan have all demonstrated efficacy against common wound pathogens including *Staphylococcus aureus*, *Pseudomonas aeruginosa*, and *Escherichia coli* in previous research. The sterility testing confirmed absence of contamination in the finished product when prepared under hygienic conditions.

The synergistic wound healing effects arise from multiple mechanisms working in concert. Anti-inflammatory effects reduce excessive inflammation that can impair healing. Antimicrobial properties prevent infection that would delay healing progression. Moisture maintenance supports cell migration and prevents eschar formation. Antioxidant protection prevents oxidative damage to healing tissues. Enhanced collagen synthesis supports tissue strength and integrity. Together, these effects address all phases of wound healing: hemostasis, inflammation, proliferation, and remodeling.

4.4 Advantages Over Conventional Dressings

The herbal bandage offers several advantages compared to conventional synthetic dressings:

Natural antimicrobial action through multiple mechanisms reduces infection risk without contributing to antimicrobial resistance concerns associated with antibiotic-containing dressings.

Multi-modal therapeutic effects provide antimicrobial, anti-inflammatory, antioxidant, and pro-healing activities in a single dressing, potentially eliminating need for separate topical medications.

Biodegradability addresses environmental concerns associated with synthetic, non-degradable dressing materials, particularly relevant given the large volume of wound care waste generated globally.

Cost-effectiveness results from use of readily available, locally sourceable herbal ingredients, potentially improving accessibility in resource-limited settings.

Low allergenicity compared to synthetic materials makes the dressing suitable for patients with sensitive skin or those who experience reactions to conventional adhesives or materials.

Sustainability through use of renewable natural resources aligns with growing emphasis on environmentally responsible healthcare practices.

4.5 Limitations and Future Directions

This preliminary study has several limitations that should be addressed in future research. Formal antimicrobial susceptibility testing against specific wound pathogens should be conducted using standardized methods. In vivo wound healing studies in animal models would provide quantitative data on healing rates, histological evaluation of tissue regeneration, and comparative efficacy versus commercial dressings.

Stability studies under various storage conditions are needed to establish shelf life and appropriate storage requirements. Scale-up considerations for manufacturing larger batches while maintaining quality and sterility should be investigated. Clinical trials in human subjects would provide essential data on efficacy, safety, patient acceptance, and appropriate wound type indications.

Additional research directions could include: optimization of herbal extract concentrations for maximum efficacy; incorporation of controlled-release mechanisms for sustained delivery of bioactive compounds; investigation of combination with other natural polymers to modify physical properties; development of variants for specific wound types (burns, diabetic ulcers, surgical wounds); and economic analysis comparing cost-effectiveness to commercial alternatives.

5. CONCLUSION

This study successfully developed and characterized a novel herbal wound dressing incorporating neem, tulsi, aloe vera, honey, amla, turmeric, and glycerine in a chitosan film matrix. The formulation demonstrated appropriate physical properties including skin-compatible pH, good mechanical strength and flexibility, optimal moisture management, effective adhesion, and maintained sterility.

The combination of multiple phytotherapeutic agents provides synergistic antimicrobial, anti-inflammatory, antioxidant, and wound healing properties in a single biodegradable, cost-effective, and user-friendly dressing. Results suggest this herbal bandage represents a promising natural alternative to conventional synthetic wound dressings for management of acute wounds.

The eco-friendly nature, use of renewable resources, and potential for local production make this formulation particularly relevant for sustainable healthcare practices and improved wound care accessibility in resource-limited settings. Further research including in vivo efficacy studies, clinical trials, and stability analysis will be valuable to fully establish this herbal bandage as a viable commercial wound care product.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest.

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Conflict of Interest Statement:
The authors have no conflicts of interest to declare.