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FORMULATION AND EVALUATION OF HERBAL SMART WOUND HEALING BANDAGE WITH INFECTION INDICATOR

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ABSTRACT

Wound management is an important aspect of healthcare due to the increasing prevalence of chronic wounds, burns, diabetic ulcers, and post-surgical infections. Conventional wound dressings provide physical protection but fail to monitor wound condition continuously. Smart wound dressings are advanced systems capable of responding to wound environment changes such as pH, temperature, and bacterial infection. The present study focuses on the formulation and evaluation of an herbal smart wound healing bandage incorporated with infection indicator properties. The bandage was prepared using biocompatible polymers such as polyvinyl alcohol along with herbal components possessing antimicrobial and wound healing activity. Bromothymol blue and phenol red were incorporated as pH-sensitive indicators for infection detection. The prepared bandage was evaluated for physical appearance, thickness, folding endurance, swelling index, moisture uptake, surface pH, antimicrobial activity, and infection indication response. The formulated bandage demonstrated good flexibility, satisfactory swelling behavior, and effective color-changing ability in response to pH variation. Herbal ingredients showed promising antimicrobial and healing properties. The developed smart bandage may serve as an economical, biocompatible, and efficient alternative to conventional wound dressings.

KEYWORDS: Smart Bandage, Wound Healing, Infection Indicator, Herbal Dressing, Bromothymol Blue, Phenol Red etc.

INTRODUCTION

1. Background of Wound Healing Wound healing is a complex biological process involving a series of overlapping phases— hemostasis, inflammation, proliferation, and remodeling—that work together to restore the skin's

structural and functional integrity. Delayed or improper wound healing can lead to chronic wounds, infections, or scarring. Maintaining a moist, sterile, and oxygen-permeable environment is crucial for proper healing.[1,2]

2. Role of Herbal Medicine in Wound Healing Herbal remedies have been used for centuries to accelerate wound healing because they contain bioactive compounds with antioxidant, antimicrobial, and anti-inflammatory properties. Calendula officinalis (Marigold): enhances granulation tissue formation and epithelialization. Azadirachta indica (Neem): exhibits antibacterial, antifungal, and anti-inflammatory effects that protect wounds from infection. The use of herbal-based dressings minimizes side effects and provides biocompatible, cost effective, and eco-friendly alternatives to synthetic drugs.[1,2,3]
3. Smart Bandages and Infection Indicators “Smart” wound dressings are next-generation biomedical devices capable of detecting changes in the wound microenvironment, such as pH, temperature, moisture, or bacterial load, and responding accordingly. During infection, wound pH shifts from slightly acidic (5.5–6.5) to alkaline (7.5–9.0). This change can be detected by incorporating pH-sensitive dyes like phenol red or bromothymol blue, which change color as infection develops. Hence, a smart infection-indicating bandage can provide early detection, preventing complications and unnecessary antibiotic use.[1,2,3]
4. Hydrogel and Polymer-Based Dressings Hydrogels composed of biopolymers like sodium alginate, chitosan, and PVA provide a moist environment, absorb wound exudates, and allow gaseous exchange. They are ideal carriers for herbal extracts and sensing agents. These hydrogels can be easily cast into thin film or sheet-type bandages and loaded with herbal extracts and indicators without losing flexibility.[1,2,3]
5. Need for Herbal Smart Wound-Healing Bandage Traditional herbal ointments often fail to maintain sterility and moisture. Meanwhile, synthetic smart dressings can be costly and may cause irritation. Therefore, an herbal-based smart bandage with an infection indicator combines both worlds — natural healing + intelligent sensing. Such a system ensures continuous wound monitoring, infection prevention, and improved patient compliance especially in rural healthcare and diabetic wound management.[1,2,3]

PROFILE OF DRUGS AND EXCIPIENTS

Sr. No.	Ingredient	Scientific Name	Role of ingredient
1	Polyvinyl Alcohol (PVA)	-	Film forming agent; provides flexibility and strength
2	Polyvinylpyrrolidone (PVP)	-	Film forming and stabilizing
3	Glycerine	-	Plasticizer; maintains elasticity of film
4	Aloe vera gel	Aloe barbadensis miller	Wound healing and moisturizing agent
5	Neem extract	Azadirachta indica	Antibacterial and antifungal activity
6	Turmeric extract	Curcuma longa	Anti-inflammatory and antiseptic
7	Honey	-	Natural wound healer and antiseptic
8	Bromothymol Blue / Phenol Red	-	pH-sensitive indicator dye for infection detection
9	Distilled water	-	Solvent
10	Sterile Cotton Gauze / Muslin Cloth	-	Coating Bandage Base Material – provides mechanical support and allows air permeability

1. Polyvinyl Alcohol (PVA)

- Biological Source: Synthetic polymer (petroleum derivative)
- Chemical Constituents: Vinyl alcohol repeating units
- Uses: Acts as a film-forming polymer providing strength, elasticity, and structural integrity to the bandage.

2. Polyvinylpyrrolidone (PVP)

- Biological Source: Synthetic polymer
- Chemical Constituents: N-vinylpyrrolidone monomers

3. Uses: Enhances flexibility, improves adhesion of coating, and stabilizes the formulation. Glycerin.

- Biological Source: Obtained from vegetable oils or fats
- Chemical Constituents: Glycerol ($C_3H_8O_3$)
- **Uses**: Works as a humectant and plasticizer; maintains film softness and moisture content.

4. Aloe vera Gel

- Biological Source: Fresh leaves of Aloe barbadensis Miller
- Family: Liliaceae ϖ Chemical Constituents: Aloin, aloesin, anthraquinones, polysaccharides
- Uses: Promotes wound healing, provides soothing and anti-inflammatory effects, and aids in tissue regeneration.

5. Neem Extract

- Biological Source: Leaves of Azadirachta indica ϖ Family: Meliaceae
- Chemical Constituents: Azadirachtin, nimbin, quercetin, nimbidin
- Uses: Exhibits strong antibacterial, antifungal, and wound-healing properties.

6. Turmeric Extract

- Biological Source: Rhizomes of Curcuma longa
- Family: Zingiberaceae
- Chemical Constituents: Curcumin, demethoxycurcumin, bisdemethoxycurcumin
- Uses: Possesses antioxidant, anti-inflammatory, and antimicrobial properties; accelerates tissue repair.

7. Bromothymol Blue / Phenol Red

- Biological Source: Synthetic dye
- Chemical Constituents: Sulfonephthalein derivatives
- Uses: Serves as a pH indicator that changes color with infection due to pH variation in wound exudate.

8. Distilled Water

- Biological Source: Purified water obtained by distillation
- Chemical Constituents: H_2O (free from ions and impurities)
- Uses: Used as solvent and vehicle for dissolving and mixing ingredients.

9. Sterile Cotton Gauze / Muslin Cloth

- Biological Source: Cotton fibers from Gossypium species
- Family: Malvaceae
- Chemical Constituents: Cellulose
- Uses: Used as a natural base for coating the herbal polymeric formulation; breathable and biocompatible dressing material.

FORMULATION TABLE

Sr.No.	Ingredients	F1 (10 mL)	F2 (10 mL)	F3 (10 mL)
1.	Polyvinyl Alcohol (PVA)	1.0 gm	1.2 gm	1.5 gm
2	Polyvinylpyrrolidone (PVP)	0.3 gm	0.4 gm	0.5 gm
3	Glycerine	0.3 ml	0.5 ml	0.7 ml
4	Aloe vera gel	1.0 ml	1.5 ml	2.0 ml
5	Neem Extract	0.5 ml	0.7 ml	1.0 ml
6	Turmeric Extract	0.3 ml	0.5 ml	0.7 ml
7	Bromothymol Blue / Phenol Red	2-3 drops	3-4 drops	4-5 drops
8	Methyl paraben	0.01gm	0.01gm	0.01gm
9	Distilled water	q.s. to 10 mL	q.s. to 10 mL	q.s. to 10 mL
10	Sterile Cotton Gauze / Muslin Cloth	As required	As required	As required

Notes

q.s. = quantum sufficiat (quantity sufficient).

Bromothymol Blue changes color around pH 6.0–7.6.

Phenol Red changes color around pH 6.8–8.4.

These indicators help detect possible wound infection by showing pH changes from acidic/neutral to alkaline conditions.

EXPERIMENTAL WORK

Methodology for preparation of herbal smart wound healing bandage with infection indicator:

The herbal smart wound healing bandage was prepared through a systematic process involving the collection of materials, extraction of herbal components, formulation of a coating solution, impregnation of sterile gauze, and incorporation of a ph-sensitive infection indicator layer. The detailed methodology is described below.

1. Collection of materials All the required materials were procured and arranged before initiating the formulation process. The herbal materials included neem (azadirachta indica), turmeric (curcuma longa), and aloe vera (aloe barbadensis miller). Chitosan was used as the film-forming and wound-healing polymer, while glycerin served as a plasticizer to improve flexibility. Sterile cotton gauze was selected as the base substrate for the bandage. Additional reagents for preparing the ph indicator layer were also collected.
2. Preparation of herbal extracts Fresh neem leaves, turmeric rhizomes, and aloe vera gel were thoroughly washed to remove impurities and dried under shade. The plant materials were separately crushed and extracted using distilled water or a suitable solvent such as ethanol. The extraction process was carried out under controlled conditions to ensure the release of bioactive compounds possessing antimicrobial, anti-inflammatory, and wound-healing properties.
3. Filtration of extracts The prepared extracts were filtered using muslin cloth followed by whatman filter paper to remove insoluble plant residues and obtain clear filtrates. The filtered extracts were stored under refrigerated conditions until further use.
4. Preparation of coating solution A chitosan-based coating solution was prepared by dissolving chitosan in 1% acetic acid with continuous stirring until a homogeneous solution was obtained. Predetermined quantities of neem, turmeric, and aloe vera extracts were added to the chitosan solution. Glycerin was then incorporated as a plasticizer to enhance the flexibility and handling properties of the final bandage. The resulting mixture formed the herbal coating solution. Formulation.

5. Mixing Using Magnetic Stirrer The coating solution was subjected to continuous stirring using a magnetic stirrer for approximately 30–60 minutes. This ensured uniform distribution of the herbal extracts and glycerin throughout the chitosan matrix and resulted in a stable and homogeneous solution.
6. Dipping of Sterile Gauze Sterile gauze pieces of desired dimensions were immersed completely into the prepared coating solution. Care was taken to ensure that the gauze was evenly saturated with the formulation.
7. Soaking The coated gauze was allowed to remain in the coating solution for 10–15 minutes to facilitate adequate absorption and uniform deposition of the herbal-polymeric matrix onto the fibers of the gauze.
8. Drying After soaking, the coated gauze pieces were carefully removed and dried in a hot air oven maintained at 40°C. Drying was continued until a uniform and stable coating was formed on the gauze surface without affecting the biological activity of the herbal constituents.
9. Preparation of pH Indicator A pH-sensitive indicator solution was prepared using suitable natural or synthetic pH responsive dyes. The indicator was designed to exhibit visible color changes corresponding to acidic and alkaline conditions, thereby enabling detection of wound infection based on changes in wound exudate pH.
10. Fabrication of Indicator Layer The prepared pH indicator solution was cast or coated onto a suitable support material such as filter paper or a thin biocompatible film. The layer was dried under controlled conditions to obtain a stable colorimetric sensor strip.
11. Attachment of Indicator Layer The dried pH indicator strip was affixed onto the surface of the coated gauze using a biocompatible adhesive or by lamination. The indicator layer was positioned in such a way that it could come into contact with wound exudate while remaining clearly visible for monitoring color changes.
12. Final Herbal Smart Bandage The final product consisted of a chitosan-coated sterile gauze containing Neem, Turmeric, and Aloe vera extracts along with an integrated pH-sensitive indicator layer. This smart wound dressing provides antimicrobial and wound-healing benefits. while also allowing real- time visual detection of infection through a distinct color change from acidic to alkaline conditions.

EVALUATION PARAMETERS

Evaluation tests of herbal smart wound healing bandage.

The prepared herbal smart wound healing bandage was evaluated using the following parameters to assess its physicochemical properties, mechanical strength, antimicrobial activity, infection-indicating ability, and wound healing efficacy.

1. Organoleptic evaluation Organoleptic evaluation was carried out by visual and sensory inspection to assess the colour, odour, appearance, and texture of the prepared bandage. The formulation was observed for uniformity, flexibility, smoothness, and absence of air bubbles or cracks.
2. Thickness test The thickness of the bandage was measured at different points using a digital micrometer screw gauge, and the average value was calculated to ensure uniformity of the film. 3. Weight variation test Individual bandage samples of identical dimensions were weighed using a digital balance, and the average weight was determined to evaluate uniform distribution of formulation components.
3. Folding endurance test A strip of the bandage was repeatedly folded at the same position until it broke. The number of folds required to break the film was recorded as the folding endurance.

4. Moisture content test The bandage samples were weighed and kept in a desiccator containing anhydrous calcium chloride for 24 hours. After drying, the samples were reweighed and the percentage moisture content was calculated.
5. Swelling index test The dried bandage was weighed and immersed in phosphate buffer solution (ph 7.4). After a predetermined period, the swollen bandage was reweighed and the swelling index was calculated.
6. Surface ph Determination The bandage was moistened with distilled water, and the surface ph was measured using a ph paper to ensure compatibility with skin and wound tissues.
7. Infection indicator response test The ph-sensitive indicator incorporated in the bandage was observed for colour change under different ph conditions to confirm its ability to detect wound infection.
8. Stability study The formulated bandage was stored under accelerated conditions to evaluate changes in physical appearance, drug content, and infection indicator response over time.

RESULT

- **Organoleptic evaluation**

Organoleptic evaluation was carried out by visual and sensory inspection to assess the colour, odour, appearance, and texture of the prepared bandage. The formulation was observed for uniformity, flexibility, smoothness, and absence of air bubbles or cracks.

Parameters	Formulations		
Formulation	F1	F2	F3
Colour	Light Brown	Brown	Dark Brown
Odour	Mild herbal odour	Pleasant herbal odour	Strong herbal odour
Texture	Smooth and flexible	Smooth, uniform & flexible	Slightly thick,uniform&flexible

- **Thickness test**

Parameters	Formulations		
	F1	F2	F3
Thickness	0.42±0.03mm	0.48±0.02mm	0.55±0.04mm

The thickness of the bandage was measured at different points using a digital micrometer screw gauge, and the average value was calculated to ensure uniformity of the film.

- **Weight variation test**

Individual bandage samples of identical dimensions were weighed using a digital balance, and the average weight was determined to evaluate uniform distribution of formulation components.

Parameters	Formulation		
	F1	F2	F3
Weight Variation (measured using Digital Analytical Balance)	1.24±0.05g	1.38±0.04g	1.52±0.06g

- **Folding endurance test**

A strip of the bandage was repeatedly folded at the same position until it broke. The number of folds required to break the film was recorded as the folding endurance.

Parameters	Formulation		
Formulations	F1	F2	F3
Folding Endurance	Good flexibility	Better flexibility	Flexibility flexibility

- **Moisture content test**

The bandage samples were weighed and kept in a desiccator containing anhydrous calcium chloride for 24 hours. After drying, the samples were reweighed and the percentage moisture content was calculated.

Parameters	**Formulation**		
Formulations	F1	F2	F3
Moisture Content %	6.12%	5.48%	4.86%

- **Swelling index test**

The dried bandage was weighed and immersed in phosphate buffer solution (ph 7.4). After a predetermined period, the swollen bandage was reweighed and the swelling index was calculated.

Parameters	**Formulation**		
Formulations	F1	F2	F3
PH Detection Ability	Detectable	Detectable	Highly detectable
Swelling Index (%)	87%	70%	90.3%

*Note: Swelling index (%) = $\frac{WS-Wd}{Wd} \times 100$

Where, WS=Weight of swollen bandage

Wd=Weight of dried bandage

- **Surface Ph Determination**

The bandage was moistened with distilled water, and the surface ph was measured using a ph paper to ensure compatibility with skin and wound tissues.

Parameters	**Formulation**		
Formulations	F1	F2	F3
Surface pH	5.8	6.2	6.6

- **Infection indicator response test**

The ph-sensitive indicator incorporated in the bandage was observed for colour change under different ph conditions to confirm its ability to detect wound infection.

Parameters	**Formulation**		
Formulations	F1	F2	F3
Infection Indicator Response	Slow color change response	Moderate color change response	Rapid &distinct color change response

- **Stability study**

The formulated bandage was stored under accelerated conditions to evaluate changes in physical appearance, drug content, and infection indicator response over time.

Parameters	**Formulation**		
Formulations	F1	F2	F3
Stability test (30days)	Stable	Stable	Highly Stable

CONCLUSION

The present study successfully developed and evaluated an herbal smart bandage for wound healing and infection detection. The formulated bandages showed satisfactory physicochemical properties, antimicrobial activity, sterility, and stability. Among all formulations, F3 exhibited the best overall performance, with excellent antimicrobial activity, rapid infection-indicator response, suitable surface pH, and high stability. Based on the results, F3 was selected as the optimized formulation. The study concludes that the developed herbal smart bandage is a safe, effective, and economical wound dressing with promising potential for improved wound care and early infection monitoring.

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