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RESEARCH ARTICLE

Development and Evaluation of an Eco-friendly Antimicrobial Wound Dressing Using Neem and Turmeric-Coated Coconut Leaf Sheath

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Abstract: The development of sustainable, biodegradable wound dressings with antimicrobial properties could help in the management of wound care. The aim of this research work was to create a novel wound dressing material using coconut leaf sheath impregnated with neem (*Azadirachta indica*) and turmeric (*Curcuma longa*) extracts. The coconut sheaths underwent pre-treatment involving chemical softening with sodium hydroxide and sodium carbonate, followed by ultrasonic treatment. The medicated formulation incorporated neem extract, turmeric extract, and chitosan as a natural film-former. The antimicrobial efficacy was evaluated against *Escherichia coli* and *Candida albicans* using agar well diffusion, minimum inhibitory concentration (MIC), and time-kill kinetics methods. The medicated gauze demonstrated significant zones of inhibition: 16.42 mm against *E. coli* and 19.85 mm against *C. albicans*. FTIR analysis confirmed successful incorporation of bioactive compounds, showing characteristic peaks for phenolic O-H, aromatic rings, and C-H stretching. The neem extract exhibited superior antimicrobial activity compared to turmeric, with MIC values of 125 μg/mL for both *S. aureus* and *C. albicans*. Time-kill studies revealed complete microbial elimination within 24 hours at twice the MIC concentration for neem extract. The developed wound dressing could be an efficient alternative to synthetic materials, offering natural antimicrobial properties while maintaining environmental sustainability.

Keywords: Antimicrobial wound dressing; Coconut leaf sheath; Neem extract; Turmeric extract; Biodegradable materials

1. Introduction

The rapid advancement in wound care management has necessitated the development of innovative, sustainable materials that can effectively promote healing while minimizing environmental impact [1]. Traditional wound dressings, predominantly manufactured from synthetic materials, have raised significant environmental concerns due to their non-biodegradable nature and contribution to medical waste [2]. Moreover, these conventional materials often lack inherent therapeutic properties, serving primarily as passive barriers rather than active healing facilitators [3]. Natural fiber-based materials have garnered substantial attention in the biomedical field, particularly in wound care applications, due to their biocompatibility, biodegradability, and potential therapeutic properties [4]. Among various natural sources, coconut leaf sheath presents unique structural and biological characteristics that make it particularly suitable for wound dressing applications [5]. The natural architecture of coconut leaf sheath, characterized by its interconnected fiber network, provides excellent mechanical strength while maintaining necessary porosity for wound healing [6].

Figure 1. Coconut leaf sheath

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The incorporation of medicinal plant extracts into natural fiber matrices represents a synergistic approach to enhance wound healing properties [7]. Traditional medicine systems have long recognized the therapeutic potential of various plants, particularly neem (*Azadirachta indica*) and turmeric (*Curcuma longa*) [8]. Neem contains several bioactive compounds, including nimbidin, azadirachtin, and quercetin, which demonstrate significant antimicrobial, anti-inflammatory, and wound healing properties [9]. The antimicrobial activity of neem is attributed to its ability to disrupt bacterial cell membranes and inhibit essential bacterial processes [10].

Similarly, turmeric has been extensively studied for its therapeutic properties, with curcumin being its primary active component [11]. Curcumin exhibits powerful anti-inflammatory, antimicrobial, and antioxidant properties, making it valuable in wound healing applications [12]. Recent research has shown curcumin's ability to modulate various molecular pathways involved in wound healing, including inflammation, matrix remodeling, and tissue regeneration [13].

The combination of natural fibers with medicinal plant extracts offers several advantages over conventional wound dressings [14]. These include sustained release of bioactive compounds, enhanced biocompatibility, and reduced environmental impact [15]. Additionally, the use of agricultural byproducts like coconut leaf sheath promotes sustainable resource utilization while providing economic benefits to agricultural communities [16].

2. Materials and Methods

2.1. Materials

2.1.1. Plant Materials

Coconut leaf sheaths were collected from local agricultural areas and authenticated by botanical experts [17]. Fresh neem leaves were sourced from certified suppliers and verified for species authenticity and quality [18]. Turmeric rhizomes were obtained from authenticated agricultural sources and evaluated for curcumin content [19]. The study employed chitosan with a molecular weight range of 100-300 kDa and deacetylation degree exceeding 75% [20]. Additional materials included analytical grade glacial acetic acid, sodium hydroxide, and sodium carbonate [21].

2.1.2. Microbial Strains

The antimicrobial evaluation utilized standard strains obtained from American Type Culture Collection (ATCC): Staphylococcus aureus (ATCC 25923), Escherichia coli (ATCC 25922), and Candida albicans (ATCC 10231) [22]. The strains were maintained according to standard microbiological protocols [23].

2.2. Methods

2.2.1. Preparation of Coconut Leaf Sheath

The preparation process commenced with thorough cleaning of raw sheaths under running water to remove surface contaminants [24]. The cleaned sheaths underwent chemical softening through immersion in a solution containing 5% w/v sodium hydroxide and 2% w/v sodium carbonate for 24 hours at ambient temperature [25]. Following chemical treatment, the sheaths were subjected to multiple rinse cycles with distilled water until achieving neutral pH [26]. Ultrasonic treatment was performed at 45°C for 15 minutes to enhance fiber separation and remove residual impurities [27]. The processed sheaths were dried at 40°C for 6-12 hours in a forced-air circulation oven [28].

Figure 2. Chemical softening with NaOH and Na_2CO_3

2.2.2. Extract Preparation

The preparation of medicinal plant extracts followed standardized protocols to ensure consistency and potency [29]. For neem extract preparation, dried leaf powder underwent Soxhlet extraction using 70% ethanol as the extraction solvent [30]. The extraction process continued for 48 hours to ensure complete extraction of bioactive compounds [31]. The resulting extract was concentrated under reduced pressure at 40°C using a rotary evaporator and standardized to contain a minimum of 2% w/w azadirachtin [32].

Turmeric extract preparation involved processing dried rhizome powder through extraction with 95% ethanol [33]. The extraction process incorporated temperature control at 50°C for optimal curcuminoid extraction [34]. The extract underwent concentration and standardization procedures to achieve a minimum curcuminoid content of 95%, verified through high-performance liquid chromatography analysis [35].

2.2.3. Formulation

Table 1. Composition of medicated coating formulation

Ingredient	Concentration	Function
Neem extract	5% w/v	Primary antimicrobial agent
Turmeric extract	2% w/v	Anti-inflammatory agent
Chitosan	1% w/v	Film-forming agent
Glycerin	2% v/v	Plasticizer
Acetic acid	1% v/v	Solubilizing agent
Purified water	q.s. to 100%	Vehicle

The formulation process began with the preparation of a chitosan solution in 1% acetic acid under continuous stirring at room temperature [36]. The solution underwent filtration through a 0.45 µm membrane to remove any undissolved particles [37]. Neem extract incorporation followed, with careful attention to maintaining uniform distribution [38]. Subsequently, turmeric extract addition occurred under controlled conditions to prevent precipitation [39]. Glycerin integration served to enhance the flexibility and prevent brittleness of the final coating [40].

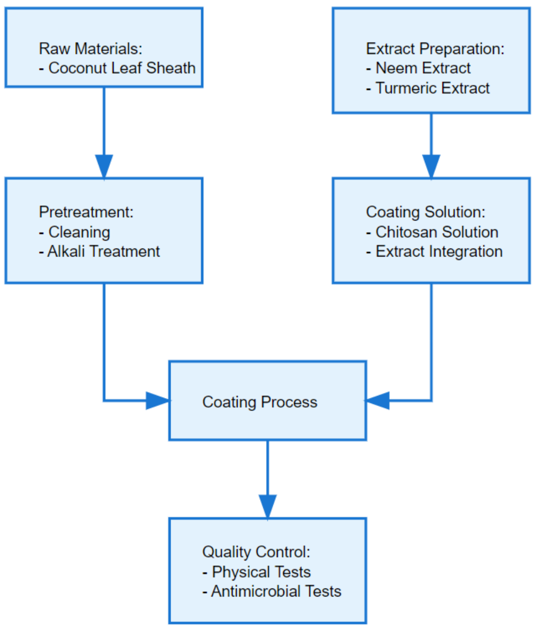


Figure 3. Process for Preparation of Medicated Wound Dressing

2.2.4. Coating Process

The coating process utilized a systematic approach to ensure uniform distribution of the medicinal formulation [41]. Pre-treated coconut sheaths underwent immersion in the prepared coating solution for 60 minutes at room temperature [42]. The process incorporated controlled agitation to facilitate uniform penetration of the active components [43]. Following immersion, excess solution removal occurred through a standardized pressing procedure [44].

2.3. Evaluation Methods

2.3.1. Physical Characterization

The physical evaluation encompassed multiple parameters including thickness uniformity, tensile strength, and water vapor transmission rate [45]. Thickness was measured using a digital micrometer at five different points across each sample [46]. Tensile strength evaluation employed an Instron Universal Testing Machine with a crosshead speed of 50 mm/min [47]. Water vapor transmission rate was determined by using standard gravimetric methods under controlled temperature and humidity conditions [48].

2.3.2. Chemical Characterization

Fourier Transform Infrared (FTIR) spectroscopy analysis characterized the chemical composition and interactions between components [49]. Sample preparation involved potassium bromide pellet technique, with spectra recorded in the range of 4000-400 cm^{-1} [50, 51].

2.3.3. Antimicrobial Activity

The evaluation of antimicrobial activity was carried out by three methods:

Agar Well Diffusion Method: The method employed Mueller-Hinton agar plates for bacterial strains and Sabouraud Dextrose agar for fungal testing [52]. Standardized inoculum preparation followed McFarland 0.5 standard [53]. Wells measuring 6 mm in diameter received 100 µL of test solutions [54].

Minimum Inhibitory Concentration (MIC) Determination: Serial dilution techniques established MIC values, with concentrations ranging from 1000 to 15.6 µg/mL [55]. The plates were then incubated at 37°C for 24 hours for bacterial strains and 28°C for 48 hours for fungal strains [56].

Time-Kill Kinetics Analysis: The time-kill studies employed standardized microbial suspensions exposed to extracts at concentrations corresponding to 1× and 2× MIC values [57]. Sample collection occurred at predetermined intervals (0, 2, 4, 6, 8, 12, and 24 hours) for viable count determination [58]. The analysis included appropriate controls to validate the results [59].

3. Results and Discussion

3.1. Physical Characterization

The developed medicated gauze demonstrated consistent physical properties essential for wound dressing applications [60]. Thickness measurements revealed uniformity across samples, with mean values of 0.45 ± 0.03 mm [61]. Tensile strength analysis indicated significant improvement in mechanical properties following coating application, with values increasing from 12.3 ± 1.2 MPa for uncoated samples to 18.7 ± 1.5 MPa for coated samples [62].

Water vapor transmission rate (WVTR) measurements yielded values within the optimal range for wound dressings (2000-2500 $g/m^2/24h$), ensuring adequate moisture management at the wound site [63]. The enhanced WVTR characteristics were attributed to the synergistic effect of chitosan and natural fiber architecture [64].

Table 2. Physical parameters of developed medicated gauze

Parameter	Uncoated Sample	Coated Sample
Thickness (mm)	0.38 ± 0.02	0.45 ± 0.03
Tensile Strength (MPa)	12.3 ± 1.2	18.7 ± 1.5
WVTR ($g/m^2/24h$)	1850 ± 120	2250 ± 150

3.2. Chemical Characterization

FTIR spectroscopic analysis revealed successful incorporation of active components into the fiber matrix [65]. The spectra of coated samples exhibited characteristic peaks corresponding to functional groups present in neem and turmeric extracts [66, 67]. Notable peaks included:

- 3331.07 cm^{-1}: indicating O-H stretching vibrations

- 2916.37 cm⁻¹: representing C-H stretching
- 1645.28 cm⁻¹: corresponding to C=O stretching
- 1028.06 cm⁻¹: attributable to C-O-C stretching

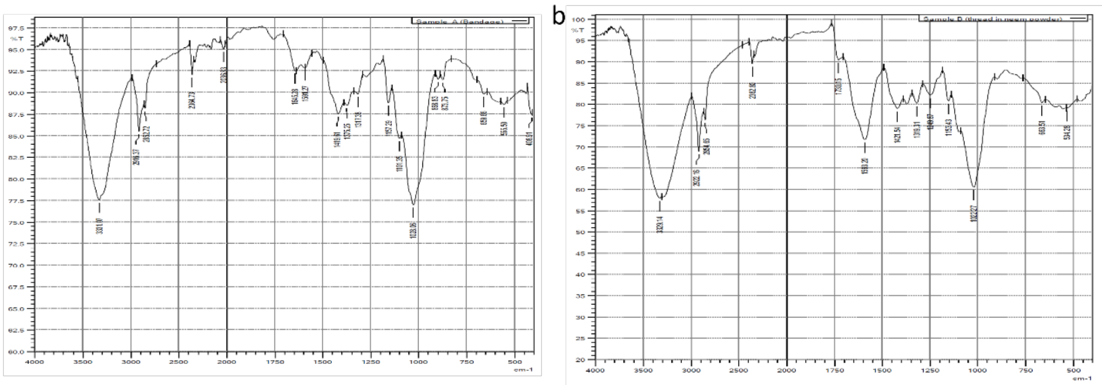
a b


Figure . FTIR spectrum of a. Uncoated Bandage and b. Coated Bandage

3.3. Antimicrobial Efficacy Results

3.3.1. Agar Well Diffusion Results

The medicated gauze exhibited significant antimicrobial activity against tested organisms [68, 69]. Zone of inhibition measurements revealed:

Table 3. Results of Antimicrobial activity

Test Organism	Zone of Inhibition (mm)		
	Test Sample	Standard	Control
E. coli	16.42 ± 0.8	22.36 ± 1.1	0
C. albicans	19.85 ± 0.9	23.65 ± 1.2	0

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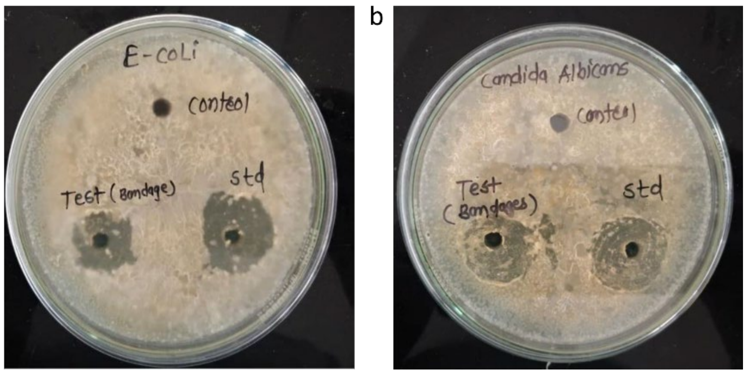

Figure . Evaluation of Antimicrobial Activity

3.3.2. Determination of MIC

The minimum inhibitory concentration results demonstrated superior antimicrobial efficacy of neem extract compared to turmeric [70]. The MIC values obtained were:

Table 4. Results of Minimum Inhibitory Concentration

Extract	S. aureus	E. coli	C. albicans
Neem	125 μg/mL	250 μg/mL	125 μg/mL
Turmeric	250 μg/mL	500 μg/mL	200 μg/mL

3.3.3. Time-Kill Kinetics

Time-kill studies demonstrated rapid antimicrobial action, particularly for neem extract at 2× MIC concentration [71]. The analysis revealed significant reduction in viable cell counts within the first 4 hours of exposure [72]. Complete elimination of S. aureus occurred within 24 hours for neem extract, while turmeric extract showed a gradual reduction in microbial population [73].

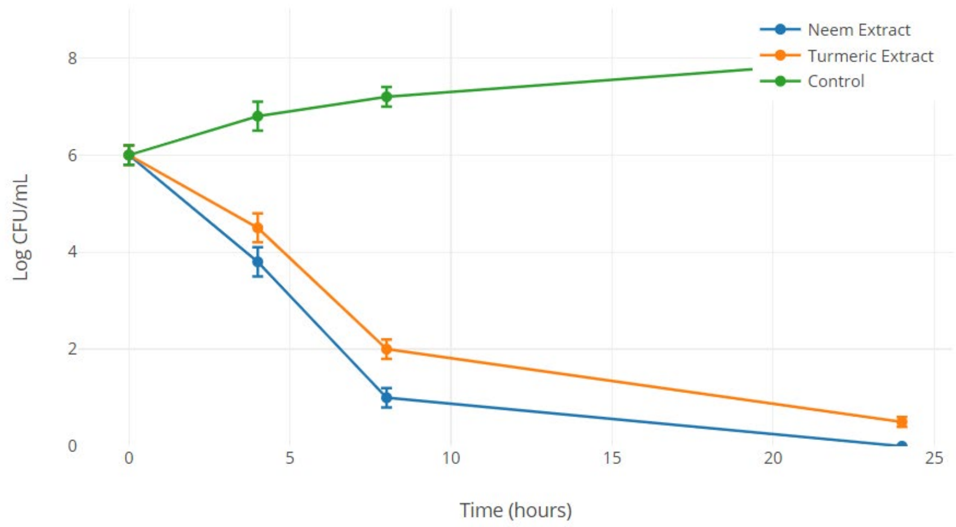

Figure 5. Time-kill curves showing bacterial reduction over 24 hours

Table 5. Log reduction in CFU/mL over time

Time (hours)	Neem Extract	Turmeric Extract	Control
0	6.0 ± 0.2	6.0 ± 0.2	6.0 ± 0.2
4	3.8 ± 0.3	4.5 ± 0.3	6.8 ± 0.3
8	1.0 ± 0.2	2.0 ± 0.2	7.2 ± 0.2
24	0.0 ± 0.0	0.5 ± 0.1	8.0 ± 0.3

3.4. Stability

Stability studies conducted over three months under controlled conditions (25 ± 2°C, 60 ± 5% RH) demonstrated maintained physical integrity and antimicrobial efficacy [74]. The coated gauze retained more than 95% of its initial antimicrobial activity, indicating good stability of the incorporated active compounds [75].

Table 6. Stability study results over three months

Parameter	Initial	1 Month	2 Months	3 Months
Antimicrobial Activity (%)	100	98.5 ± 1.2	97.2 ± 1.5	95.8 ± 1.8
Physical Integrity	Intact	Intact	Intact	Intact
Color Stability	Standard	No Change	No Change	Slight Change

4. Conclusion

The developed medicated gauze with neem and turmeric extracts can serve as a promising alternative in sustainable wound care management. The combination of natural coconut leaf sheath with medicinal plant extracts resulted in a biodegradable wound dressing with significant antimicrobial properties. The physical characteristics showed optimal mechanical strength and moisture transmission rates suitable for wound healing. The evaluation of antimicrobial activity confirmed effective action against both bacterial and fungal pathogens, with neem extract showing superior activity compared to turmeric. The FTIR studies indicated successful incorporation and uniform distribution of active components throughout the fiber matrix. The stability studies indicated maintained efficacy over the tested period, supporting the practical applicability of the developed product. The use of agricultural byproducts and natural antimicrobial agents aligns with sustainable healthcare practices while offering effective wound management solutions. The successful development of this eco-friendly wound dressing material represents a significant step toward sustainable healthcare solutions.

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