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**Review Article**

# Banana Peel-Derived Biomaterials for Smart Wound Healing: Advances in Chitosan Composites, Responsive Dressings, and Future Applications

**Dr. Satish Kilaje*, Aprajeeta Kumbhar, Ashrita Magdum**

*Dr. J. J. Magdum Pharmacy College, Shirol-Wadi Road, Near M.S.E.B. Office, Jaysingpur – 416101, Taluka Shirol, District Kolhapur, Maharashtra, India.*

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## ABSTRACT

Wound management remains an important challenge in healthcare, particularly in chronic wounds, where prolonged inflammation, microbial contamination, oxidative stress, and delayed tissue regeneration can interfere with normal healing. Conventional wound dressings primarily protect the wound and absorb exudates; however, they may not provide active therapeutic support or information about changes in the wound environment. Consequently, increasing research attention has been directed towards multifunctional biomaterials capable of supporting tissue repair while maintaining a suitable wound microenvironment. Banana peel, an abundant agricultural by-product, contains potentially valuable phytochemicals and structural components that may support the development of sustainable wound-care materials. Experimental studies have investigated banana peel extracts for antioxidant, antimicrobial, and wound-healing activities. In addition, banana peel powder has been incorporated into chitosan-based films and nanocomposites to investigate their physicochemical properties and suitability for wound-dressing applications. Chitosan provides film-forming capacity, biocompatibility, and potential antimicrobial functionality, while banana-derived materials may contribute additional structural and biological properties. This review discusses the phytochemical characteristics of banana peel, its reported biological activities, and its application in chitosan-based wound dressings. It also examines the potential development of smart wound-dressings incorporating pH-responsive indicators, moisture monitoring, and infection-associated sensing. Although smart wound-dressings and responsive chitosan-based materials have been investigated in broader biomaterials research, an integrated banana-peel-based dressing with validated real-time sensing and clinical effectiveness remains an area for future investigation. Important challenges include extract standardisation, mechanical stability, sterilisation, biocompatibility, reproducibility, and clinical validation.

***Corresponding Author:** Dr. Satish Kilaje
**Address:** Dr. J. J. Magdum Pharmacy College, Shirol-Wadi Road, Near M.S.E.B. Office, Jaysingpur – 416101, Taluka Shirol, District Kolhapur, Maharashtra, India
**Email** ✉: satishkilajegnr@gmail.com

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Banana peel-derived biomaterials may therefore represent a promising approach to sustainable wound care, provided that their safety and performance are established through systematic experimental studies.

## INTRODUCTION

Wound healing is a complex biological process involving haemostasis, inflammation, proliferation, and tissue remodelling. These stages work together to restore the structure and function of damaged tissue. The healing process can be delayed by infection, excessive inflammation, oxidative stress, inadequate blood supply, and underlying medical conditions. Chronic wounds are particularly challenging because they may remain in the inflammatory phase for an extended period and require repeated clinical assessment.

Conventional wound dressings primarily provide a protective barrier, absorb wound exudates, and reduce exposure to external contamination. Although these functions are essential, the performance of a dressing also depends on its ability to maintain suitable moisture conditions, avoid excessive tissue adhesion, and provide adequate mechanical support. These requirements have encouraged the development of advanced dressings based on natural polymers, hydrogels, fibres, and composite biomaterials.

Natural polymers such as chitosan, alginate, cellulose, and other polysaccharides have received considerable attention because of their potential biocompatibility, film-forming ability, and usefulness in wound-care formulations. However, individual polymers may have limitations, including insufficient mechanical strength, uncontrolled swelling, poor stability in highly exudative wounds, or limited capacity for delivering therapeutic compounds. Combining polymers with natural fibres or plant-derived materials is one approach to addressing these limitations.

Banana (*Musa* species) is widely cultivated, and its processing generates substantial quantities of peel waste. Instead of treating this material exclusively as waste, researchers have investigated its possible use as a source of phytochemicals and biomaterial ingredients. Banana peel extracts have been evaluated in experimental wound-healing models, while banana peel powder and chitosan have been studied as components of composite films.

The development of smart wound-dressings introduces another potential direction. Such dressings aim to respond to changes in the wound environment or provide information about parameters associated with healing. Examples include pH-responsive colour changes, moisture monitoring, and sensors designed to detect selected biochemical indicators. Combining banana peel-derived materials with these technologies may offer a route towards sustainable and multifunctional wound-care systems.

However, the evidence must be interpreted carefully. Demonstrating biological activity in an extract is not equivalent to proving that a finished dressing heals wounds effectively. Similarly, developing a composite film does not establish that it can monitor wound conditions in real time. These distinctions are essential when evaluating the current state of banana-peel-based wound-care research.

### 1.1 Objectives of the review

The objectives of this review are:

1. To discuss the potential value of banana peel as a source of bioactive compounds and biomaterial ingredients.
2. To summarise experimental findings on the wound-healing, antioxidant, and antimicrobial activities of banana peel preparations.
3. To examine banana peel and chitosan composite films developed for wound-dressing applications.
4. To discuss the potential incorporation of responsive and monitoring technologies into banana-derived wound dressings.
5. To identify major formulation, safety, manufacturing, and research challenges that must be addressed before clinical application.

## 2. REVIEW METHODOLOGY

This article is a narrative review based on the research papers and supporting literature identified for the topic. The reviewed material includes experimental studies of banana peel extracts, investigations of banana peel–chitosan composite materials, and broader research on

natural-polymer wound dressings and responsive biomaterials.

The literature was considered in four main categories: biological activity of banana peel extracts, development and characterisation of banana peel-containing films, use of natural polymer composites for wound care, and potential applications of smart wound-dressing technologies.

Experimental findings are described according to the material, formulation, and model investigated in each study. Results obtained from different extracts, animal models, cell-based assays, and composite formulations are not treated as directly interchangeable.

This review is not a systematic review or meta-analysis. It does not claim that every relevant publication has been identified. Before journal submission, the search strategy should be expanded and documented using appropriate bibliographic databases, and all references should be checked against their original publications.

## 3. BANANA PEEL AS A SOURCE OF BIOACTIVE AND STRUCTURAL MATERIALS

### 3.1 Phytochemical characteristics

Banana peel contains a complex mixture of plant-derived compounds. Depending on the banana variety, maturity, geographical origin, and extraction method, reported constituents may include phenolic compounds, flavonoids, tannins, and other secondary metabolites. The peel also contains structural carbohydrates and other components that may be relevant to material development.

Phenolic compounds and flavonoids are of particular interest because some members of these groups can participate in free-radical scavenging reactions. Oxidative stress is one factor that may contribute to prolonged inflammation and tissue damage during wound healing. Consequently, antioxidant activity is frequently investigated when evaluating plant extracts for potential wound-care applications.

Nevertheless, the presence of a phytochemical group does not independently establish therapeutic effectiveness. The concentration of individual compounds, their stability, their availability from the finished formulation, and their interactions with the wound environment require further investigation.

### 3.2 Influence of extraction methods

The composition of banana peel extracts depends strongly on the extraction procedure. Hydroalcoholic, methanolic, and other solvent systems may recover different proportions of phytochemicals because compounds vary in polarity and solubility.

Padilla-Camberos and colleagues investigated the antioxidant capacity and wound-healing activity of banana peel extracts. Their findings indicated substantial antioxidant activity in the tested preparations and differences in wound-healing performance among extracts obtained using different solvents. [1]

These results illustrate an important formulation consideration: banana peel extract should not be treated as a chemically uniform ingredient. For reproducible pharmaceutical development, the extraction process should be standardised, and the resulting extract should be characterised using appropriate analytical methods.

Potential quality-control parameters include extraction yield, total phenolic content, chromatographic fingerprint, moisture content, residual solvents, microbial contamination, and stability during storage.

### 3.3 Structural components and agricultural waste valorisation

Banana peel can also be investigated as a source of solid material for incorporation into polymeric films. Powdered peel and isolated structural fractions may influence the physical properties of a composite, including surface morphology, water uptake, flexibility, and interaction between polymer components.

However, whole peel powder, purified cellulose, extracted pectin, and concentrated phytochemical extract are different materials. Their functions within a wound dressing may also differ.

Whole peel powder may provide a mixture of structural and chemical components, whereas a purified fraction may offer greater compositional consistency. Extracts may contribute soluble compounds but do not necessarily provide the reinforcement required for a mechanically stable dressing.

Therefore, the choice between whole peel powder, purified structural material, and peel extract should be guided by the intended function of the formulation.

## 4. BIOLOGICAL ACTIVITIES RELEVANT TO WOUND HEALING

### 4.1 Antioxidant activity

Oxidative stress can influence inflammatory signalling and damage cellular components. Excessive reactive oxygen species may interfere with the normal progression of tissue repair. For this reason, antioxidant activity is commonly investigated in plant-derived materials intended for wound-care applications.

Padilla-Camberos et al. evaluated banana peel extracts and reported approximately 89–90% DPPH radical inhibition in the tested preparations. The study also reported differences in wound-healing activity between extracts obtained with different solvents. [1]

DPPH testing provides an indication of free-radical scavenging under the specified laboratory conditions. It does not directly measure the ability of a material to reduce oxidative stress in a human wound. The results also depend on extract concentration, assay conditions, solvent, and the method used to calculate inhibition.

Further studies should therefore examine antioxidant performance in the final dressing rather than relying exclusively on the activity of the original extract.

### 4.2 Antimicrobial activity

Microbial contamination can delay wound healing and increase the risk of complications. Antimicrobial activity is consequently an important parameter in the evaluation of wound dressings.

Rizka and colleagues investigated a spray-gel formulation containing banana peel extract at concentrations of 10%, 15%, and 20%. In the reported antimicrobial tests, inhibition zones were approximately 14.2 ± 0.38 mm against Escherichia coli and 14.6 ± 0.21 mm against Staphylococcus aureus. The 20% formulation showed the strongest overall performance among the tested concentrations. [4]

These findings support further investigation of banana peel extract as a potential ingredient in wound-care formulations. However, inhibition zones alone cannot establish clinical effectiveness. The observed activity may be influenced by the concentration of the extract, diffusion through the agar medium, formulation characteristics, and the susceptibility of the tested microorganisms.

Future investigations should include appropriate positive and negative controls, quantitative antimicrobial methods where suitable, and tests against a broader range of clinically relevant organisms. The effect of incorporating the extract into a polymer matrix should also be evaluated because the matrix may change the release and availability of the active compounds.

### 4.3 Experimental wound-healing activity

Animal studies have investigated banana peel preparations for their possible effects on wound contraction and tissue repair.

Tamri and colleagues evaluated a hydroalcoholic extract of banana fruit peel in rabbits and reported findings consistent with improved wound contraction, a reduced epithelialisation period, and increased skin breaking strength under the experimental conditions. [3]

Rizka and colleagues also evaluated banana peel extract spray gels in a rabbit wound model. Their reported observations included differences in healing time, collagen density, and epidermal thickness among treatment groups. The 20% extract formulation performed better than the lower-concentration formulations in several reported outcomes. [4]

These studies provide experimental evidence supporting continued investigation. Nevertheless, animal models cannot establish effectiveness or safety in humans. Differences in species, wound creation methods, extract preparation, dosage, and outcome assessment also limit direct comparison between studies.

The biological activity of a finished composite dressing must therefore be evaluated independently rather than inferred solely from studies of extracts.

## 5. DEVELOPMENT OF BANANA PEEL-CHITOSAN COMPOSITE DRESSINGS

### 5.1 Role of chitosan

Chitosan is a polysaccharide derived from the deacetylation of chitin. It has been widely investigated

for biomedical applications because of its film-forming ability, interaction with biological environments, and potential contribution to antimicrobial formulations. [5,8]

In wound-dressing development, chitosan can function as a matrix for incorporating plant extracts, powders, and other functional ingredients. It can also provide a structure that maintains the formulation at the wound surface.

However, the performance of a chitosan dressing depends on factors such as molecular weight, degree of deacetylation, polymer concentration, crosslinking, plasticiser content, and preparation method. Chitosan alone does not guarantee optimal flexibility, swelling, moisture retention, or antimicrobial effectiveness.

### 5.2 Banana peel powder incorporated into chitosan films

Rihayat and colleagues investigated wound dressing materials based on banana peel waste and chitosan, with lignin considered as a strengthening component. The study examined banana peel powder loadings of 0%, 1%, 3%, 5%, 7%, and 10% by weight in chitosan films. [2]

The reported swelling values after 48 hours decreased as the banana peel powder loading increased. The values were approximately 120.59%, 100.00%, 79.29%, 68.18%, 61.92%, and 45.40% for the respective formulations.

The study also examined the composite structure and interactions using analytical techniques, including scanning electron microscopy and Fourier-transform infrared spectroscopy. Its reported observations indicated differences in morphology and polymer interactions across formulations. Antimicrobial testing was also performed against *E. coli* and *S. aureus*.

These findings demonstrate that the addition of banana peel powder can alter the measured properties of a chitosan-based film.

The decline in swelling should not automatically be interpreted as an improvement in overall wound-dressing performance. A dressing needs sufficient fluid-handling capacity without losing structural integrity or becoming unsuitable for the wound. The optimal swelling behaviour depends on the intended application, wound exudate level, and other formulation properties.

### 5.3 Interpreting swelling and fluid management

Swelling capacity is important because wound exudate contains water, proteins, salts, and other substances that may influence the dressing during use. A dressing with insufficient fluid-handling capacity may allow fluid accumulation, while excessive swelling may weaken the structure or contribute to leakage.

Accordingly, swelling should be assessed alongside other performance measures, including:

- Fluid absorption and retention capacity.
- Water vapour transmission rate.
- Wet-state tensile strength.
- Flexibility and handling characteristics.
- Adhesion to the wound surface.
- Integrity during removal.
- Drug release and stability.
- Biocompatibility and cytotoxicity.

A balanced combination of these properties is more meaningful than maximising or minimising a single parameter.

### 5.4 Related evidence from banana stem fibre composites

A related study by Krishnamoorthy and colleagues, published in Scientific Reports in 2026, investigated a wound-healing patch made from banana pseudostem fibre, chitosan, xanthan gum, and a hydrogel system containing Tridax procumbens extract. [7]

The authors reported a crystallinity index of approximately 78.43%, antioxidant activity of around 60%, and 78% wound closure in a 24-hour scratch assay at the specified extract concentration. Their MTT assay also reported 75% cell viability at a stated test concentration.

The patch inhibited the tested bacterial species and demonstrated measurable antioxidant activity under the reported experimental conditions.

This study is relevant because it demonstrates the broader potential of combining banana-derived

structural materials with natural polymers and plant extracts. However, banana pseudostem fibre is not banana peel. The study should therefore be considered supporting evidence for natural-fibre composite design rather than direct proof of the performance of banana peel–chitosan dressings.

It also illustrates the importance of evaluating several properties together, including morphology, chemical interactions, crystallinity, antimicrobial activity, antioxidant activity, cell viability, and cell migration.

## 6. SMART WOUND DRESSINGS: PRINCIPLES AND POTENTIAL APPLICATIONS

### 6.1 From passive protection to responsive wound care

Conventional dressings generally provide physical protection and fluid management. Smart wound dressings aim to add functions such as environmental sensing, controlled release, or a visible response to changes associated with wound status.

The wound environment is dynamic. Changes in pH, temperature, moisture, oxygen availability, and biochemical markers may accompany changes in the healing process. However, no single parameter reliably identifies every wound complication.

A responsive dressing should therefore be designed around a defined clinical purpose and validated against suitable reference measurements.

### 6.2 pH-responsive indicators

Wound pH can vary according to wound type, healing stage, microbial activity, and other local factors. Some smart dressing systems use pH-sensitive materials that change colour as the surrounding environment changes.

A potential banana peel–chitosan dressing could incorporate a validated pH-sensitive indicator into a separate functional layer. The indicator might provide a visual signal that prompts further assessment when a predefined change occurs.

This concept requires experimental development. Banana peel pigments should not automatically be assumed to provide reliable pH sensing. Their colour may be affected by light exposure, oxidation, extract composition, and interactions with the polymer matrix.

A suitable system would require calibration across the intended pH range, testing in simulated wound fluid, assessment of colour stability, and comparison with a reference pH measurement.

### 6.3 Moisture and exudate monitoring

Exudate management is a central requirement for wound-dressing performance. Moisture sensors may help identify changes in fluid accumulation or dressing saturation.

A possible design would combine a banana peel–chitosan absorbent layer with a separate moisture-responsive element. The structural layer would provide fluid management, while the monitoring element would indicate changes in moisture.

The sensing element must not compromise the dressing's flexibility, sterility, biocompatibility, or ability to maintain an appropriate wound environment. Its output should also be interpreted in relation to the type of wound and the dressing's absorption characteristics.

### 6.4 Temperature and infection-associated monitoring

Local temperature changes may accompany inflammation or infection, but temperature alone is not a definitive diagnostic indicator. Smart dressings may use temperature-sensitive components to identify changes that warrant further assessment.

Other research explores sensors for wound-associated biochemical indicators. These systems may offer additional information, but their performance depends on the specificity of the sensing mechanism, the stability of the sensor, and interference from wound fluid components.

For banana-peel-based materials, these functions should be regarded as potential future applications rather than established properties of existing peel-chitosan dressings.

### 6.5 Responsive release of therapeutic compounds

A smart dressing may be designed to release a therapeutic compound in response to selected environmental conditions. Chitosan and other polysaccharides can be

incorporated into responsive hydrogel and drug-delivery systems. [10]

For a banana-peel-based dressing, one possible approach would be to load a characterised peel extract into a polymer matrix and investigate whether its release can be controlled by changes in pH or hydration.

Such a system would require measurements of loading efficiency, release kinetics, chemical stability, biological activity after release, and local safety. A change in swelling or colour alone would not establish controlled therapeutic delivery.

## 7. PROPOSED CONCEPT FOR A BANANA PEEL-BASED SMART DRESSING

Based on the existing literature, a potential development pathway is to combine banana peel-derived material, a chitosan-based matrix, and a separately validated sensing component.

The proposed system is a research concept and should not be interpreted as a finished or clinically validated product.

### 7.1 Proposed functional layers

**Layer 1: Wound-contact layer**

A chitosan-based film or hydrogel could provide the primary interface with the wound. Its composition should be selected to support biocompatibility, appropriate moisture conditions, and atraumatic removal.

**Layer 2: Banana peel-derived functional layer**

A standardised banana peel extract or appropriately characterised peel-derived material could be incorporated into the matrix. The selected material should be tested for chemical consistency, stability, and biological activity.

**Layer 3: Fluid-management layer**

A compatible polymer or hydrogel layer could be used to support fluid absorption and retention. Its performance would require optimisation for the intended wound type.

**Layer 4: Monitoring component**

A validated pH indicator, moisture sensor, or other suitable sensing component could be placed in a position that allows measurement without compromising the wound-contact layer.

**Layer 5: Protective backing**

An appropriate backing could help protect the dressing from external contamination while maintaining suitable moisture and gas exchange.

The number and arrangement of layers would depend on the intended use. Not every wound dressing requires every proposed component.

### 7.2 Development workflow

A research programme could proceed through the following stages:

1. Collect and authenticate the banana material.
2. Establish a reproducible preparation method.
3. Characterise the extract or structural fraction.
4. Prepare chitosan-based films using controlled formulation conditions.
5. Evaluate physicochemical and mechanical properties.
6. Investigate fluid handling and stability under simulated wound conditions.
7. Test antimicrobial and antioxidant activity using appropriate controls.
8. Assess cytotoxicity and relevant cell-based responses.
9. Integrate a suitable sensing component, if justified.
10. Calibrate and validate the sensing response.
11. Conduct appropriate preclinical studies after satisfactory laboratory results.
12. Evaluate manufacturing reproducibility, sterility, packaging, and regulatory requirements.

The proposed sequence separates material development from sensor validation and biological evaluation. This is important because successful film fabrication does not automatically demonstrate therapeutic benefit.

## 8. EVALUATION AND CHARACTERISATION OF THE PROPOSED DRESSING

### 8.1 Physical and mechanical characterisation

Physical testing should establish whether the dressing can be handled, applied, and removed without premature failure. Relevant measurements include thickness, tensile strength, elongation, flexibility, surface morphology, and stability under wet conditions.

Scanning electron microscopy may be used to investigate surface morphology and the distribution of material within a composite. However, a favourable microscopic appearance does not independently establish biocompatibility or wound-healing efficacy.

### 8.2 Fourier-transform infrared spectroscopy

FTIR spectroscopy can help identify functional groups and investigate changes associated with interactions among the polymer components.

For banana peel–chitosan composites, comparisons between the individual ingredients and the finished film may help identify changes in characteristic absorption bands.

Interpretation should be based on the measured spectra and appropriate controls. The presence of a peak does not, by itself, prove a specific therapeutic effect.

### 8.3 Water absorption and vapour transmission

Swelling, fluid absorption, fluid retention, and water vapour transmission should be measured using defined and reproducible procedures.

These parameters are related but not interchangeable. A film may absorb water while retaining limited structural strength, or it may maintain its structure while absorbing insufficient exudate.

Testing should therefore assess both fluid-handling capacity and structural integrity.

### 8.4 Antimicrobial and antioxidant testing

Antimicrobial evaluation may include agar diffusion testing and other suitable quantitative methods. The choice of method should account for the potential difficulty of measuring activity when an active compound is embedded in a polymer matrix.

Antioxidant evaluation may include DPPH radical scavenging or other appropriate assays. The concentration of the sample, incubation conditions, and calculation method should be reported clearly.

Results from in vitro assays should be described as laboratory findings and not as proof of clinical infection prevention or wound healing.

### 8.5 Cytotoxicity and cell-based evaluation

Cytotoxicity testing is necessary to determine whether the material adversely affects relevant cells under the test conditions. An MTT assay or another validated method may be selected according to the formulation and research objectives.

Cell migration assays may provide preliminary information about cellular responses associated with wound closure. However, scratch assays do not reproduce the complete biological environment of a living wound.

**Further evaluation may be needed to investigate inflammation, tissue compatibility, degradation products, and the effects of repeated or prolonged exposure.**

### 8.6 Validation of smart functions

If a sensing component is incorporated, it should be evaluated separately from the structural dressing.

For a pH-responsive system, testing should include calibration, response time, reversibility where relevant, colour stability, interference, and performance in simulated wound fluid.

For a moisture-monitoring system, validation should examine the relationship between sensor output and measured fluid content or dressing saturation.

For temperature monitoring, accuracy and response time should be compared with a suitable reference method.

The results should demonstrate that the sensor produces reproducible and interpretable measurements under realistic conditions.

## DISCUSSION

The available literature supports continued investigation of banana-derived materials for wound-care applications. Banana peel extracts have demonstrated

antioxidant activity and promising effects in selected experimental wound-healing models. Banana peel powder has also been incorporated into chitosan-based films, where its addition altered swelling and other material characteristics.

These findings provide two complementary research directions. The first is the development of extract-based formulations intended to deliver characterised phytochemicals. The second is the development of composite materials in which banana peel-derived components influence the physical and functional properties of a polymer matrix.

Chitosan offers a useful platform for investigating these approaches, but formulation performance cannot be predicted from the properties of the individual ingredients alone. The concentration of banana peel powder, the chemical composition of the extract, polymer characteristics, processing conditions, and interactions among components may influence the final material.

The literature on banana stem fibre composites further demonstrates that banana-derived structural materials can be integrated with natural polymers and hydrogel networks. However, this evidence should not be interpreted as direct confirmation that banana-peel-based dressings will exhibit the same mechanical or biological performance.

The development of a smart dressing introduces additional challenges. A useful sensor must provide a reliable response, remain stable during use, and avoid interfering with the primary functions of the dressing. A visible colour change is useful only when its relationship to the measured parameter is established and the result can be interpreted appropriately.

Similarly, an extract-containing dressing should be assessed for active-compound release and biological safety. The activity of the original extract may change after incorporation into a polymer, storage, sterilisation, or exposure to wound fluid.

A major limitation of the current evidence is the variation among materials and experimental models. Different banana varieties, extraction solvents, concentrations, polymer compositions, and biological assays make direct comparisons difficult. Standardised reporting and reproducible manufacturing procedures would improve the quality of future research.

Overall, banana peel-derived biomaterials are a promising research area at the intersection of sustainable material development and wound-care technology. Their practical value will depend on demonstrating reproducible material performance, acceptable safety, and a clear benefit over appropriate comparator dressings.

## 10. RESEARCH GAPS AND FUTURE PERSPECTIVES

### 10.1 Standardisation of banana peel raw materials

Banana peel composition may vary with cultivar, maturity, cultivation conditions, storage, and processing. Future studies should establish raw-material specifications and analytical methods that allow batches to be compared.

### 10.2 Identification and quantification of active compounds

Further work should identify the compounds associated with observed biological activity and determine whether they remain stable during formulation and storage.

### 10.3 Optimisation of the polymer matrix

The influence of banana peel concentration on swelling, mechanical strength, flexibility, fluid handling, and active-compound release should be systematically investigated. Formulations should be optimised for defined wound-care requirements rather than a single laboratory outcome.

### 10.4 Validation of smart monitoring

Future work should evaluate whether a sensing component provides reliable information beyond what can be obtained through conventional wound assessment. Sensor performance should be validated under realistic conditions, including exposure to proteins, salts, moisture, and other potentially interfering substances.

### 10.5 Safety and biocompatibility

Studies should evaluate cytotoxicity, irritation potential, sensitisation where applicable, degradation

products, and the effects of relevant residual processing chemicals.

### 10.6 Manufacturing and sterilisation

A potential clinical product would require reproducible manufacturing, suitable packaging, validated sterilisation, and evidence that these processes do not compromise material performance or active compounds.

### 10.7 Preclinical and clinical validation

Laboratory and animal findings should not be extrapolated directly to human effectiveness. Appropriate preclinical studies and, where justified, well-designed clinical investigations would be necessary to establish safety and therapeutic benefit.

### 10.8 Environmental and economic assessment

The use of agricultural by-products may support waste valorisation, but environmental benefit should be evaluated across collection, extraction, processing, sterilisation, packaging, and disposal. A sustainable dressing must also meet appropriate safety and performance requirements.

## 11. LIMITATIONS OF THE REVIEW

This review is based on selected publications and is intended to provide a narrative overview rather than an exhaustive systematic assessment. Differences among experimental models, extraction methods, material compositions, and testing procedures limit direct comparison of reported findings.

Furthermore, the proposed smart banana-peel-based dressing is a conceptual development pathway. The reviewed evidence does not establish that a fully integrated banana peel–chitosan dressing with validated real-time monitoring and clinical effectiveness has already been developed.

The findings discussed here should therefore be interpreted as a basis for further research rather than a recommendation for clinical use.

## CONCLUSION

Banana peel-derived materials offer a potentially useful combination of agricultural waste valorisation, phytochemical research, and natural-polymer formulation. Experimental studies have reported antioxidant activity and promising wound-healing outcomes for selected banana peel preparations. Research on banana peel–chitosan films has also demonstrated that peel powder can alter composite properties, including swelling behaviour.

Chitosan-based matrices provide a possible platform for developing wound dressings that combine fluid management with the incorporation of characterised plant-derived ingredients. Future formulations may also investigate pH-responsive indicators, moisture monitoring, or other sensing functions. However, these smart applications require independent design, calibration, and validation.

The central research priority is to establish a reproducible and safe formulation whose physical, chemical, biological, and monitoring properties are supported by experimental evidence. Standardisation of raw materials, mechanical and fluid-management testing, biocompatibility assessment, controlled release studies, and appropriate preclinical evaluation will be essential.

Banana peel-based smart wound-dressings should therefore be regarded as a promising research direction, not an established clinical technology. Their eventual value will depend on whether rigorous studies demonstrate reliable performance, meaningful therapeutic benefits, and practical advantages over existing wound-care materials.

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