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Smart Biodegradable Wound Dressing Using Pomegranate Peel Extract: Bioactive Potential, Formulation Strategies, and Evidence Gaps

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ABSTRACT

The search for sustainable wound-care materials has encouraged investigation of plant-derived compounds within biodegradable polymer systems. Pomegranate (*Punica granatum L.)* peel is a food-processing by-product containing polyphenols, including hydrolysable tannins and phenolic acids, that have been studied for antioxidant and antimicrobial properties. This narrative review considers the potential role of pomegranate peel extract in hydrogel, film, and other polymer-based wound dressing systems. It discusses raw-material processing, extraction and standardization, the selection of biodegradable or biocompatible polymer matrices, and evaluation parameters relevant to pharmaceutical development. Published studies have already explored pomegranate peel extract in several wound dressing formats, including polyvinyl alcohol/carboxymethyl cellulose hydrogels, bacterial cellulose/dextran materials, and multilayer fibre dressings. Therefore, the principal opportunity is not simply to combine peel extract with a polymer, but to define a reproducible formulation, establish its safety and performance, and identify a specific unresolved need. Important considerations include extract variability, compatibility with polymers, moisture handling, mechanical integrity, release behaviour, microbiological quality, stability, and biocompatibility. A dressing should be described as "smart" only when a measurable response to a relevant stimulus—such as pH or temperature—has been designed and demonstrated. This review outlines a practical evidence framework for evaluating such systems and highlights the need for transparent methods, appropriate controls, and cautious interpretation of preclinical findings. Pomegranate peel extract is a promising research input for sustainable dressing development, but clinical suitability cannot be inferred from phytochemical composition or in-vitro activity alone.

Keywords: Pomegranate peel extract; *Punica granatum*; biodegradable wound dressing; polyphenols; wound-care materials; chitosan; sodium alginate; smart biomaterials; antimicrobial activity; sustainability.

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INTRODUCTION

Dressings are intended to protect the wound, manage exudate, and support a local environment compatible with tissue repair. The choice of dressing depends on wound type, exudate level, infection risk, and clinical context. Conventional gauze and advanced dressings such as films, foams, hydrocolloids, and hydrogels have different strengths and limitations; no single material is appropriate for every wound. [10,12]

Biodegradable and naturally derived polymers are being studied as alternatives or complements to conventional dressing materials. Hydrogels are of particular interest because their water-rich networks can conform to irregular surfaces and may support local delivery of incorporated compounds. However, high water content alone does not establish adequate mechanical strength, fluid handling, sterility, or safety. [10,11]

Pomegranate *(Punica granatum L.)* peel is generated in substantial quantities during fruit processing and is often treated as a low-value by-product. Its polyphenolic profile has motivated research into food, pharmaceutical, and biomedical applications. Recent primary studies have already tested peel extract in gel formulations and polymer-based dressings, so a useful new review must critically compare formulation choices and evidence rather than present the general concept as unprecedented [1–5].

The aim of this review is to evaluate the potential and limitations of pomegranate peel extract as a functional ingredient in biodegradable wound dressing systems.

Specific objectives are to: (i) summarize relevant phytochemical groups; (ii) describe processing and extraction considerations; (iii) compare candidate polymer matrices and dressing formats; (iv) identify appropriate formulation and biological evaluation tests; and (v) outline research gaps that may guide a student-level formulation project.

Review Approach and Search Strategy

This draft is structured as a narrative review, not a registered systematic review. Before submission, the author should perform and document a reproducible literature search in PubMed, Google Scholar, and relevant publisher databases. Suggested search strings include: “pomegranate peel extract” AND “wound dressing”; *“Punica granatum”* AND hydrogel; “pomegranate peel” AND biocompatibility; and “pH-responsive” AND wound dressing.

Record the date of each search, databases used, exact search strings, year range, number of records screened, and reasons for excluding papers. Prioritize peer-reviewed primary studies and reviews with clear bibliographic information. Verify every reference against the publisher or PubMed

record, and ensure claims in the final manuscript are supported by the cited sources. Do not describe the review as systematic unless a systematic method was actually followed.

Phytochemical Basis and Standardization

Pomegranate peel contains polyphenolic constituents, including hydrolysable tannins such as punicalagin and punicalin, and phenolic acids such as ellagic acid and gallic acid. The profile and measured concentration can vary with cultivar, maturity, growing conditions, drying, storage, solvent composition, extraction time, and temperature [1,2,5]. [7,14] [20,15]

These compounds provide a rationale for testing antioxidant or antimicrobial activity, but biological effects depend on dose, extraction conditions, assay design, and formulation. Activity observed in a test tube does not prove wound healing in humans. In addition, high tannin content may affect colour, polymer interactions, or cell compatibility; these effects need to be evaluated rather than assumed. [7,14] [20,15]

For reproducibility, the raw material should be identified and its collection and preparation recorded. Report peel source, washing and drying conditions, particle size, extraction solvent, solid-to-solvent ratio, extraction time and temperature, filtration, concentration method, extraction yield, and storage. Where available, use a validated marker-compound method; total phenolic content alone is a broad measure and does not identify individual active compounds.

Extraction and Processing Considerations

Drying methods such as shade, oven, vacuum, or other controlled methods can affect residual moisture and phytochemical recovery. The most suitable method is not necessarily the one that produces the highest measured total phenolic content: it should also be affordable, reproducible, safe, and compatible with the intended use.

Water or hydroalcoholic extraction may be considered for preliminary pharmaceutical research, subject to solvent compatibility and adequate removal of residual solvent. More specialized methods, including ultrasound-assisted or pressurized extraction, may improve extraction in some settings but can require equipment and optimization. The method should be selected according to available laboratory facilities and the target analytical endpoint.

Extracts intended for wound-contact materials require particular attention to microbial quality, residual solvent, contaminants, batch consistency, and storage stability. A crude plant extract should not be presumed sterile or suitable for direct application to an open wound.

Polymer Matrices and Dressing Formats

Sodium alginate is a polysaccharide commonly explored in absorbent wound-care materials. Its gel behaviour depends on polymer concentration and the method used to form or cross-link the

network. Alginate-based systems may be useful where fluid uptake is important, but their wet integrity and release behaviour must be measured. [13]

Chitosan is a chitin-derived polymer studied for film formation and interactions with biological materials. Its properties depend on molecular weight, degree of deacetylation, pH, and processing. Claims of antimicrobial performance must be tested for the complete formulation rather than inferred solely from the polymer's reputation. [12]

Cellulose derivatives, including carboxymethyl cellulose (CMC), can alter viscosity, swelling, and matrix structure. Polyvinyl alcohol (PVA) is widely used in hydrogel research but is not automatically biodegradable under all conditions; the term "biodegradable" should be supported by the material composition and relevant evidence. Carbomer, xanthan gum, and other viscosity modifiers may help create a gel, but their inclusion alone does not establish a smart or biodegradable dressing. [2,8]

Reported dressing formats include topical gels, cast films, hydrogels, nanofibrous layers, and composite materials. Published examples already include PVA/CMC hydrogels loaded with peel extract, bacterial cellulose/dextran dressings, multilayer fibre dressings, and pH-responsive hydrogel films [2–4]. A new project should therefore specify what is different—for example, a distinct polymer combination, measurable response, improved reproducibility, lower-cost processing, or a carefully defined comparison. [18]

What Makes A Dressing "Smart"?

The term "smart" should be reserved for a dressing that responds to a defined stimulus or provides a measurable function beyond passive coverage. Possible concepts include pH-responsive swelling or release, temperature-responsive behaviour, colour change associated with a validated indicator, or a measurable change in a property linked to wound conditions. [8]

A credible smart-dressing claim requires: (i) a clear design rationale; (ii) a defined stimulus and response; (iii) quantitative testing across relevant conditions; (iv) controls that separate the response from ordinary swelling or colour changes; and (v) evidence that the response does not compromise safety or material integrity. A gel containing pomegranate peel extract, without such testing, is more accurately described as an extract-loaded hydrogel dressing. [18]

Formulation Development and Evaluation

Preformulation should assess extract solubility or dispersibility, pH, colour, compatibility with candidate polymers, and any precipitation or phase separation. Prepare trial batches using documented quantities and a consistent mixing sequence. Change one factor at a time during

preliminary screening or use a suitable design-of-experiments approach when facilities and expertise permit.

Physical tests may include appearance, homogeneity, pH, viscosity, spreadability where appropriate, film thickness, folding endurance, tensile properties, swelling ratio, moisture retention, and integrity after contact with aqueous media. The chosen tests should match the intended format: a gel and a self-supporting film do not require identical characterization.

Chemical and release testing may include total phenolic content, marker-compound analysis when available, and release profiles under justified test conditions. Assays should include appropriate blanks and controls because the colour and reducing capacity of plant extracts can interfere with some analytical methods.

Biological evaluation may include a validated antioxidant assay, antimicrobial testing with suitable positive and negative controls, and cytocompatibility testing using an appropriate model. The method, organism or cell model, replicate number, and statistical approach should be stated. Animal or clinical studies require appropriate ethical approval and should not be undertaken solely to support a college formulation without qualified supervision. [12,14]

Stability testing should monitor appearance, pH, viscosity or mechanical integrity, marker content where feasible, and microbial quality under defined storage conditions. A product intended for wound contact requires a rigorous safety and quality plan; a classroom prototype is not ready for clinical use merely because it forms a gel.

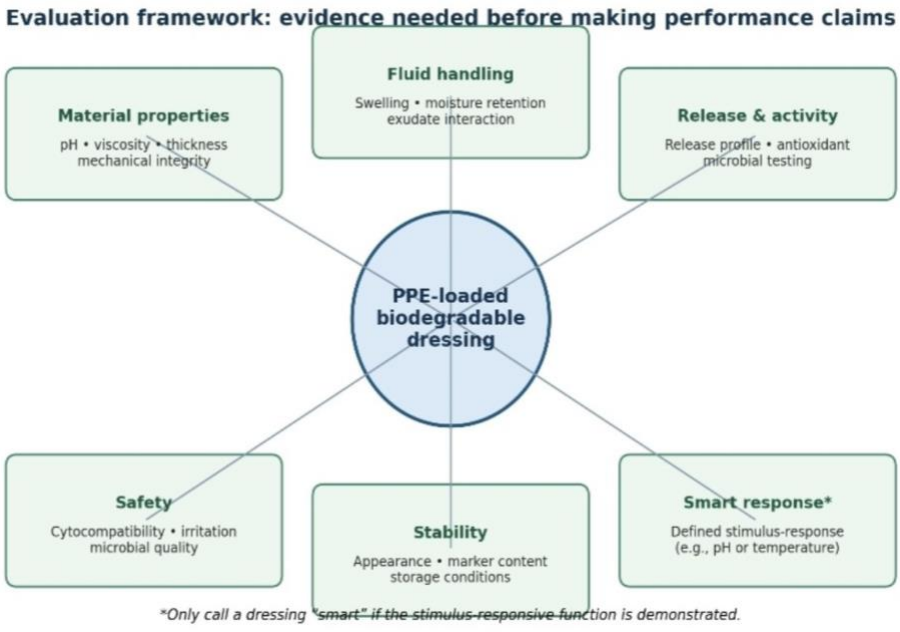


Figure 2: Evaluation framework for extract-loaded biodegradable dressings. "Smart response" requires a defined and demonstrated stimulus-response function.

Evidence Landscape and Research Gap

The literature confirms that pomegranate peel extract-based wound materials are not an entirely unexplored concept. A 2023 study reported PVA/CMC hydrogel wound dressings containing peel extract [2]. Another 2023 publication described a bacterial cellulose/dextran biopolymer dressing [3], and a multilayer cellulose/pectin/soy-protein dressing was reported in 2024 [4]. A 2024 paper evaluated a gel formulation for antimicrobial and wound-healing applications [5], while a 2025 study investigated dry crude extract as a bio-input for medicinal gels [1]. The literature also includes a pH-responsive pomegranate-peel-extract hydrogel film and a modified-chitosan hydrogel system, which are relevant precedents for stimulus-responsive and polymer-based wound-dressing research [8,9]. [16,18]

Consequently, the novelty of a new project should not be claimed simply because pomegranate peel is combined with alginate, carbomer, or another common polymer. A defensible research gap might instead concern a specific, testable question: how polymer ratio affects swelling and release; whether a low-cost extraction protocol gives consistent marker content; whether a defined pH response is reproducible; or how a formulation compares with an extract-free polymer control. The exact gap must be confirmed by an updated search before the manuscript is submitted.

At present, evidence across studies cannot be compared reliably without considering differences in extract preparation, formulation composition, test conditions, and outcome measures. Standardized methods and transparent reporting are needed before stronger conclusions can be drawn about relative performance.

Limitations and Safety Considerations

Plant extracts can vary from batch to batch and may contain unwanted contaminants. Extracts may also irritate tissue or affect cell viability at some concentrations. Antioxidant activity is not a substitute for antimicrobial testing, and antimicrobial activity does not establish clinical wound-healing efficacy. [7,14] [16,17]

Biodegradability, biocompatibility, sterility, and clinical effectiveness are separate properties. Each needs evidence appropriate to the intended use. In particular, a material described as biodegradable should have a defensible basis for that claim, and a wound-contact product requires careful quality and safety assessment.

FUTURE PERSPECTIVES

Future studies should emphasize reproducible raw-material processing, marker-based standardization, polymer compatibility, well-designed control groups, and clinically relevant safety

endpoints. Where a smart feature is proposed, researchers should define the stimulus-response mechanism before formulation and quantify its performance.

From a B. Pharmacy project perspective, a manageable initial study could compare a small number of polymer ratios and evaluate pH, homogeneity, swelling, viscosity or mechanical integrity, and extract release. Antioxidant or antimicrobial tests should be added only where suitable facilities, validated methods, controls, and supervision are available. The project should present measured results transparently and avoid claims beyond the evidence

Table 1: Candidate Materials and Formulation Considerations

Sr no	Material / format	Potential role	Key checks / cautions
1	Sodium alginate	Water uptake and gel-forming matrix	Wet integrity, cross-linking, swelling, release
2	Chitosan	Film or composite matrix	Solubility, pH dependence, batch properties, compatibility
3	Carboxymethyl cellulose	Viscosity and moisture management	Polymer ratio, swelling, mechanical properties
4	PVA / composite hydrogel	Flexible hydrogel network	Do not assume biodegradability; assess release and integrity
5	Carbomer / xanthan gum	Gel consistency and rheology	pH, viscosity, extract compatibility; not “smart” by default
6	PPE extract	Source of polyphenolic constituents	Standardization, residual solvent, microbial quality, cytocompatibility

CONCLUSION

Pomegranate peel extract is a potentially valuable source of polyphenols for research into sustainable wound-care materials. Existing studies demonstrate that extract-loaded gels, hydrogels, and composite dressings have already been investigated, making careful comparison and a clearly defined research question essential. Formulation success depends on standardized extraction, suitable polymer selection, reproducible manufacturing, material characterization, biological evaluation, stability, and safety. The term “smart” should be used only when a measurable responsive function is demonstrated. Further controlled studies are required before any particular formulation can be recommended for clinical wound care.

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