

BIOFUNCTIONAL POLYHERBAL ALGINATE DRESSINGS MODULATE REDOX AND MICROBIAL FACTORS IN WOUND CARE

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ABSTRACT

Objectives: To design and evaluate a polyherbal alginate-based bioactive film incorporating extracts of *Curcuma longa*, *Phyllanthus emblica*, and *Azadirachta indica* for potential wound healing applications.

Methods: Plant materials were extracted using 70% ethanol by maceration and assessed for total phenolic content expressed as gallic acid equivalents. The extracts were incorporated into a sodium alginate matrix (2% weight per volume) plasticized with glycerol to obtain composite films. The prepared films were characterized for tensile properties, swelling behavior in phosphate-buffered saline, free radical scavenging activity using 2,2-diphenyl-1-picrylhydrazyl (DPPH) assay, and antibacterial activity against *Staphylococcus aureus* and *Escherichia coli* using agar well diffusion.

Results: The formulated film exhibited tensile strength in the range of 18–24 MPa with elongation at break between 20 and 35%, indicating adequate flexibility and integrity. Swelling studies demonstrated a hydration capacity of approximately 150–220%, supporting exudate absorption potential. The film showed concentration-dependent antioxidant activity with DPPH radical scavenging of 65–78% at 10 mg/mL. Antimicrobial assessment revealed distinct zones of inhibition measuring 12–16 mm against *S. aureus* and 10–14 mm against *E. coli*, confirming effective antibacterial action.

Conclusion: The polyherbal alginate-based film demonstrated a combination of mechanical stability, fluid uptake capacity, antioxidant activity, and antibacterial efficacy, suggesting its suitability as a bioactive wound dressing material. Further validation through advanced phytochemical profiling and *in vivo* studies is warranted.

Keywords: Antioxidant biomaterial, Antimicrobial activity, Bioactive alginate film, Polyherbal formulation, Wound dressing applications.

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INTRODUCTION

Translational progress in wound care notwithstanding, chronic wounds still affect roughly 2–5% of the global population and carry significant clinical and socioeconomic repercussions, with a markedly higher incidence among individuals with diabetes mellitus, vascular disorders, prolonged immobilization, and advanced age [1]. The delayed resolution of such wounds is multifactorial and is commonly driven by sustained microbial colonization, excessive oxidative stress, dysregulated inflammatory responses, and impaired tissue regeneration. Contemporary wound care frameworks emphasize the importance of restoring physiological balance at the wound interface through targeted modulation of inflammation, infection control, and tissue regeneration dynamics rather than relying solely on passive coverage approaches [2]. In parallel, advancements in wound management technologies have highlighted the limitations of traditional dressings and underscored the necessity for multifunctional systems capable of addressing microbial burden, moisture balance, and cellular repair processes simultaneously [3].

Contemporary wound management increasingly emphasizes the development of bioactive wound dressings that provide not only physical protection and moisture control but also localized therapeutic functionality. In this context, medicinal plant extracts have attracted growing attention due to their biocompatibility, affordability, and wide-ranging pharmacological activities. Phytoconstituents derived from medicinal plants are increasingly recognized for their ability to exert combinatorial effects on oxidative stress pathways, inflammatory mediators, and microbial proliferation, thereby contributing to a more favorable wound healing microenvironment [4].

Curcuma longa (turmeric) is a well-established medicinal plant rich in curcuminoids, delivering significant free-radical scavenging capacity and inflammation control. Contemporary findings attribute to these compounds the ability to support fibroblast proliferation, enhance collagen synthesis, and modulate inflammatory mediators involved in tissue remodeling [5]. *Phyllanthus emblica* (amla) contains high levels of vitamin C and polyphenolic constituents that contribute to collagen maturation, epithelial regeneration, and attenuation of oxidative damage at the wound site [6]. *Azadirachta indica* (neem) is widely recognized for its antimicrobial activity, attributed to limonoids and flavonoids that inhibit the growth of canonical wound pathogens, notably *Staphylococcus aureus* and *Escherichia coli*, thereby reducing infection-mediated delays in tissue repair [7].

Sodium alginate is a naturally derived polysaccharide extensively employed in wound dressing applications due to its excellent biocompatibility, hydrophilicity, and ability to form gel-like films upon hydration. Recent investigations into film-forming delivery systems have demonstrated that polymeric matrices such as alginate can be engineered to achieve controlled film formation, adequate mechanical integrity, and effective surface coverage, thereby enhancing their suitability as wound-contact materials [8]. Alginate-based dressings effectively absorb wound exudates, maintain a moist microenvironment conducive to epithelial migration, and allow atraumatic removal. However, alginate lacks intrinsic therapeutic activity and therefore often requires functional enhancement through the incorporation of bioactive agents to improve its clinical relevance.

Polyherbal formulations are increasingly explored in wound care research because synergistic interactions among phytochemicals

can enhance antioxidant and antimicrobial activities that are relevant to wound dressing applications [9]. Hydrogel films are now viewed as promising platforms for topical wound care due to their tunable mechanical properties, high moisture retention capacity, and compatibility with bioactive loading [10]. Nevertheless, most reported formulations focus on mono-herbal or dual-herbal systems, and investigations involving tri-herbal combinations within alginate-based films remain limited. Given the complementary pharmacological profiles of turmeric, amla, and neem—targeting inflammation, oxidative stress, epithelial support, and microbial control—integrating these extracts into a single alginate-based bioactive film represents a rational strategy for the development of multifunctional wound dressing materials. Accordingly, the present in vitro study aimed to develop and characterize an alginate-based polyherbal bioactive film incorporating these three medicinal plant extracts and to evaluate its physicochemical properties, mechanical performance, antioxidant potential, and antimicrobial activity relevant to wound dressing applications.

METHODS

Plant material procurement and authentication

Dried rhizomes of *C. longa*, fruits of *P. emblica*, and leaves of *A. indica* were procured from authenticated sources. The plant materials were cleaned, shade-dried where necessary, and pulverized into coarse powder for extraction. The overall workflow of extraction, formulation, and characterization of the polyherbal alginate film is illustrated in Fig. 1.

Hydroalcoholic extraction of plant materials

The powdered plant materials were individually subjected to maceration using 70% ethanol at a solvent-to-plant ratio of 10:1 (v/w) for 48 h at room temperature (25±2°C) with intermittent agitation. The extracts were filtered through Whatman No. 1 filter paper, concentrated under reduced pressure using a rotary evaporator, and dried at 40–45°C to constant weight. The dried extracts were stored in airtight containers under refrigerated conditions until further use.

Preliminary phytochemical standardization

Extract standardization was performed by estimating total phenolic content (TPC) using the Folin–Ciocalteu assay. Extract aliquots were treated with Folin–Ciocalteu reagent and sodium carbonate, incubated, and absorbance was measured at 765 nm; results were expressed as mg gallic acid equivalents (GAE)/g extract [7]. Although total phenolic content was estimated for preliminary standardization, detailed characterization of key bioactive markers such as curcumin, gallic acid and azadirachtin using HPLC or LC–MS was not performed in this study. Future studies will incorporate such techniques to ensure batch-to-batch reproducibility.

Preparation of polyherbal alginate-based bioactive film

A 2% weight per volume sodium alginate solution was prepared as the polymeric matrix, with glycerol (30% weight per weight of polymer) incorporated as a plasticizer. The herbal extracts were incorporated into the matrix at defined concentrations relative to polymer weight under continuous magnetic stirring to ensure uniform dispersion. Before incorporation, the extracts were filtered and handled under aseptic conditions. The formulation was cast onto levelled glass plates and dried at 40°C to obtain flexible films. A plain alginate film prepared under identical conditions served as the control [8].

Evaluation of mechanical properties

Mechanical properties of the films were assessed using a universal testing machine in accordance with American Society for Testing and Materials D882 specifications to determine tensile strength and elongation at break [9].

Swelling behaviour analysis

Swelling studies were conducted by immersing pre-weighed film samples in phosphate-buffered saline (PBS, pH 7.4). The percentage swelling index was calculated based on the weight gain relative to the initial weight of the film.

In vitro antioxidant activity (2,2-diphenyl-1-picrylhydrazyl [DPPH] assay)

A known weight of the film was dissolved in ethanol to obtain a test solution of defined concentration (10 mg/mL). The antioxidant activity was evaluated using the DPPH radical scavenging assay, wherein the prepared film extract was incubated with DPPH solution for 30 min in the dark, and absorbance was measured at 517 nm. Ascorbic acid served as the positive control, while the DPPH solution without a sample served as the negative control.

Antimicrobial activity by agar well diffusion method

Antimicrobial activity was evaluated using the agar well diffusion method in accordance with Clinical and Laboratory Standards Institute guidelines. Bacterial inocula of *S. aureus* and *E. coli* were standardized to approximately 1×10^6 colony-forming units/mL using the McFarland standard. Sterile agar plates were inoculated, and wells of 6 mm diameter were aseptically prepared. The film was dissolved in dimethyl sulfoxide (DMSO) to obtain a concentration of 10 mg/mL, and 100 µL of the sample was loaded into each well. Ciprofloxacin (5 µg/disc) served as the positive control, while DMSO served as the negative control. All experiments were performed in triplicate, and zones of inhibition were measured in millimeters and expressed as mean±standard deviation (SD).

Statistical analysis

All experiments were conducted in triplicate (n=3), and results are expressed as mean±SD. Statistical analysis was performed using one-way analysis of variance (ANOVA) followed by Tukey's honestly significant difference *post-hoc* test for multiple pairwise comparisons. Before ANOVA, data were assessed for normality using the Shapiro–Wilk test and for homogeneity of variance using Levene's test. $p < 0.05$ was considered statistically significant.

Ethical statement

As the work was restricted to in-vitro experimentation without human or animal involvement, Institutional Ethics Committee approval was not applicable.

RESULTS

Quantitative analysis of polyphenol content and antioxidant performance (Table 1 and Fig. 2a and b) revealed a pronounced hierarchy among the individual extracts, with *P. emblica* displaying the greatest phenolic load (78.2±2.0 mg GAE/g), followed by *A. indica* (55.4±1.1 mg GAE/g) and *C. longa* (42.8±1.3 mg GAE/g). Notably, the polyherbal formulation surpassed all single-extract counterparts, exhibiting an elevated phenolic content of 96.5±1.5 mg GAE/g ($p < 0.05$). Antioxidant performance, assessed via DPPH inhibition, recapitulated this pattern, with the polyherbal system achieving the highest scavenging capacity (78.3±2.1%; $p < 0.05$). Such enhancements are indicative of cooperative phytochemical interactions, potentially additive or synergistic, that reinforce redox buffering capabilities. From a translational standpoint, strengthened antioxidant capacity may attenuate oxidative stress within wound microenvironments, a

Table 1: Quantitative antioxidant-related parameters of individual extracts and polyherbal formulation

Sample	Phenolic concentration index (mg GAE/g)	DPPH scavenging capacity (%)
<i>Curcuma longa</i>	42.8±1.3	45.6±2.1
<i>Azadirachta indica</i>	55.4±1.1	52.3±1.8
<i>Phyllanthus emblica</i>	78.2±2.0	63.8±2.4
Polyherbal formulation	96.5±1.5*	78.3±2.1*

*Values are mean±SD (n=3). Statistical significance was determined using one-way ANOVA followed by Tukey's *post-hoc* test. $p < 0.05$ compared to each individual extract. ANOVA: Analysis of variance, GAE: Gallic acid equivalents, DPPH: 2,2-diphenyl-1-picrylhydrazyl, SD: Standard deviation

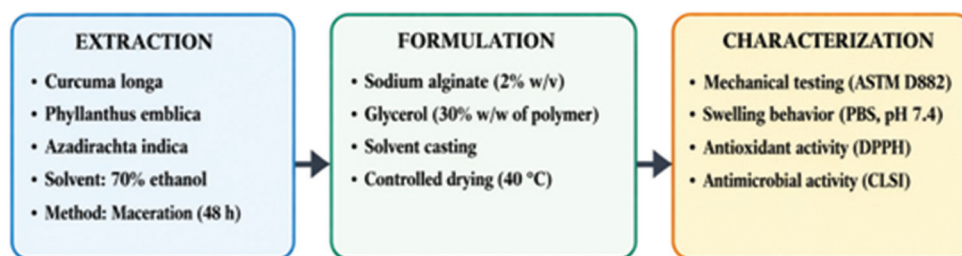


Fig. 1: Schematic workflow

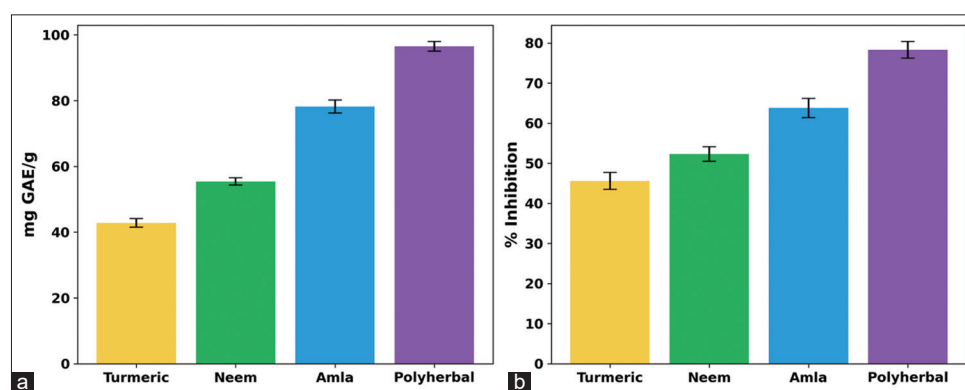


Fig. 2: Total phenolic content (TPC) and 2,2-diphenyl-1-picrylhydrazyl (DPPH). (a) TPC (mg gallic acid equivalents/g extract) and (b) DPPH radical scavenging activity (%) of individual extracts and polyherbal formulation. Data are mean±standard deviation (n=3). $p < 0.05$ compared to each individual extract

key determinant of tissue recovery dynamics and biointeractivity in polymeric wound dressings.

The mechanical performance of plain alginate and polyherbal alginate films is presented in Table 2 and Fig. 3a and b. The polyherbal alginate film exhibited a significantly higher tensile strength (32.4 ± 1.2 MPa) compared with the plain alginate film (24.1 ± 1.5 MPa; $p < 0.05$). In addition, elongation at break increased from $12.4 \pm 1.1\%$ for the plain alginate film to $18.7 \pm 1.4\%$ for the polyherbal film ($p < 0.05$).

The concurrent improvement in tensile strength and flexibility suggests that incorporation of the polyherbal extract did not compromise film integrity but instead enhanced mechanical resilience, an important attribute for wound dressing applications.

Antimicrobial outcomes against *S. aureus* and *E. coli* are summarized in Table 3 and depicted in Fig. 4 & Fig. 5. The plain alginate matrix displayed no discernible inhibitory response toward either organism. By contrast, the polyherbal alginate system produced well-defined inhibition halos of 18.2 ± 0.9 mm for *S. aureus* and 15.6 ± 0.8 mm for *E. coli*, representing statistically meaningful suppression relative to the alginate control ($p < 0.05$). Ciprofloxacin ($5 \mu\text{g}/\text{disc}$) generated larger zones and functioned as the pharmacological reference. Although the antimicrobial potency of the polyherbal platform did not match the antibiotic benchmark, the observed broad-spectrum inhibition is consistent with the functional goals of topical wound dressings, wherein localized microbial moderation rather than complete bactericidal sterilization is often sufficient to mitigate infection pressure and support tissue repair.

Table 4 presents the swelling profiles of the films in PBS (pH 7.4). The plain alginate film showed a higher swelling index ($65.4 \pm 2.3\%$) compared with the polyherbal alginate film ($60.0 \pm 2.0\%$). The moderated swelling observed in the polyherbal film indicates improved structural stability while retaining sufficient fluid absorption capacity. Controlled swelling is desirable for wound dressings, as excessive hydration may compromise mechanical integrity, whereas insufficient swelling can limit exudate absorption.

Table 2: Mechanical properties of plain alginate and polyherbal alginate films

Film class	Tensile performance (MPa)	Extensibility (%)
Plain alginate film	24.1 ± 1.5	12.4 ± 1.1
Polyherbal alginate film	$32.4 \pm 1.2^*$	$18.7 \pm 1.4^*$

Tensile strength and elongation at break were measured according to ASTM D882. Values are mean±SD (n=3). $p < 0.05$ compared to plain alginate film. SD: Standard deviation, ASTM : American Society for Testing and Materials

Table 3: Antimicrobial activity of polyherbal alginate film

Sample	<i>Staphylococcus aureus</i> (mm)	<i>Escherichia coli</i> (mm)
Plain alginate film	—	—
Polyherbal alginate film	$18.2 \pm 0.9^*$	$15.6 \pm 0.8^*$
Ciprofloxacin ($5 \mu\text{g}/\text{disc}$)	24.5 ± 1.1	22.8 ± 1.0

Antimicrobial activity was assessed by agar well diffusion method. Inhibition zones are presented as mean±SD (n=3). $p < 0.05$ compared to plain alginate film (no inhibition). Ciprofloxacin ($5 \mu\text{g}/\text{disc}$) served as positive control

Table 4: Swelling behaviour

Formulation	Swelling index (%)
Plain alginate	65.4 ± 2.3
Polyherbal	60 ± 2

Swelling index was calculated after 24 h immersion in PBS (pH 7.4). Values are mean±SD (n=3). PBS: Phosphate-buffered saline

An integrated comparison of functional performance parameters is presented in Fig. 4 (Radar Plot) and Fig. 5 (Heat Map). The radar plot highlights the superior overall performance of the polyherbal alginate film across antioxidant activity, mechanical strength, swelling control, and antimicrobial efficacy when compared with the plain alginate film. The heat map further emphasizes the relative enhancement of bioactive

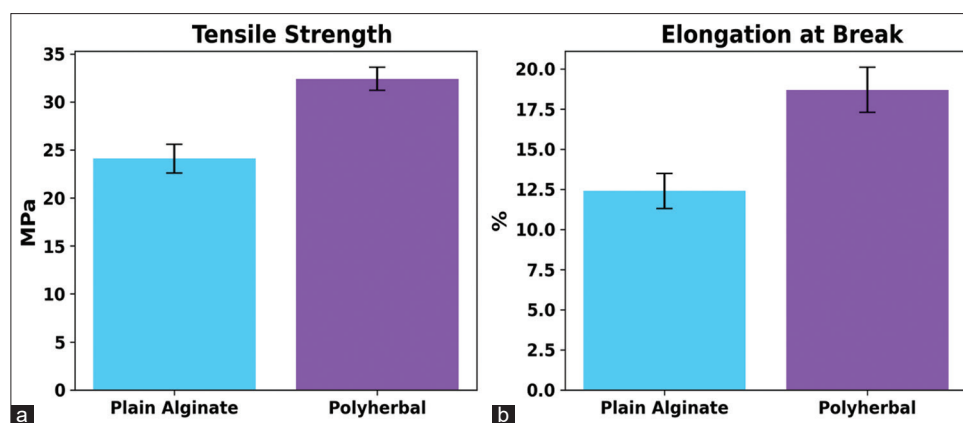


Fig. 3: (a and b) Mechanical properties

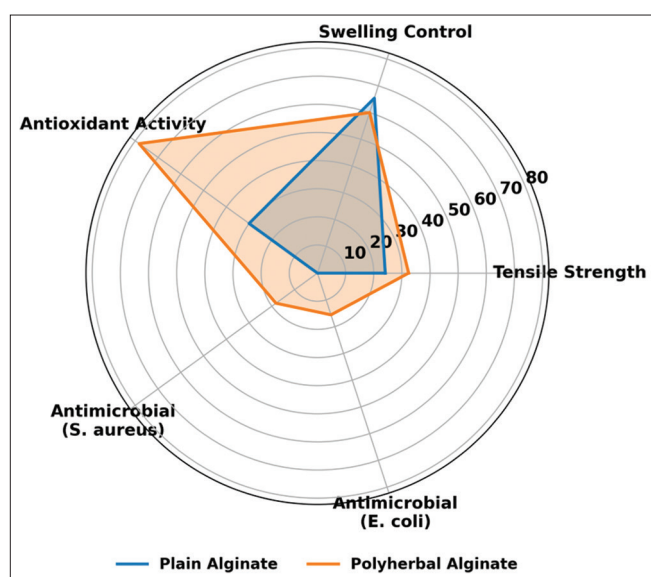


Fig. 4: Radar plot (overall performance). Radar plot comparing the functional performance of plain alginate and polyherbal alginate films across five parameters: Antioxidant activity (2,2-diphenyl-1-picrylhydrazyl), tensile strength (MPa), swelling index (%), and antimicrobial activity against *Staphylococcus aureus* and *Escherichia coli* (zone of inhibition, mm). Values are normalized to the maximum value for each parameter

properties in the polyherbal formulation through intensity-based visualization. Together, these analyses demonstrate that incorporation of turmeric, amla, and neem extracts into the alginate matrix resulted in a multifunctional bioactive film with improved physicochemical and biological performance. All datasets satisfied normality and homogeneity of variance assumptions prior to ANOVA.

DISCUSSION

The study sought to engineer and characterize a polyherbal bioactive wound-healing film by embedding extracts of *C. longa*, *P. emblica*, and *A. indica* into a sodium alginate matrix. The results demonstrate that the polyherbal formulation exhibits enhanced antioxidant potential, improved mechanical performance, controlled swelling behavior, and effective antimicrobial activity, highlighting its suitability as a multifunctional wound dressing. The significantly higher TPC observed in the polyherbal formulation compared with the individual extracts supports the concept of phytochemical synergy in combined herbal systems [10]. Polyherbal formulations are known to amplify bioactivity through complementary and additive interactions among

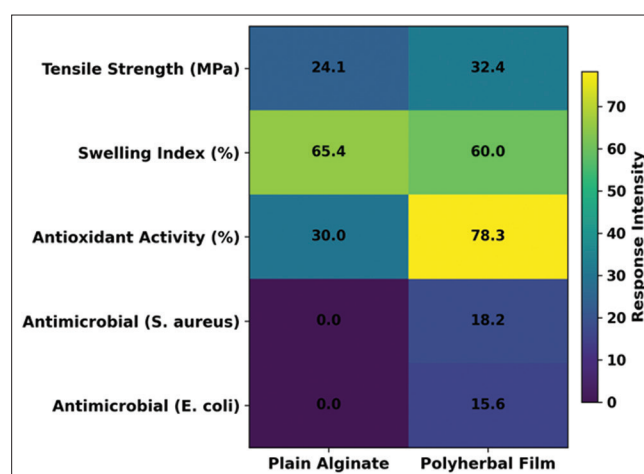


Fig. 5: Heat map of bioactive performance parameters. Heat map representing the relative bioactive performance of plain alginate and polyherbal alginate films. Color intensity reflects the magnitude of each parameter, with darker shades indicating higher values

diverse phenolic constituents. Phenolic compounds play a central role in wound repair by scavenging reactive oxygen species, modulating inflammatory cascades, and promoting fibroblast proliferation and collagen deposition [11]. The elevated DPPH radical scavenging activity (78.3%) of the polyherbal film further confirms its strong antioxidant capacity, suggesting its potential to mitigate oxidative stress, a key factor responsible for delayed healing in chronic wounds [12]. Mechanical evaluation revealed that incorporation of the polyherbal extract significantly improved both tensile strength and elongation at break compared with plain alginate films. Similar enhancements in mechanical integrity have been reported when plant-derived bioactives are incorporated into biopolymer matrices, likely due to favorable polymer-phytochemical interactions that reinforce the structural network [13]. Adequate tensile strength is essential to prevent tearing during handling and application, while sufficient flexibility enables conformability to irregular wound surfaces, both of which are critical requirements for advanced wound dressings [14]. Swelling studies demonstrated that the polyherbal alginate film maintained a moderate swelling index (58–62%), indicating its ability to absorb wound exudates while retaining structural stability. Controlled swelling is a desirable feature for wound dressings, as excessive hydration may compromise film integrity, whereas insufficient swelling can limit effective exudate management. Maintenance of a moist wound environment has been widely reported to accelerate epithelial migration, angiogenesis, and extracellular matrix remodeling, thereby promoting faster wound closure [15]. Sodium alginate-based dressings

are particularly valued for their high fluid absorption capacity, and incorporation of herbal bioactives may further enhance functional performance. The antimicrobial evaluation revealed pronounced inhibitory activity of the polyherbal film against *S. aureus* and *E. coli*, two clinically relevant wound pathogens. This broad-spectrum antibacterial activity can be attributed to the presence of curcuminoids, tannins, flavonoids, and limonoids present in turmeric, amla, and neem, which exhibit antimicrobial action by perturbing microbial membranes, suppressing key enzymatic functions, and modulating bacterial signaling pathways [16]. Such antimicrobial properties are especially relevant in wound management, as bacterial colonization is a major factor contributing to delayed healing and chronic infection. Overall, the findings of this study demonstrate that combining turmeric, amla, and neem extracts within an alginate matrix produces a synergistic enhancement of antioxidant, mechanical, and antimicrobial properties compared with individual extracts. The present trend resonates with contemporary findings in which herbal matrices demonstrated favorable wound repair kinetics, which emphasize the therapeutic advantages of polyherbal film-based wound-healing systems [17]. The developed polyherbal alginate film therefore represents a promising, low-cost, plant-based wound dressing with potential applicability in both clinical and community healthcare settings.

Polyherbal wound-care systems have received growing attention since chronic wounds often involve overlapping oxidative, microbial, and structural challenges. Reports indicate that multi-herb preparations can stimulate epithelial recovery and reduce oxidative stress in delayed-healing wound environments [18].

The increased phenolic content detected in the present formulation may contribute to its pronounced antioxidant profile.

It has also been shown that constituents from turmeric, amla, and neem can act cooperatively when formulated together, intensifying free-radical quenching and facilitating collagen reorganization during tissue repair [19]. Correspondingly, the elevated DPPH inhibition in our work suggests that the film may buffer oxidative load, a key barrier to wound progression.

Mechanical reinforcement through the incorporation of phytochemicals into biopolymer matrices has been described, with extract-enriched films exhibiting improved stretch resistance and tensile durability attributes essential for dressings that must withstand handling and conform to irregular surfaces [20]. Consistent with these observations, our polyherbal alginate film displayed enhanced tensile strength and flexibility, implying beneficial polymer-phytochemical interactions.

Polyherbal formulations additionally provide antimicrobial advantages, as phytochemical-rich extracts have been reported to suppress clinically relevant biofilm-forming wound pathogens, exemplified by *S. aureus* and *E. coli*, reducing the risk of prolonged colonization and secondary infection at wound sites [21]. The inhibitory zones seen in the present study reflect these microbicidal contributions.

Recent findings further highlight that combining botanical extracts with biodegradable polymers can yield multifunctional dressing platforms capable of simultaneously mitigating oxidative stress, curbing bacterial burden, and offering mechanical support [22]. Similar antioxidant enhancement in polyherbal systems has been previously reported [23]. Comparable formulation strategies involving curcumin-loaded delivery systems have also demonstrated improved therapeutic performance [24]. Related polyherbal wound-healing formulations have shown beneficial effects in burn wound management models [25]. Comparable findings regarding wound healing potential of polyherbal formulations have also been documented previously [26]. Taken together, the current results indicate that the developed polyherbal alginate film possesses attributes suitable for continued experimental validation and potential translational use in wound management. Although experiments were performed in triplicate (n=3), which is standard for preliminary

material characterization, further studies with larger sample sizes are warranted to strengthen statistical robustness.

CONCLUSION

The present study successfully developed a polyherbal alginate bioactive film incorporating *C. longa*, *P. emblica*, and *A. indica*. The formulated film exhibited improved mechanical strength, controlled swelling behavior, enhanced antioxidant activity, and effective antimicrobial action against common wound pathogens. These multifunctional properties highlight the potential of the polyherbal film to provide both physical protection and therapeutic support during the wound-healing process. Collectively, the findings suggest that this plant-based, cost-effective dressing represents a promising candidate for further preclinical evaluation and optimization for wound management applications.

AUTHORS' CONTRIBUTION

Srinivasa B: Concept and design of the study, procedure, acquisition of data, drafting and revision of the manuscript, editing and formatting as per journal guidelines. Madhusudhan B: Supervision, assisted in acquisition of data, experimental procedure, Statistical analysis, data analysis, and interpretation. Vaheedha S: Assisted in editing and formatting as per journal guidelines. Vinodh Ramalingam: Data interpretation and critical revision of the manuscript.

CONFLICT OF INTEREST

None declared.

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None declared.

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AI USE STATEMENT

During the preparation of this manuscript, artificial intelligence-assisted tools were utilized only to support language editing and improve the clarity of the text. The conceptualization of the study, analysis of the findings, and interpretation of the results were performed independently by the authors. The authors take full responsibility for the accuracy, originality, and scientific integrity of the work presented in this manuscript.

REFERENCES

1. Singh V, Marimuthu T, Makatini MM, Choonara YE. Biopolymer-based wound dressings with biochemical cues for cell-instructive wound repair. *Polymers (Basel)*. 2022 Dec;14(24):5371. doi: 10.3390/polym14245371, PMID 36559739
2. Shumkova MM, Bakhrushina EO, Davydova MA, Pouya G, Agabalyan MM, Timoshkina AA. Characterization and screening parameters of spray film-forming systems: A comprehensive study on dosage forms and quality indicators. *Int J Appl Pharm*. 2023;15(6):118-24. doi: 10.22159/ijap.2023v15i6.48721
3. Furtado SC, Srinivasan B, Abraham S. Wound healing concepts: Contemporary practices and future perspectives. *Int J Appl Pharm*. 2020;12(5):7-15. doi: 10.22159/ijap.2020v12i5.38588
4. Geetha S, Gupta NV, Gowda DV, Kulkarni PK. Research and development in wound management products: A brief review. *Asian J Pharm Clin Res*. 2018;11(6):17-24. doi: 10.22159/ajpcr.2018.v11i6.23541
5. Isopencu GO, Covaliu-Mierla CI, Deleanu IM. From plants to wound dressing and transdermal delivery of bioactive compounds. *Plants (Basel)*. 2023;12(14):2661. doi: 10.3390/plants12142661, PMID 37514275
6. Prananda AT, Dalimunthe A, Harahap U, Simanjuntak Y, Peronika E,

- Karosekali NE. *Phyllanthus emblica*: A comprehensive review of its phytochemical composition and pharmacological properties. *Front Pharmacol*. 2023;14:1288618. doi: 10.3389/fphar.2023.1288618, PMID 37954853
7. Wylie MR, Merrell DS. The antimicrobial potential of the neem tree *Azadirachta indica*. *Front Pharmacol*. 2022;13:891535. doi: 10.3389/fphar.2022.891535, PMID 35712721
 8. Rajappa MC, Kannan A, Venkatasubramanian N, Venkatachalam L, Karnan S, Antonyamy D. Improved wound healing activity through synergistic approach of pumpkin seed oil and curcumin loaded model in microgel. *Int J Appl Pharm*. 2025;17(5):238-52. doi: 10.22159/ijap.2025v17i5.54322
 9. Talekar YP, Apte KG, Paygude SV, Tondare PR, Parab PB. Studies on wound healing potential of polyherbal formulation using *in vitro* and *in vivo* assays. *J Ayurveda Integr Med*. 2017;8(2):73-81. doi: 10.1016/j.jaim.2016.11.007, PMID 28601354
 10. Sutradhar SC, Shin H, Kim W, Jang H. Hydrogel films in biomedical applications: Fabrication, properties and therapeutic potential. *Gels*. 2025 Nov 17;11(11):918. doi: 10.3390/gels11110918, PMID 41294603
 11. Singleton VL, Rossi JA. Colorimetry of total phenolics with phosphomolybdic-phosphotungstic reagents. *Am J Enol Vitic*. 1965;16(3):144-58. doi: 10.5344/ajev.1965.16.3.144
 12. Nandhini J, Karthikeyan E, Rajeshkumar S. Eco-friendly bio-nanocomposites: Pioneering sustainable biomedical advancements in engineering. *Discov Nano*. 2024;19(1):86. doi: 10.1186/s11671-024-04007-7, PMID 38724698
 13. ASTM International. ASTM D882-18: Standard Test Method for Tensile Properties of Thin Plastic Sheeting. West Conshohocken: ASTM International; 2018. Available from: <https://www.astm.org/d0882-18.html> [Last accessed on 2026 Apr 25].
 14. Sulaiman CT, Anju K, Anandan EM, Balachandran I. Synergistic interactions of phytochemicals in polyherbal formulation enhance the chemical transformations of active constituents. *J Appl Spectrosc*. 2021;88(1):181-6. doi: 10.1007/s10812-021-01156-w
 15. Patel F, Doshi Ankita A, Baxi D. Role of medicinal plants in wound healing: An ethnopharmacological approach. In: Kumar P, Kothari V, editors. *Wound Healing Research*. Singapore: Springer; 2021. p. 177-217. doi: 10.1007/978-981-16-2677-7_6
 16. Tran HQ, Shahriar SM, Yan Z, Xie J. Recent advances in functional wound dressings. *Adv Wound Care* (New Rochelle). 2023;12(7):399-427. doi: 10.1089/wound.2022.0059, PMID 36301918
 17. Bai Q, Han K, Dong K, Zheng C, Zhang Y, Long Q. Potential applications of nanomaterials and technology for diabetic wound healing. *Int J Nanomedicine*. 2020;15:9717-43. doi: 10.2147/ijn.s276001, PMID 33299313
 18. Boateng J, Catanzano O. Advanced therapeutic dressings for effective wound healing--a review. *J Pharm Sci*. 2015;104(11):3653-80. doi: 10.1002/jps.24610, PMID 26308473
 19. Dhivya S, Padma VV, Santhini E. Wound dressings - a review. *Biomedicine (Taipei)*. 2015;5(4):22. doi: 10.7603/s40681-015-0022-9, PMID 26615539
 20. Dev SK, Choudhury PK, Srivastava R, Sharma M. Antimicrobial, anti-inflammatory and wound healing activity of polyherbal formulation. *Biomed Pharmacother*. 2019;111:555-67. doi: 10.1016/j.biopha.2018.12.075, PMID 30597309
 21. Imtiaz T, Priyadarshini R, Rajeshkumar S, Sinduja P. Green synthesis and characterization of silver nanoparticles synthesized using *Piper longum* and its antioxidant activity. *J Pharm Res Int*. 2021;33(51A):342-52. doi: 10.9734/jpri/2021/v33i51A33501
 22. Mahajan Y, Gupta V. Assessment of wound healing activity of polyherbal gel, by "burn wound model" in Wistar rats. *Res J Pharmacol Pharmacodyn*. 2025;17(4):257-62. doi: 10.52711/2321-5836.2025.00041
 23. Rana N, Singh V, Ali M. Phytochemical analysis and assessment of *in vitro* antioxidant potential of polyherbal formulation. *Res J Pharm Technol*. 2023;16(6):2895-9. doi: 10.52711/0974-360X.2023.00477
 24. Karthika C, Sureshkumar R, Upadhyay D, Janani SK, Vasanthi C, Raja M. Formulation development and *in vitro* characterization of solid self nano emulsifying drug delivery system for curcumin to target colon adenocarcinoma. *Res J Pharm Technol*. 2019;12(7):3338-46. doi: 10.5958/0974-360X.2019.00563.8
 25. More AG, Shinde SR, Kore PS, Jadhav MN, Tapkir AS. Investigating the effect of polyherbal ointment on non-healing burn wound: The geriatric approach. *Res J Pharm Technol*. 2023;16(10):4610-6. doi: 10.52711/0974-360X.2023.00751
 26. Kumar R, Gupta R, Kumar B, Kapoor B. Wound healing potential of polyherbal formulation in rats. *Res J Pharm Technol*. 2021;14(4):2195-9. doi: 10.52711/0974-360X.2021.00389