

Development of Biopolymer-Based Herbal Hydrogel Patches Loaded with Aloe vera, Dandelion and Ginger Extracts for Dermatological Applications

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ABSTRACT

Acne vulgaris is a chronic inflammatory disorder of the pilosebaceous unit characterised by sebum overproduction, follicular hyperkeratinisation and bacterial colonisation. Conventional therapies such as topical retinoids, benzoyl peroxide or systemic antibiotics can cause dryness, irritation and foster antimicrobial resistance. Hydrogels formed from natural and synthetic macromolecules offer a biocompatible platform for the sustained topical delivery of phytochemicals. Objective: To develop and characterise herbal hydrogel patches containing extracts of Aloe vera, Dandelion (*Taraxacum officinale*) and Ginger (*Zingiber officinale*) using a hybrid polymer matrix and to evaluate their physicochemical properties and chemical compatibility. Methods: Plant extracts were obtained via maceration or Soxhlet extraction, concentrated and combined with a polymer mixture of sodium alginate, gelatine and polyethylene glycol. Free-radical polymerisation using ammonium persulfate and citric acid yielded four formulations (F1–F4) differing in their extract composition. Patches were assessed for colour, transparency and smoothness, swelling index, pH, and analysed by Fourier transform infrared (FTIR) spectroscopy. Results: Physical examinations showed that increasing herbal loading produced a darker colour and reduced transparency, with F2 (Aloe + Dandelion) being the opaque. Swelling indices ranged from 37 % (F1) to 53 % (F2 and F4), indicating good hydration capacity. All formulations had pH values between 6.95 and 7.75, matching the skin's acid mantle. FTIR spectra confirmed the presence of characteristic –OH, C=O and C–O–C bands without new peaks, suggesting no deleterious chemical interactions. Conclusions: The hybrid biopolymer matrix successfully accommodated herbal extracts without altering their chemical integrity. F2 patches offered optimum hydration and structural stability, positioning them as promising candidates for plant-based acne therapy. Further studies on antimicrobial efficacy and in vivo performance are warranted.

Keywords: Aloe vera; *Taraxacum officinale*; *Zingiber officinale*; biopolymer hydrogel; FTIR spectroscopy; swelling index; acne vulgaris.

INTRODUCTION

Acne vulgaris is a multifactorial inflammatory disease of the pilosebaceous unit, manifesting as comedones, papules, pustules or cystic lesions primarily in adolescents and young adults. Its pathogenesis involves increased sebum production, abnormal follicular keratinisation and proliferation of *Cutibacterium acnes* coupled with inflammation. Current treatments utilise topical retinoids, antibiotics, and benzoyl peroxide, but are associated with dryness, irritation, and the emergence of

antibiotic resistance. Consequently, there is growing interest in phytomedicines with multi-targeted mechanisms and milder side-effect profiles.

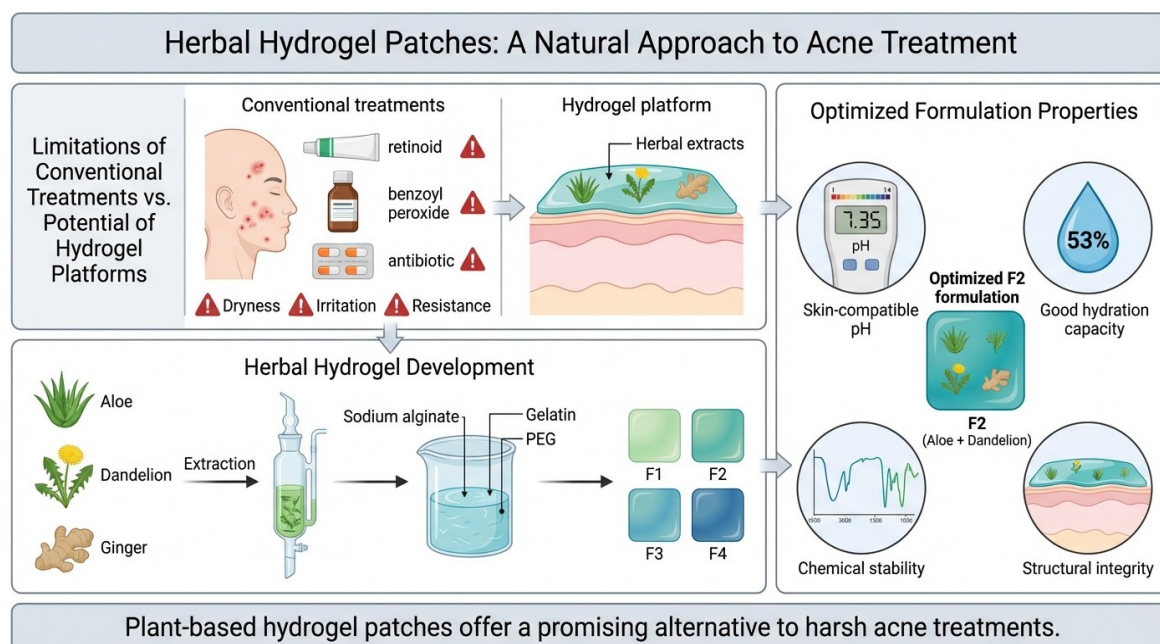
Hydrogels are three-dimensional networks of hydrophilic macromolecules that can hold large amounts of water. They hydrate the stratum corneum, disrupt lipid organization and facilitate transdermal transport of incorporated bioactives. Natural hydrogels derived from polysaccharides (e.g. alginate, chitosan) or proteins (e.g. gelatine) exhibit excellent biocompatibility but limited mechanical

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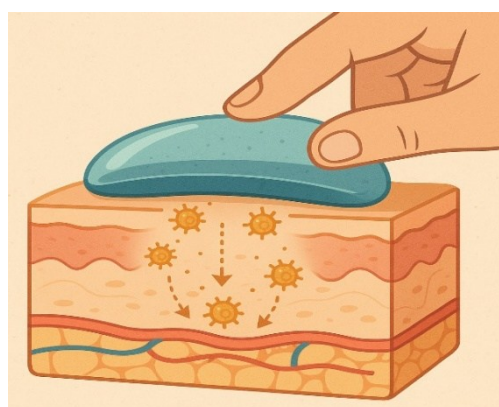
strength; synthetic hydrogels such as PEG or PVA offer adjustable mechanical properties but lack bioactivity. Hybrid hydrogels combine natural and

synthetic polymers to balance mechanical robustness with biocompatibility.

Graphical abstract



Aloe vera gel contains polysaccharides (acemannan), vitamins and enzymes conferring anti-inflammatory and wound-healing properties. **Dandelion** (*T. officinale*) contains taraxasterol and chlorogenic acid with antioxidant and sebum-modulating effects. **Ginger** (*Zingiber officinale*) provides gingerols and shogaols, which are known for their anti-inflammatory and healing actions. Combining these botanicals with a hybrid hydrogel may provide sustained topical therapy for acne with minimal irritation.



This study aimed to develop herbal hydrogel patches using a hybrid matrix of sodium alginate, gelatine and PEG, loaded with extracts of **Aloe vera**, **Dandelion**

and **Ginger**. The physicochemical properties, swelling behaviour, pH and chemical compatibility were evaluated to identify an optimal formulation for dermatological application.

2. MATERIALS AND METHODS

2.1 Materials

Fresh **Aloe vera** leaves and ginger rhizomes were procured from local markets in Kishanganj, India; dried *T. officinale* aerial parts were purchased from a commercial supplier. Sodium alginate (polymer), PEG 400 (plasticiser), ammonium persulfate (APS, initiator), citric acid (crosslinker) and gelatine (monomer) were obtained from the departmental store at Mata Gujri College of Pharmacy. Ethanol (analytical grade) was used for extraction. Deionised water was used in all preparations. All chemicals were of analytical grade and used as received.

2.2 Extraction of herbal constituents

2.2.1 Aloe vera extraction

Fresh leaves were washed thoroughly, the outer rind was removed and the inner gel was scooped and



homogenised. The homogenate was macerated in an ethanol–water mixture (1:1) at 40 °C for several hours, and the solvent was evaporated under reduced pressure to yield a polysaccharide-rich extract. The extract was stored in sterile containers at 4–8 °C until use.

2.2.2 Dandelion extraction

Taraxacum officinale aerial and root parts were shade-dried, ground into a coarse powder and subjected to Soxhlet extraction with ethanol–water (1:1) at ≈ 40 °C for 4–6 h. The filtrate was concentrated under reduced pressure and stored in a dark, cool place to preserve flavonoids and phenolic compounds.

2.2.3 Ginger extraction

Ginger rhizomes were cleaned, thinly sliced, and dried at low temperature to preserve heat-labile gingerols. The dried slices were powdered and

extracted using Soxhlet with ethanol–water (1:1) at approximately 40 °C for 3–4 hours. The resulting extract was concentrated by solvent evaporation and stored at low temperature until use in formulation.

2.3 Preparation of hydrogel patches

Hydrogel patches were prepared by free-radical polymerisation. Sodium alginate and gelatine were dissolved in deionised water under stirring at 37 °C. Separately, PEG 400 and the requisite herbal extracts were heated to 90 °C until homogeneous. The cooled polymer mixture was combined with the PEG–extract blend, APS (0.1 g) and citric acid (0.1 g) were added as initiator and crosslinker, and the solution was poured into Petri dishes. After polymerisation at low temperature for 2 h, the resultant films were washed with 70:30 ethanol–water to remove unreacted species and dried at 40 °C for 48 h. Five formulations were prepared: a blank film without extracts and four films, F1–F4, differing in extract composition (Table 1).

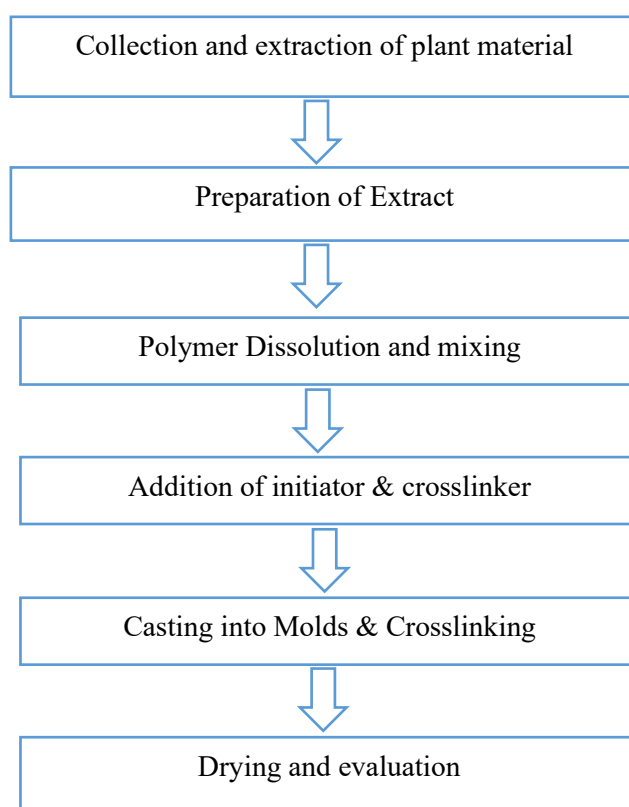


Figure: Flowchart summarising the extraction of plant materials, polymer dissolution, addition of initiator/crosslinker, casting and drying steps used to produce the herbal hydrogel patches.

Table 1. Composition of hydrogel formulations

Ingredient (per patch)	Blank	F1 (Aloe + Ginger + Dandelion)	F2 (Aloe + Dandelion)	F3 (Aloe + Ginger)	F4 (Aloe)
Sodium alginate (g)	0.1	0.1	0.1	0.1	0.1
PEG 400 (mL)	0.1	0.1	0.1	0.1	0.1
APS (g)	0.1	0.1	0.1	0.1	0.1
Citric acid (g)	0.1	0.1	0.1	0.1	0.1
Gelatine (g)	4.0	4.0	4.0	4.0	4.0
Aloe vera extract (g)	–	2	2	2	4
Dandelion extract (g)	–	0.2	0.2	–	–
Ginger extract (g)	–	0.2	–	0.4	–

2.4 Evaluation methods

2.4.1 Physical characteristics

Colour, transparency and surface smoothness were assessed by visual and tactile inspection. Colour uniformity across each film indicated homogeneous distribution of extracts; transparency was evaluated under ambient light and classified qualitatively (transparent, translucent or opaque). Surface smoothness was examined by gently gliding fingertips across the patch and categorised as smooth, slightly smooth or moderately smooth.

2.4.2 Swelling index

Circular discs (1 cm diameter) were cut from each patch, weighed (W_0) and immersed in phosphate buffer (pH 5.5) at room temperature. Samples were removed after 4 h, blotted to remove surface water and re-weighed (W_t). The swelling index was calculated using Eq. (1):

$$\text{Swelling Index (\%)} = \frac{W_t - W_0}{W_0} \times 100$$

2.4.3 pH evaluation

Patches (0.5 g) were dispersed in 10 mL deionised water and allowed to equilibrate at room temperature for 2 h. The pH of the resulting dispersion was measured using a calibrated digital pH meter. A pH

range of 6.5–7.5 is considered compatible with normal skin.

2.4.4 FTIR spectroscopy

Fourier transform infrared spectra of dried films were recorded over 4000–400 cm^{-1} to assess chemical compatibility of the polymers and extracts. Major absorption peaks were identified and compared with those of individual components.

2.4.5 Data analysis

All experiments were performed in triplicate. Quantitative data are presented as mean $\pm$ SD. Graphs were plotted using Python (Matplotlib).

3. RESULTS AND DISCUSSION

3.1 Physical characteristics

Colour and transparency of the hydrogels reflected the phytoconstituent load. The blank film was nearly colourless and transparent, whereas F1 and F3 appeared pale yellow, F4 was very pale yellow and F2 exhibited a darker yellowish-brown tone due to the higher loading of dandelion flavonoids (Table 2). Transparency decreased with increasing extract content: F2 was opaque while F1, F3 and F4 were translucent, consistent with the presence of suspended plant particles. All films, except F2, were smooth to the touch; F2 showed a moderately rough surface, possibly due to its higher solid content.



Table 2. Physical appearance of hydrogel formulations

Formulation	Colour	Transparency	Smoothness
Blank	Very pale & almost clear	Almost transparent	Smooth
F1	Pale yellow	Slightly translucent	Slightly smooth
F2	Dark yellowish–brown	Opaque	Moderately smooth
F3	Pale yellow	Translucent	Smooth
F4	Very pale yellow	Translucent, bubbly	Smooth

3.2 Swelling index and pH evaluation

Swelling indices (Figure 1) ranged from 37 % (F1) to 53 % (F2 and F4), demonstrating good fluid uptake capacity. The high swelling of F2 may be attributed to the synergistic hydrophilicity of Aloe and Dandelion polysaccharides; F4 (Aloe only) exhibited a similar swelling value, underscoring the influence of acemannan. An adequate swelling index facilitates prolonged skin contact and sustained drug release.

pH values of all formulations lay between 6.95 and 7.75 (Figure 2), within the physiological skin range. F1 displayed the highest pH (7.75), possibly due to alkaline components in ginger extract. Maintaining a skin-compatible pH is essential to minimise irritation and preserve the stratum corneum barrier.

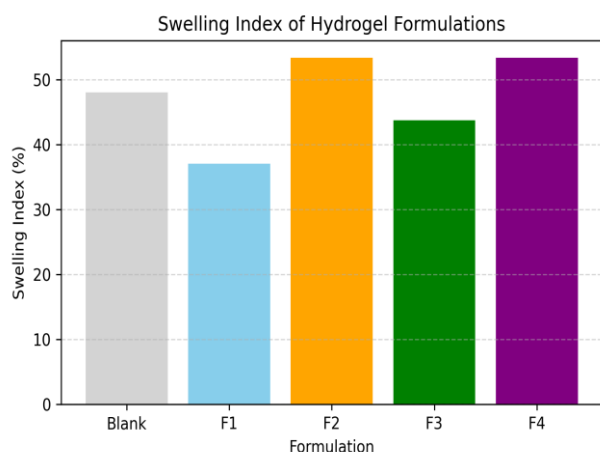


Figure 1. Swelling index (%) of blank and herbal hydrogel formulations (mean $\pm$ SD).

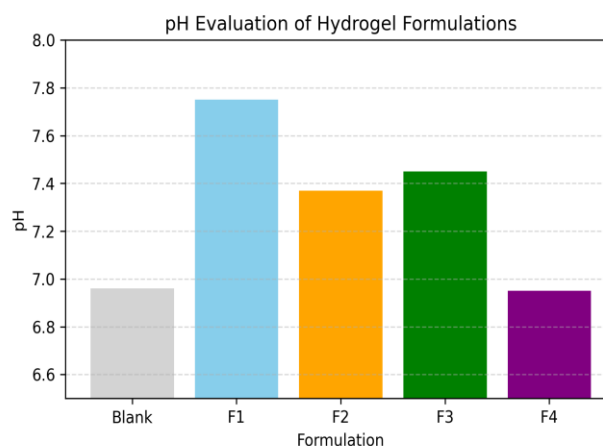


Figure 2. pH of blank and herbal hydrogel formulations (mean $\pm$ SD).

3.3 FTIR spectroscopy

FTIR spectra for F1–F4 (Figure 3) revealed major absorption bands at $\sim 3300\text{ cm}^{-1}$ (broad $-\text{OH}$ stretching), $\sim 2920\text{ cm}^{-1}$ ($\text{C}-\text{H}$ stretching), $\sim 1640\text{ cm}^{-1}$ ($\text{C}=\text{O}$ stretching), $\sim 1380\text{ cm}^{-1}$ (COO^- vibrations) and $\sim 1040\text{--}1100\text{ cm}^{-1}$ ($\text{C}-\text{O}-\text{C}$ or $\text{C}-\text{O}$ stretching). These peaks correspond to polysaccharides, carboxylic acids and flavonoids present in the extracts and to the polymer backbone. The absence of new peaks or significant shifts indicates that free-radical polymerisation preserved the chemical identity of the plant constituents and did not generate undesirable interactions with the polymers.

F2 displayed slightly higher band intensities at $\sim 3300\text{ cm}^{-1}$ and $\sim 1640\text{ cm}^{-1}$, reflecting the higher concentration of phenolic compounds from dandelion. These findings corroborate previous reports that hybrid hydrogels can encapsulate sensitive phytochemicals without structural degradation.



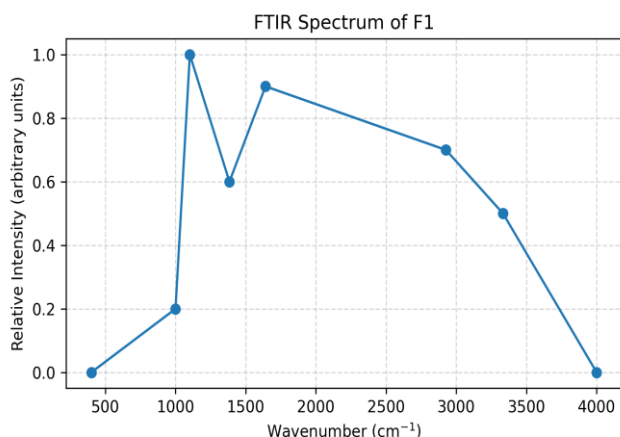


Figure 3. Representative FTIR spectrum of hydrogel formulation F1. The main absorption bands correspond to hydroxyl (~3300 cm⁻¹), carbonyl (~1640 cm⁻¹) and C–O–C groups.

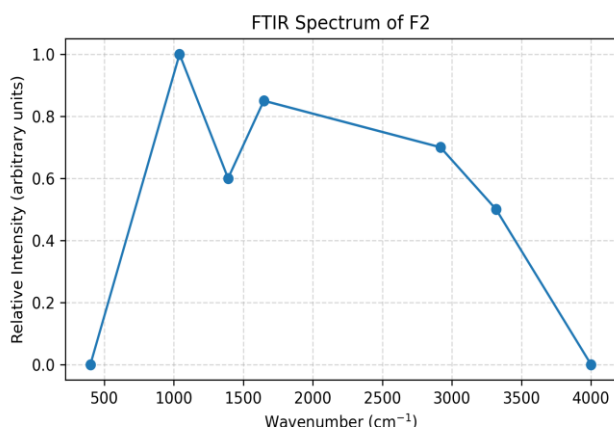


Figure 4. FTIR spectrum of formulation F2 (Aloe + Dandelion). Enhanced band intensities reflect the higher load of phenolic constituents.

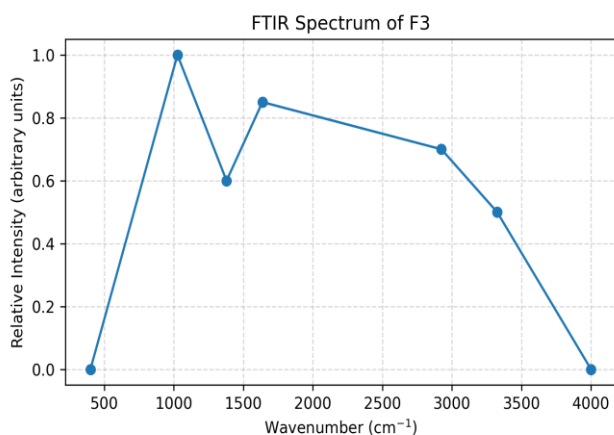


Figure 5. FTIR spectrum of formulation F3 (Aloe + Ginger).

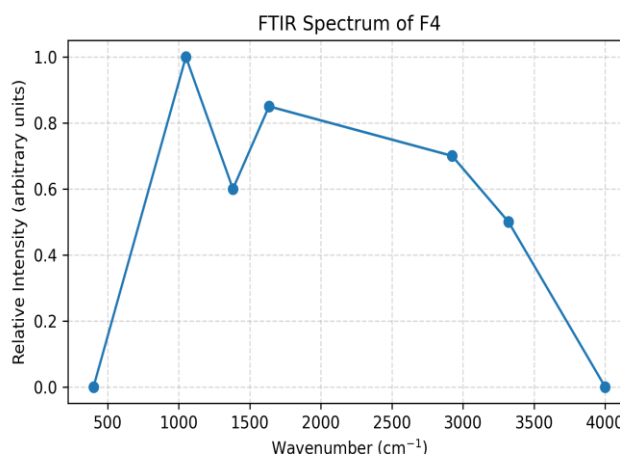


Figure 6. FTIR spectrum of formulation F4 (Aloe only).

3.4 Comparative analysis and implications

The combination of natural and synthetic polymers produced films with favourable mechanical and hydration properties. Similar hybrid hydrogels have been reported to enhance drug permeation and retention by hydrating the stratum corneum and disrupting lipid organisation. In our study, F2 delivered a balance between hydration (53 % swelling) and mechanical integrity, suggesting that the combination of Aloe polysaccharides and dandelion flavonoids created an optimal network.

The pH profile (6.95–7.75) falls within the ideal range for topical preparations, reducing the risk of irritation and providing a slightly alkaline environment that may help neutralise sebum. The FTIR findings substantiate that the polymerisation process did not degrade the active compounds, an essential requirement for preserving bioactivity.

Comparisons with recent studies indicate that our multi-herb formulation offers advantages over single-extract hydrogels. Lin et al. (2021) prepared a single-herb hydrogel for acne and reported good antimicrobial activity but moderate swelling. Saeed et al. (2023) used synthetic polymers to deliver antibiotics in wound-healing patches. Our F2 hydrogel leverages natural flavonoids and polysaccharides to provide antioxidant, antimicrobial and sebum-regulating properties with satisfactory physical characteristics, supporting the concept of holistic, plant-based dermatological therapy.



4. CONCLUSION

Hybrid hydrogels composed of sodium alginate, gelatine and PEG successfully incorporated extracts of **Aloe vera**, **Dandelion** and **Ginger** without chemical incompatibility. Among the formulations studied, F2 (Aloe + Dandelion) exhibited the most favourable balance of colour, smoothness, swelling index and pH. FTIR spectroscopy confirmed the preservation of characteristic functional groups, indicating that free-radical polymerisation did not compromise phytoconstituent integrity. These findings support the development of plant-based hydrogel patches as a promising alternative for acne management. Future work should assess antimicrobial efficacy, in vitro skin permeation and in vivo therapeutic outcomes.

Declaration of competing interest

The author declares no competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Raw numerical data for swelling and pH evaluations are provided in the supplementary tables and figures.

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